

Gulf and Caribbean Research

Volume 13 | Issue 1

January 2001

Utilization of Saltmarsh Shorelines by Newly Settled Sciaenids in a Texas Estuary

Bert W. Geary

Texas A&M University, Galveston

Jay R. Rooker

Texas A&M University, Galveston

James W. Webb

Texas A&M University, Galveston

Follow this and additional works at: <https://aquila.usm.edu/gcr>



Part of the [Marine Biology Commons](#)

Recommended Citation

Geary, B. W., J. R. Rooker and J. W. Webb. 2001. Utilization of Saltmarsh Shorelines by Newly Settled Sciaenids in a Texas Estuary. *Gulf and Caribbean Research* 13 (1): 29-41.

Retrieved from <https://aquila.usm.edu/gcr/vol13/iss1/3>

DOI: <https://doi.org/10.18785/gcr.1301.03>

This Article is brought to you for free and open access by The Aquila Digital Community. It has been accepted for inclusion in *Gulf and Caribbean Research* by an authorized editor of The Aquila Digital Community. For more information, please contact aquilastaff@usm.edu.

UTILIZATION OF SALTMARSH SHORELINES BY NEWLY SETTLED SCIAENIDS IN A TEXAS ESTUARY

Bert W. Geary¹, Jay R. Rooker, and James W. Webb

Department of Marine Biology, Texas A&M University, 5007 Avenue U, Galveston, Texas 77551, USA

¹corresponding author: Texas A&M University, 5007 Avenue U, Galveston, TX 77551, USA, Phone: 409-740-4784, Fax: 409-740-5002, E-mail: gearyb@tamug.tamu.edu

ABSTRACT Post-settlement patterns of habitat use along saltmarsh shorelines of Galveston Bay, Texas were examined for three sciaenids; spotted seatrout (*Cynoscion nebulosus*), red drum (*Sciaenops ocellatus*), and Atlantic croaker (*Micropogonias undulatus*). Collections were made summer through fall of 1997 and 1998 using a 1.5-m beam trawl hand-towed along the outside edge of salt marshes. Sciaenids were collected from tidal pass, bay, and remote tidal creek areas to assess large-scale (bay-wide) patterns of distribution and abundance. *Cynoscion nebulosus* were smaller and most numerous at bay stations, with densities peaking in June. Conversely, *S. ocellatus* were collected in higher numbers, and smaller sizes, at stations near the tidal pass, with peak densities in September. *Micropogonias undulatus* occurred in high numbers near both the tidal pass and remote tidal creeks, with undetectable size differences among areas and peak densities in November. Densities of *C. nebulosus* and *S. ocellatus* were greater at sites nearer the larval supply; patterns were less clear for *M. undulatus*. Small-scale patterns of habitat use were investigated within remote tidal creeks, with trends in density and size apparent for *M. undulatus*, while few *C. nebulosus* and *S. ocellatus* were collected. Interannual variability in densities occurred within and among stations, although total densities for each species were relatively similar between 1997 and 1998.

INTRODUCTION

Estuarine saltmarshes are productive systems utilized by many commercially important fishes and shellfishes (Nixon and Oviatt 1973, Zimmerman and Minello 1984, Cowan and Birdsong 1985, Day et al. 1989, Hettler 1989, Deegan 1993, Rozas and Minello 1998), and are known to play an important role in the development of many species (Ayvazian et al. 1992, Rountree and Able 1992, Kneib 1997, Peterson et al. 2000). It is generally thought that larval and juvenile fishes benefit from increased prey resources and/or from decreased predation pressure, although the relative contribution of each remains unclear (Boesch and Turner 1984). Saltmarsh edge, or shoreline, provides a foraging area for nekton and access to the marsh interior where nekton can forage during high tide (Rozas and Hackney 1984, Kneib and Wagner 1994, Minello et al. 1994). Moreover, structure provided by vegetation may serve as a refuge from predators (Minello and Zimmerman 1983, Stunz 1999).

Depending upon the spatial scale examined, different processes can be important in determining patterns of settlement and habitat use (Booth and Brosnan 1995, Caley et al. 1996). Within estuaries, high spatial variability in recruitment density at small scales (m's) can result from habitat choice, while lower variability at larger scales (km's) is affected more by larval delivery (Bell and Westoby 1986). High spatial and temporal variability in density at even larger scales (10's of km)

can result from the patchy nature of planktonic larvae (Bell and Westoby 1986, Doherty 1991, Tolimieri 1995). Habitat location and exposure can also affect recruitment levels, with higher recruitment to areas with increased exposure to currents (Gaines and Roughgarden 1985). On smaller scales, a form of recruitment limitation occurs when downcurrent areas receive fewer recruits than upcurrent areas (Olson 1985). This hypothesis, important in structuring fish assemblages among seagrass beds (Bell and Westoby 1986), has not been fully examined in saltmarshes.

The purpose of this study was to examine how the location of saltmarshes within a bay relates to patterns of habitat use. To accomplish this, patterns of distribution and abundance were examined for larvae and juveniles of 3 commercially important sciaenid species; spotted seatrout *Cynoscion nebulosus* (Cuvier), red drum *Sciaenops ocellatus* (Linnaeus), and Atlantic croaker *Micropogonias undulatus* (Linnaeus). The contrasting life history strategies of these species (*C. nebulosus* spawn within estuaries, *S. ocellatus* spawn nearshore, and *M. undulatus* spawn offshore; Johnson 1978) allowed us to examine the effects that spawning location may have on recruitment to various nursery areas. At a bay-wide scale (10's of km), densities and sizes of larval and juvenile sciaenids were compared among saltmarsh shorelines of tidal pass, bay, and remote tidal creek areas. Also at this large scale, we examined the abundance of sciaenids within a relatively similar habitat at varying distances from the tidal pass. At a smaller scale

(1-2 km), we assessed densities and size frequencies of young sciaenids at differing distances along tidal creeks within a saltmarsh complex. Finally, densities from the fall of both 1997 and 1998 were examined to evaluate interannual variability.

MATERIALS AND METHODS

Study site

Sampling was conducted along saltmarsh shorelines of West Galveston Bay in the Galveston Bay complex, Texas (Figure 1). The Galveston Bay complex is a large

barrier-built estuary that experiences mixed tides with a tidal range of 0.2 to 0.4 m (Britton and Morton 1989, White et al. 1993). Tides are often modified by meteorological forcing that create periods of sustained high water in spring and fall, while winter water heights are below mean levels (Rozas 1995). Tidal exchange for the far eastern portion of West Galveston Bay occurs through Bolivar Roads (tidal pass), while San Luis Pass provides tidal exchange for the western portion of the bay, including the sampling locations of this experiment (Texas Department of Water Resources 1982). All references in

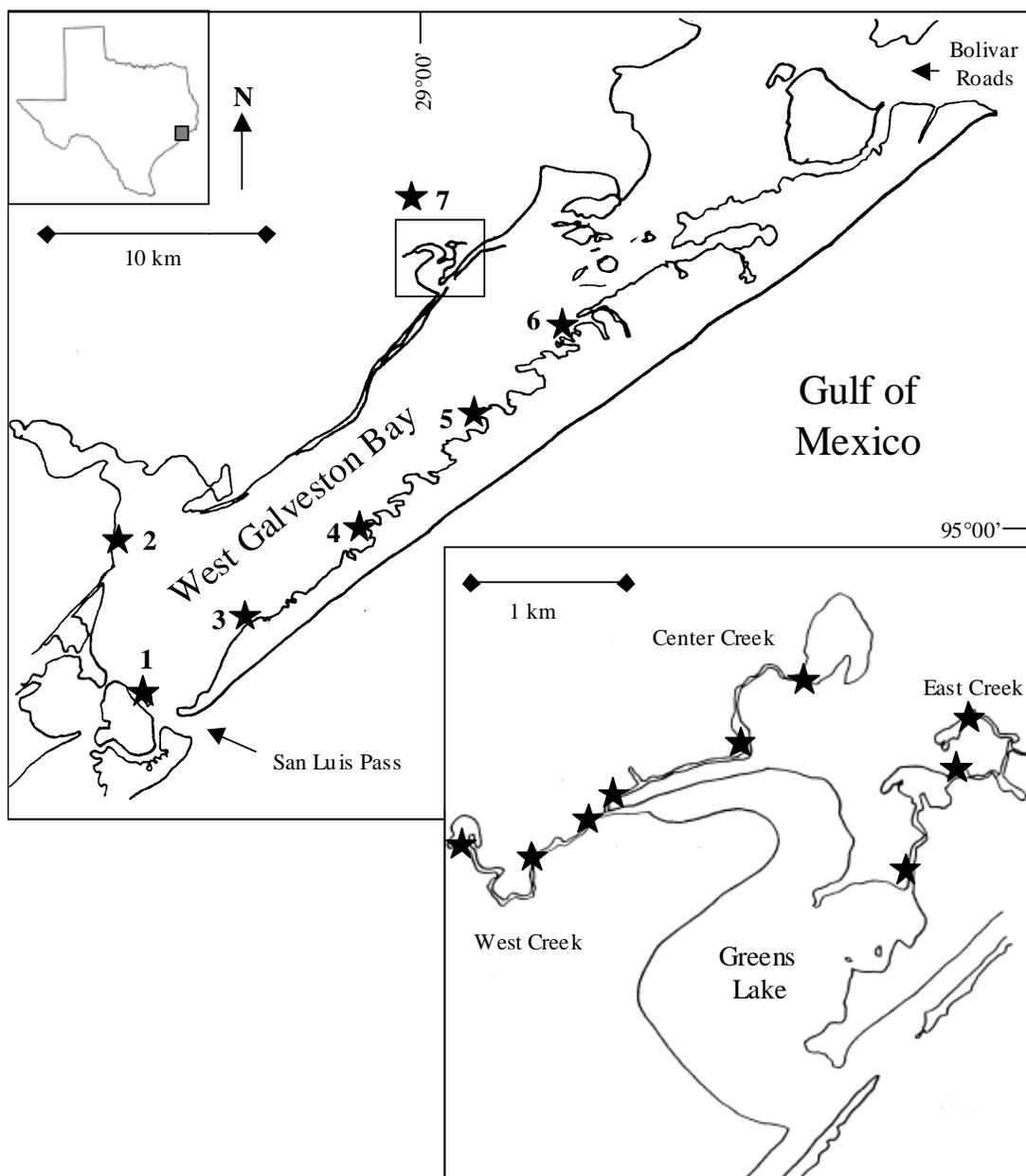


Figure 1. Location of sampling stations along saltmarsh shorelines within the West Galveston Bay complex. Tidal pass (1–3), bay (4–6), and tidal creek (7) stations are shown in the first inset. The second inset gives the substations located at the front, mid, and back of 3 tidal creeks in Greens Lake.

this paper to 'tidal pass' refer to San Luis Pass. The low marsh, dominated by smooth cordgrass *Spartina alterniflora* (Loisel), on the southern shoreline of West Galveston Bay is usually 10–50 m wide, while the north shoreline consists of spoil banks with sparse amounts of *S. alterniflora*, and 5 satellite bays surrounded by expansive saltmarsh complexes. Greens Lake is a small (about 2.25 km²) satellite bay separated from West Galveston Bay by the Intracoastal Canal Waterway. The saltmarsh complex around Greens Lake is over 3.75 km² and surrounds the east, north, and west shorelines of the bay. Three similar tidal creek channels, each over 1.5 km in length, extend from Greens Lake into the marsh complex and terminate in large, shallow (mean depth < 0.5 m) expanses of open water. All 3 channels branch often, connecting to numerous pools, creeks, and ponds. The 3 channels are bordered by *S. alterniflora* in areas with low elevations, while maritime saltwort *Batis maritima* (Linnaeus) and Carolina wolfberry *Lycium carolinianum* (Walter) dominate at slightly higher elevations, generally along steep banks.

Sampling design

Collections were made monthly, May through December in 1997, and twice monthly September through December in 1998 at Stations 1–6 around the bay shoreline, ranging from 2–25 km in distance from the tidal pass, and at 3 tidal creeks of Greens Lake (Station 7). Each tidal creek was stratified into 3 sampling sections (front, mid, and back) based on distance along creek channels, creating a total of 9 tidal creek substations. No collections were made at Station 6 during the first month of sampling in May 1997, and no collections were made at tidal creek Station 7 in June 1997 or December of 1997 or 1998.

Large-scale variation in habitat use patterns by sciaenids was examined among 3 marsh-edge areas at differing locations within West Galveston Bay in 1997. Sampling stations were grouped into 1) pass (Stations 1–3), 2) bay (Stations 4–6), and 3) tidal creek (Station 7, pooling all 9 Greens Lake substations). The effect of distance from a tidal pass on marsh use by sciaenids was investigated using 4 similar stations (Station 3 = 5 km, Station 4 = 11 km, Station 5 = 19 km, and Station 6 = 25 km) that were in a linear transect along the south shoreline of West Galveston Bay in 1997. Front, mid, and back tidal creek substations in Greens Lake were compared in 1997 to assess small-scale patterns of habitat use. The order that shoreline stations and tidal creek substations were sampled was chosen randomly. Mean densities for each station, taken September through November of

1997 and 1998, were used to qualitatively compare interannual variability. Due to differences in sampling intensity and duration, no statistical analyses were made comparing 1997 and 1998 densities.

Larval and juvenile fishes were collected using a 1.5-m wide hand-towed beam trawl (Renfro 1963) constructed with a 1.6-mm mesh body and 750- μ m mesh codend. At each station, three 15-m tows (22.5 m² tow⁻¹) were taken within 1-m of the saltmarsh shoreline, with the exact site within the sampling station chosen haphazardly. The beam trawl was placed on the substrate and a line was walked out in an arc to avoid disturbing the area to be sampled. The trawl was then retrieved at about 1.5 m sec⁻¹ parallel to the vegetation line. Gear avoidance is a potential problem with moderate sized (< 2-m wide) trawl and sled gears (Rooker et al. 1999). Consequently, capture efficiency of the beam trawl may vary as a function of trawl size, and thus densities of the larger individuals may be biased.

The catch was washed into the codend and sorted in a 500- μ m sieve. Sciaenids were preserved in 70% ethanol and standard length (SL) was later measured to the nearest 0.01 mm using a stereoscope and Optimas 6.2 image analysis software. Larval and juvenile sciaenids were identified to species following descriptions of Ditty and Shaw (1994) and were separated into 2 size groups based on size-frequency histograms to delineate new settlers (< 10 mm SL) from post-settlers (\geq 10 mm SL).

Several environmental variables were measured at each sampling station or substation. Temperature and salinity were measured with a thermometer and either a refractometer or a digital salinity meter, respectively. Tow depth was measured with a meter stick placed at a random point along the towpath of each trawl and water depth in the adjacent vegetation was recorded. Five 0.5 m² quadrats were randomly thrown within each sampling station or substation to determine percent cover of emergent vegetation.

Data analysis

Fish densities ($x + 1$) and lengths (x) were \ln -transformed to minimize heteroscedasticity and normalize data. Harlley's test indicated that heteroscedasticity was still present (Ott 1993); however, analysis of variance (ANOVA) is robust to departures of variance homogeneity and results are unlikely to be compromised (Zar 1984). To examine large-scale habitat use patterns, we used a two-factor ANOVA to test for the separate and interactive effects of area (pass, bay, and tidal creek) and time on sciaenid densities. Because the June sampling period was excluded in this test, another ANOVA was

performed using only pass and bay stations including June. Test results were similar to the ANOVA excluding June, so only results from the former test are presented. A two-factor ANOVA tested for the effects of area (pass, bay, and tidal creek) and time on sciaenid lengths, with time blocked. To examine the effects of distance from the tidal pass (Stations 3–6) and time on densities, we used a two-factor ANOVA with interaction. Small-scale patterns of habitat use within tidal creeks were examined using a three-factor ANOVA with time blocked to test the effects and interactions of creek (west, center, east) and section (front, mid, back) on sciaenid densities. A significance level of $\alpha = 0.05$ was used for all statistical tests with significant differences among means separated *a posteriori* with either Tukey's HSD for density comparisons or Sheffé's procedure for length comparisons. Relationships between density and temperature, salinity, water depth at vegetation line, tow depth, and percent cover of emergent vegetation were examined separately for each species during the month of peak abundance with Pearson's correlation. Data analysis was performed using SYSTAT 8.0 (SPSS 1998).

RESULTS

Environmental conditions

Water temperature and salinity varied among stations and seasonally (Table 1). Late spring temperatures were 26–30°C, rose to 34–35°C in summer and then dropped to 17–20°C in late fall to early winter. Bay stations were generally 1–3°C higher than tidal creek or pass stations in the summer and 1–2°C lower in late fall to early winter. Maximum range in temperature recorded over the sampling season was 21°C, from a peak high

recorded in August (37°C) to the lowest December value (16°C). Although salinity was variable, seasonal trends were apparent; salinities were low in the late spring (14–18‰), increased during the summer (31–34‰), and then dropped again in the fall (21–26‰). During the spring, bay and tidal creek stations were about 4‰ lower than pass stations. Although summer salinities were similar among areas, fall salinities at the tidal creek station were about 5–6‰ lower than bay and pass stations. Salinity values measured during this study ranged from 36‰ in August to 10‰ in May.

Fish assemblage

A diverse assemblage of fishes, from a total of 22 families was caught in 1997 (Table 2). Four families (Sciaenidae, Gobiidae, Engraulidae, and Atherinidae) comprised over 76% of the total catch. The most numerous species included naked goby *Gobiosoma bosc* (Lacepède), darter goby *Gobionellus boleosoma* (Jordan and Gilbert), bay anchovy *Anchoa mitchilli* (Valenciennes), inland silverside *Menidia beryllina* (Cope), and 2 sciaenids (*M. undulatus* and *C. nebulosus*).

A total of 8 sciaenid species was collected during the 1997 sampling period (Table 3). The 3 most abundant, *M. undulatus*, *C. nebulosus*, and *S. ocellatus*, accounted for over 88% of sciaenids collected. Silver perch *Bairdiella chrysoura* (Lacepède) occurred in samples from May through July with numbers peaking in July, while spot *Leiostomus xanthurus* (Lacepède) were collected at the end of sampling in December. Sand seatrout *Cynoscion arenarius* (Ginsburg) and southern kingfish *Menticirrhus americanus* (Lacepède) were collected during the summer and fall in limited numbers, and a single black drum *Pogonias cromis* (Linnaeus) was col-

TABLE 1

Monthly mean (± 1 SE) water temperature (°C) and salinity (‰) values from saltmarsh shorelines at tidal pass (Stations 1–3), bay (Stations 4–6), and tidal creek (Station 7) stations in West Galveston Bay, Texas, May–December 1997. NA = not available.

Month	Pass area		Bay area		Tidal creek	
	Temperature	Salinity	Temperature	Salinity	Temperature	Salinity
May	27.5(0.15)	18.5(0.92)	30.5(0.22)	14.0(1.79)	26.5(0.49)	14.1(0.21)
June	31.3(0.45)	26.4(1.42)	30.2(0.08)	21.8(1.48)	NA	NA
July	34.8(0.38)	31.8(0.73)	34.5(0.34)	31.0(0.29)	33.2(0.09)	31.4(0.26)
August	34.0(0.21)	32.0(1.26)	35.1(0.13)	33.4(0.41)	33.9(0.30)	32.0(0.21)
September	31.5(0.22)	31.5(0.90)	32.8(0.33)	32.6(0.20)	29.6(0.26)	25.3(0.17)
October	26.0(0.29)	NA	24.7(0.44)	NA	24.6(0.77)	21.9(0.07)
November	20.8(0.36)	25.4(0.82)	18.8(0.26)	25.5(0.38)	19.9(0.31)	21.5(0.17)
December	17.3(0.44)	25.2(1.83)	NA	NA	NA	NA

TABLE 2

The number and percent composition of fishes (by family) collected with a 1.5-m beam trawl from saltmarsh shorelines in West Galveston Bay, Texas, May–December 1997.

Family	Number	Percent
Sciaenidae	1141	25.45
Gobiidae	999	22.28
Engraulidae	688	15.35
Atherinidae	612	13.65
Clupeidae	282	6.29
Gerreidae	223	4.97
Soleidae	212	4.73
Syngnathidae	123	2.74
Cyprinodontidae	64	1.43
Sparidae	31	0.69
Bothidae	16	0.36
Triglidae	13	0.29
Lutjanidae	9	0.20
Synodontidae	4	0.09
Ephippidae	3	0.07
Mugilidae	3	0.07
Antennariidae	2	0.04
Balistidae	2	0.04
Elopidae	1	0.02
Ophichthidae	1	0.02
Carangidae	1	0.02
Lobotidae	1	0.02
Unidentified larvae	52	1.16
Total	4483	100

lected in August.

Size distribution

Sciaenops ocellatus and *C. nebulosus* occurred as small as 5 mm, while the smallest *M. undulatus* collected were 7 mm (Figure 2). The most frequent sizes of *C. nebulosus* and *M. undulatus* collected were 9–11 and 9–12 mm, respectively. Conversely, the most abundant size of *S. ocellatus* was 6–8 mm. *Cynoscion nebulosus* occurred in collections at all 1-mm size classes up to 33 mm, while few *S. ocellatus* or *M. undulatus* collected were over 16 mm. Collectively, over 98% of all 8 sciaenid species collected were under 30 mm, with the largest individual 56 mm (*P. cromis*).

Seasonal variability

Cynoscion nebulosus occurred in collections from May to October, while *S. ocellatus* and *M. undulatus*

were present from September to November, and October to December, respectively (Figure 3). Densities of *C. nebulosus* < 10 mm were highest in June (44.9%), the month that also had the highest mean (± 1 SE) monthly density (0.44 ± 0.245 m⁻²). Peak tow densities of *C. nebulosus* in June were 4.71 m⁻². A minor second peak in *C. nebulosus* density occurred in September with 89% of the catch composed of individuals ≥ 10 mm. *Sciaenops ocellatus* < 10 mm comprised 96% of the peak September catch, which had a mean monthly density of 0.09 ± 0.059 m⁻². Tow densities as great as 2.71 m⁻² were collected for *S. ocellatus* in September. Unlike *C. nebulosus* and *S. ocellatus*, the highest proportion of *M. undulatus* < 10 mm (44.8%) was collected in October, not during the peak month of November which had a monthly mean density of 0.31 ± 0.098 m⁻² and peak tow densities of 3.38 m⁻².

Environmental correlations

Positive correlations between densities and environmental variables occurred for each species (Table 4). *Cynoscion nebulosus* showed significant positive correlations with temperature, salinity, tow depth, and percent cover of emergent vegetation. *Sciaenops ocellatus* showed significant positive correlations with percent cover of emergent vegetation, tow depth, and water depth at vegetation line. Significant positive correlations occurred for *M. undulatus* densities with tow depth and percent cover of emergent vegetation.

Large-scale patterns of habitat use

Large-scale variation in habitat use was observed for all 3 species among the pass, bay, and tidal creek stations. Mean (± 1 SE) densities of both *C. nebulosus* (ANOVA, $F_{2,312} = 30.381$, $P < 0.001$) and *S. ocellatus* (ANOVA, $F_{2,312} = 12.205$, $P < 0.001$) differed significantly among stations. Densities of *C. nebulosus* were higher at the bay (0.07 ± 0.014 m⁻²) stations than pass (0.02 ± 0.005 m⁻²) or tidal creek (0.01 ± 0.001 m⁻²) stations (Tukey HSD, $P < 0.05$). *Sciaenops ocellatus* densities were higher at the pass (0.06 ± 0.034 m⁻²) stations than at bay or tidal creek stations, each with densities less than 0.01 m⁻² (Tukey HSD, $P < 0.05$). Although densities of *M. undulatus* were greater at the pass (0.10 ± 0.049 m⁻²) and tidal creek (0.07 ± 0.028 m⁻²) stations than at the bay (0.01 ± 0.002 m⁻²) stations, the pattern was not significant (ANOVA, $F_{2,312} = 1.838$, $P = 0.161$). Significant interactions between area and time were found for all 3 species, indicating that changes in densities among stations were not consistent over time.

TABLE 3

Number, percent frequency, and sizes (SL) of sciaenids caught from saltmarsh shorelines in West Galveston Bay, Texas, May–December 1997. Percent composition based on total number of sciaenids collected.

Common name	Species	Number	Percent	Mean size (mm)	Size range (mm)
Atlantic croaker	<i>Micropogonias undulatus</i>	443	38.83	11.1	7.6–22.4
Spotted seatrout	<i>Cynoscion nebulosus</i>	438	38.39	13.3	5.4–38.0
Red drum	<i>Sciaenops ocellatus</i>	131	11.48	8.9	5.2–38.5
Silver perch	<i>Bairdiella chrysoura</i>	77	6.75	9.5	4.7–35.4
Spot	<i>Leiostomus xanthurus</i>	37	3.24	10.2	8.5–13.9
Sand seatrout	<i>Cynoscion arenarius</i>	9	0.79	14.6	4.7–31.1
Southern kingfish	<i>Menticirrhus americanus</i>	5	0.44	11.0	9.4–13.3
Black drum	<i>Pogonias cromis</i>	1	0.09	56.0	56.0

Patterns in size distributions and means also differed among the pass, bay, and tidal creek stations (Figure 4). Mean (± 1 SE) size of both *C. nebulosus* (ANOVA, $F_{2,160} = 5.050$, $P = 0.007$) and *S. ocellatus* (ANOVA, $F_{2,108} = 33.460$, $P < 0.001$) differed significantly among stations. Mean size of *C. nebulosus* was greater in the tidal creek (24.6 ± 1.76 mm) station than in pass (14.4 ± 1.09 mm) or bay (17.5 ± 0.61 mm) stations (Sheffé, $P < 0.05$). Similar to *C. nebulosus*, mean size of *S. ocellatus* from the tidal creek (19.5 ± 2.75 mm) station was greater than from pass (7.8 ± 0.29 mm) or bay (9.3 ± 0.43 mm) stations (Sheffé, $P < 0.05$). No significant difference in mean size of *M. undulatus* was detected among stations (ANOVA, $F_{2,428} = 2.694$, $P = 0.070$), with sizes ranging from 11.0 ± 0.01 mm at the pass stations to 12.8 ± 1.18 mm at the bay stations.

Densities of *C. nebulosus* (ANOVA, $F_{3,89} = 67.933$, $P < 0.001$) and *S. ocellatus* (ANOVA, $F_{3,89} = 6.120$, $P = 0.001$) varied among stations (Stations 3–6) as a function of distance from the tidal pass (Figure 5). Mean (± 1 SE) densities of *C. nebulosus* were significantly higher at the station farthest from the tidal pass (Station 6) than at other stations (Tukey HSD, $P < 0.05$). Similarly, densities of *S. ocellatus* were significantly higher at Station 6 (Tukey HSD, $P < 0.05$). The highest density of *M. undulatus* was found at the station closest to the tidal pass (Station 3); however, only 12 *M. undulatus* were collected from the 4 stations used and no statistical analysis was performed. Significant interactions between station and time were present for *C. nebulosus* and *S. ocellatus*. Slight increases in density of *C. nebulosus* were seen at all 4 stations during the September peak, but only Station 6 increased in density during the June peak (3.88 ± 0.544 m⁻²). September densities of *S. ocellatus*

were highest at Station 5 while Station 6 had the highest densities in October.

Small-scale patterns within a tidal creek

Densities of *C. nebulosus* and *S. ocellatus* were too low for statistical analysis, although the majority of individuals for both species were captured at the front of tidal creeks (Figure 6). Mean (± 1 SE) densities of *M. undulatus* were relatively similar between front (0.08 ± 0.063 m⁻²) and back (0.12 ± 0.057 m⁻²) substations of the tidal creeks, both areas having nonsignificantly higher densities than mid (0.01 ± 0.002 m⁻²) substations (ANOVA, $F_{2,148} = 2.614$, $P = 0.077$). Small-scale differences in mean size occurred for *M. undulatus* (ANOVA, $F_{2,234} = 69.933$, $P < 0.001$); fish from front substations were smaller (9.6 ± 0.12 mm) than fish from either mid (12.9 ± 1.63 mm) or back (12.2 ± 0.18 mm) substations (Sheffé, $P < 0.05$).

Interannual variability

Interannual variability in densities occurred within and among stations, although total densities for each species were relatively similar between 1997 and 1998 (Table 5). The spatial pattern of habitat use of *C. nebulosus* in 1998 mirrored 1997, although it shifted slightly toward the tidal pass; Stations 4 and 6 had peak densities in 1997 while Stations 3 and 5 had the peaks in 1998. Densities of *S. ocellatus* in 1997 were highest at Station 2, while the station closest to the tidal pass (Station 1) had the highest densities in 1998. The remaining pass and bay stations had higher densities of *S. ocellatus* in 1998 than in 1997. *Cynoscion nebulosus* and *S. ocellatus* were caught infrequently in tidal creeks in both 1997 and 1998. Similar to *S. ocellatus*, mean densities of *M. undulatus* increased at bay stations in 1998. Tidal creek densities of *M. undulatus* were higher than for *C.*

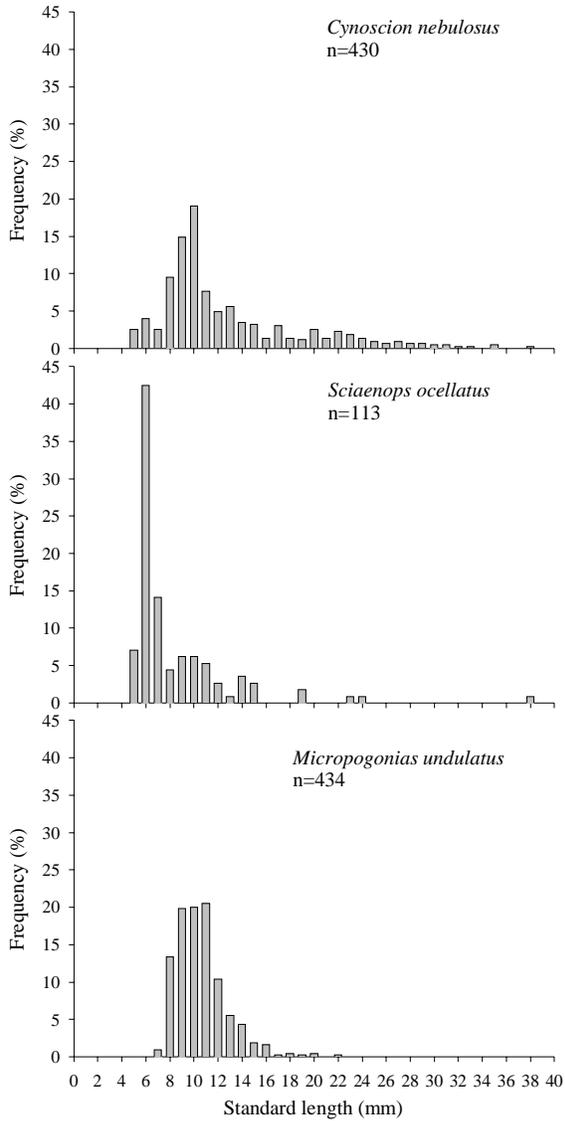


Figure 2. Size frequency (1-mm size classes) of 3 species of sciaenids collected monthly May–December 1997, from saltmarsh shorelines of West Galveston Bay, Texas.

nebulosus or *S. ocellatus*, and decreased slightly between 1997 and 1998.

DISCUSSION

Ichthyofauna utilizing saltmarsh shorelines of West Galveston Bay during this study were typical for Gulf of Mexico (Peterson and Ross 1991, Rakocinski et al. 1992, Kneib 1997, Rozas and Minello 1998, Minello 1999, Peterson et al. 2000) and southeastern Atlantic coast (Shenker and Dean 1979, Weinstein 1979, Kneib 1997) saltmarshes. Following Peterson and Turner’s (1994) classification, all 4 categories of the saltmarsh fish community were present in this study, although interior

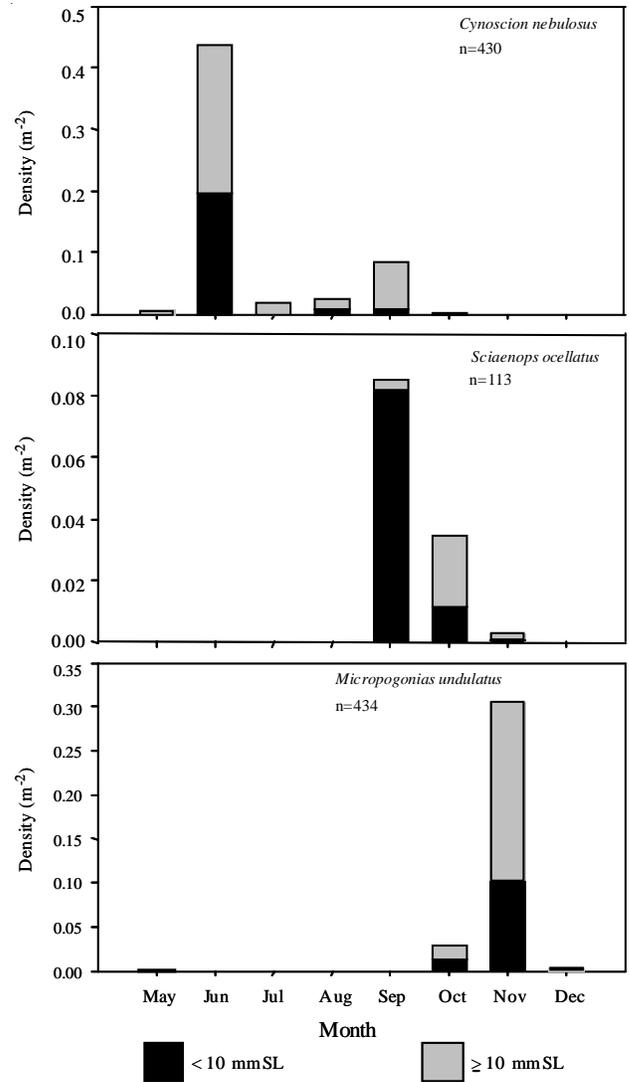


Figure 3. Monthly mean densities for 3 species of sciaenids from saltmarsh shorelines of West Galveston Bay, Texas, 1997. Two size classes (< 10 mm SL, and ≥ 10 mm SL) are shown. Y-axis scales differ among graphs.

marsh residents and interior marsh users, represented primarily by cyprinodontids, were poorly represented (< 2% of the individuals caught). Numerically, edge marsh users were the dominant group containing both marsh residents such as gobiids, and estuarine-dependent species represented by sciaenids. Subtidal marsh users included soleids as well as the seasonally abundant atherinids, engraulids, and clupeids.

Densities of *C. nebulosus*, *S. ocellatus*, and *M. undulatus* in the present study ranged from similar (Rozas and Minello 1998, Minello 1999) to an order of magnitude lower than (Rakocinski et al. 1992, Baltz et al. 1993) densities found in similar shoreline habitats on the western Gulf coast. Although densities of *C. nebulosus* from

Table 4

Results of Pearson's correlation for densities of *Cynoscion nebulosus* and *Sciaenops ocellatus* from September 1997 and *Micropogonias undulatus* from November 1997, the months of peak abundance for each species. Species values are from $\ln(x + 1)$ transformed densities. * = significant results ($P < 0.05$). The units for environmental variables can be found in materials and methods.

n = 39	<i>C. nebulosus</i>	Temperature	Salinity	Veg. Depth	Depth	Percent cover
<i>C. nebulosus</i>	1.000					
Temperature	0.619*	1.000				
Salinity	0.666*	0.742*	1.000			
Veg. Depth	0.152	0.123	0.151	1.000		
Depth	0.415*	0.200	0.183	0.614*	1.000	
Percent cover	0.374*	0.316*	0.342*	0.941*	0.804*	1.000

n = 39	<i>S. ocellatus</i>	Temperature	Salinity	Veg. Depth	Depth	Percent cover
<i>S. ocellatus</i>	1.000					
Temperature	0.188	1.000				
Salinity	0.127	0.742*	1.000			
Veg. Depth	0.499*	0.123	0.151	1.000		
Depth	0.409*	0.200	0.183	0.614*	1.000	
Percent cover	0.512*	0.316*	0.342*	0.941*	0.804*	1.000

n = 63	<i>M. undulatus</i>	Temperature	Salinity	Veg. Depth	Depth	Percent cover
<i>M. undulatus</i>	1.000					
Temperature	-0.055	1.000				
Salinity	0.031	-0.012	1.000			
Veg. Depth	0.258	0.050	0.120	1.000		
Depth	0.379*	-0.177	0.003	0.500*	1.000	
Percent cover	0.318*	0.039	0.169	0.950*	0.707*	1.000

saltmarsh shorelines were also similar to densities reported from Texas seagrass beds, densities of both *S. ocellatus* and *M. undulatus* from shorelines were several fold lower than from seagrass beds (Rooker et al. 1998, Stunz 1999). Nevertheless, differences in sampling duration and gear types between studies may affect density estimates, making direct comparisons difficult.

Three sciaenid species examined in this study appeared to settle from the plankton into saltmarsh shorelines. *Cynoscion nebulosus* and *S. ocellatus* first appeared in saltmarsh edges at a relatively small size (5 mm), consistent with the smallest sizes of these species collected from seagrass beds in the Gulf (Peters and McMichael 1987, McMichael and Peters 1989, Rooker et al. 1999, Stunz 1999). Peaks in size frequency histograms for *C. nebulosus* (about 10 mm) and *S. ocellatus* (about 6 mm) are similar to other studies, suggesting that these 2 species have fully recruited (i.e., switched from a planktonic to a demersal phase) to saltmarsh shorelines by about 10 mm (Rooker et al. 1998, Stunz 1999).

Although McMichael and Peters (1989) state that *C. nebulosus* under 15 mm may not be fully recruited to estuarine habitats of Tampa Bay, this difference may reflect the deeper waters sampled in their study. Recent research shows that at least some *S. ocellatus* spawn closer inshore than previously thought, often spawning near the end of jetties (S. Holt personal communication), or just outside of tidal passes (Murphy and Taylor 1990). This could result in some recruits entering bays earlier, at sizes closer to that of estuarine-spawned *C. nebulosus*. Larger sizes of *M. undulatus* at both first occurrence and at peak numbers may be attributable to longer larval duration. *Micropogonias undulatus* spawn farther offshore in the Gulf of Mexico than the other 2 species, generally more than 50 km from shore (Cowan and Shaw 1988, Ditty et al. 1988), resulting in planktonic durations of 60–90 days (Cowan and Shaw 1988).

Seasonal occurrence of sciaenids found in the present study was similar to that for the same species found in other estuarine areas of the Gulf (Peters and McMichael

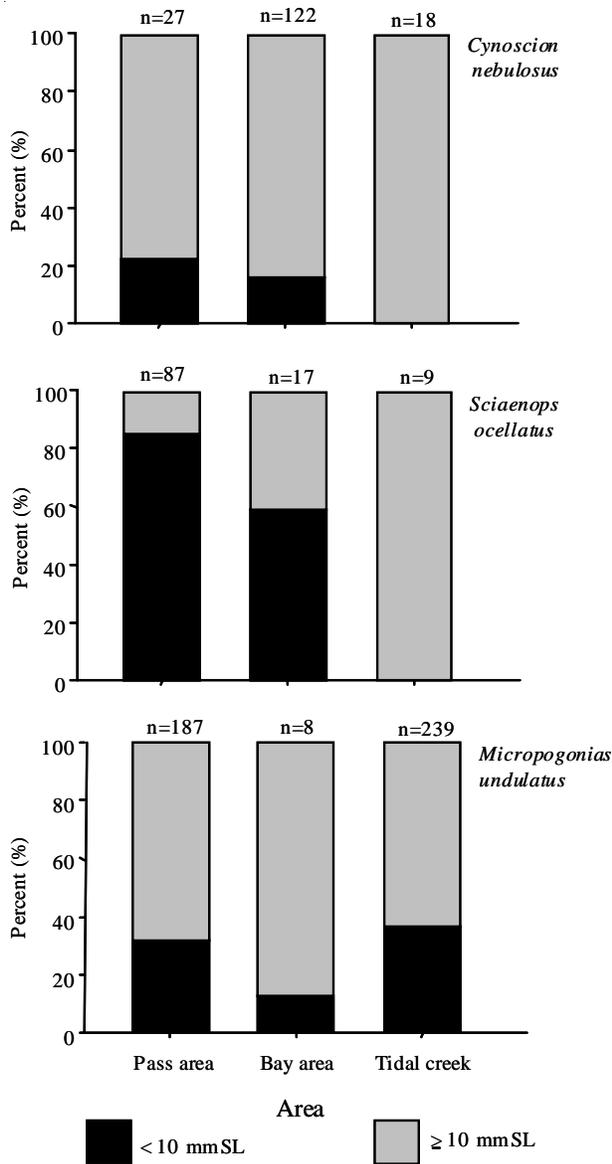


Figure 4. Percent composition of 2 size classes (< 10 mm SL, and ≥ 10 mm SL) for 3 sciaenid species collected from saltmarsh shorelines at pass, bay, and tidal creek stations of West Galveston Bay, Texas, May–November (excluding June) 1997.

1987, McMichael and Peters 1989, Rooker et al. 1998, Stunz 1999, Peterson et al. 2000) and southeastern Atlantic (Shenker and Dean 1979, Rogers et al. 1984, Nixon and Jones 1997) coasts. Water temperature may be an important factor influencing when sciaenids leave saltmarsh shorelines. In the present study, *C. nebulosus* and *S. ocellatus* became scarce in collections when water temperatures dropped to 25°C and 20°C, respectively; similar to findings from the Everglades (Janke 1971). Experiments have shown that juvenile *S. ocellatus* become inactive at 20°C (Holt et al. 1981), and Chao and Musick (1977) suggest that water temperature is a criti-

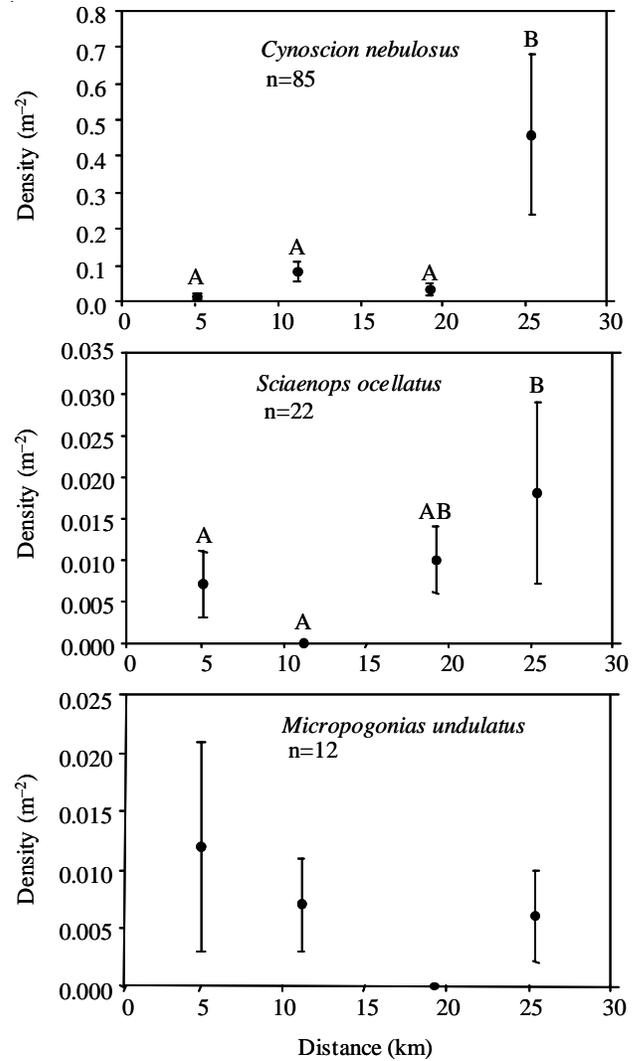


Figure 5. Mean densities (± 1 SE) for 3 sciaenid species collected from saltmarsh shorelines at varying distances from the tidal pass in West Galveston Bay, Texas. Collections were taken June–December 1997. Letters denote significantly different mean values (Tukey HSD).

cal factor determining when sciaenids (including *C. nebulosus* and *M. undulatus*) emigrate from nursery areas to deeper waters. Positive correlations of density with water temperature for *C. nebulosus* support this idea, although significant correlations with temperature were not apparent for the other two species.

Cynoscion nebulosus and *S. ocellatus* occupied different areas of the bay; however, both species were most abundant at stations nearest their putative spawning grounds (bay stations and pass stations, respectively). Small sizes of *C. nebulosus* and *S. ocellatus* found at these stations suggest that these species settle at the first suitable site encountered. Larger *C. nebulosus* and *S. ocellatus* taken from tidal creeks may indicate that post-

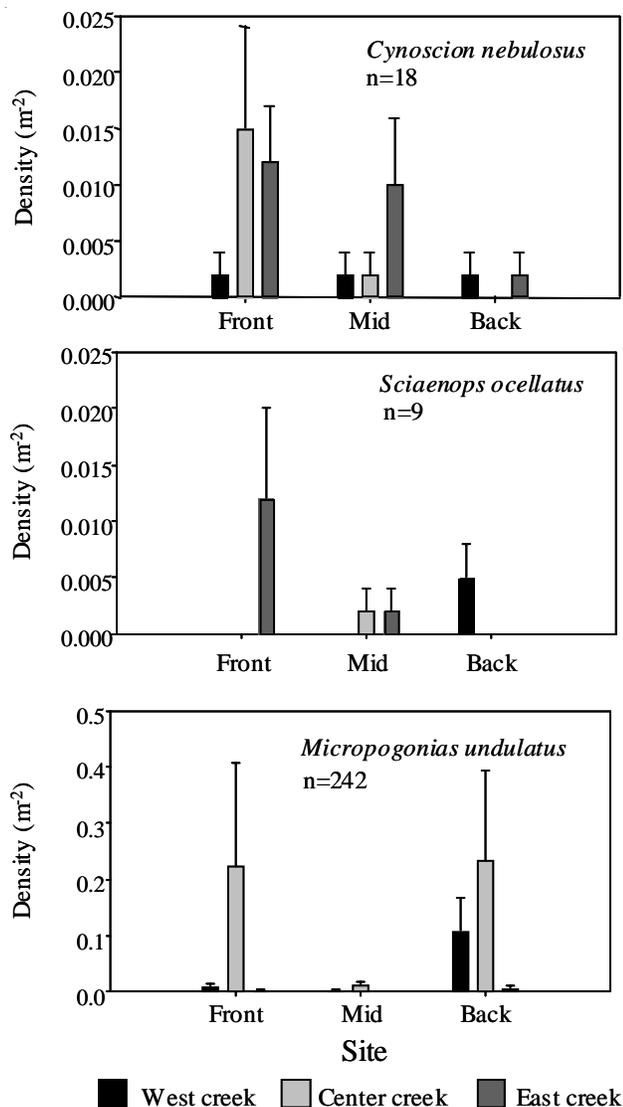


Figure 6. Mean densities (± 1 SE) for 3 species of sciaenids collected from saltmarsh shorelines at different sections of tidal creeks in the Greens Lake saltmarsh complex of West Galveston Bay, Texas, May–November (excluding June) 1997.

settlement migration to tidal creeks occurs after settlement in other areas, similar to a pattern described for *S. ocellatus* in Tampa Bay where settlement occurs along bay shorelines with later migration to backwater areas (Peters and McMichael 1987). Although high densities of *M. undulatus* at the pass area are consistent with the idea of settlement nearest spawning areas, the high number of individuals < 10 mm captured at tidal creek stations indicates that other factors are involved. On the Atlantic Coast, *M. undulatus* larvae utilize bottom currents to migrate from offshore to inshore (Hettler and Hare 1998), and continue to use up-estuary bottom flows to reach settlement sites near the estuary head (Weinstein

et al. 1980, Pietrafesa and Janowitz 1988, Nixon and Jones 1997). Individuals employing this strategy may maintain their position in the channel during transport to settlement sites and thus not utilize intermediate sites along the marsh edge. *Micropogonias undulatus* densities in West Galveston Bay appeared to follow this pattern.

Densities of *C. nebulosus* increased with distance from the tidal pass, consistent with the trend of increased numbers near the suspected spawning source. Similarly, *M. undulatus* densities were higher at stations closer to the suspected spawning source (pass stations), although within-station variability was high and results were not significant. *Sciaenops ocellatus* densities exhibited a trend opposite of that expected (higher densities farther from the larval source); however, a limited sample size and high within-station variability occurred in collections. Possible causes for this high variability may be due to wave energy and wind-driven currents that can cause variability in estuarine recruitment, especially in shallow barrier-built estuaries (Miller 1988, Dirnberger 1993, Jenkins et al. 1996, Jenkins et al. 1998, Xie and Eggleston 1999). For example, highest numbers of newly settled *C. nebulosus* were collected from an exposed point, in which hundreds of larval gobiids and engraulids were also collected, suggesting that wind-driven currents may influence the delivery of larval fishes.

On small spatial scales, movement of new recruits can modify initial settlement patterns (Baltz et al. 1998). Bell and Westoby (1986) found that post-settlement movement occurs within seagrass beds, although newly settled fish rarely migrate across bare substrate separating seagrass beds. Post-settlement movements within saltmarshes may be more extensive because fish can travel along a continuous marsh edge, without having to risk exposure by crossing bare areas. As mentioned, *C. nebulosus* and *S. ocellatus* captured from tidal creeks were relatively large (> 15 mm) individuals that may have migrated to the tidal creeks after settlement elsewhere. In contrast to *C. nebulosus* and *S. ocellatus*, newly settled *M. undulatus* at front and rear substations may be the result of 2 temporally separate settlement pulses in these tidal creeks.

Overall densities were relatively similar for all 3 sciaenids between 1997 and 1998. Although no clear trend was evident, densities of *S. ocellatus* and *M. undulatus* tended to be higher at the bay stations (4–6) in 1998. This spatial variation in density may be due to a storm event, which can transport larval fish to areas where fish may not normally reside (Miller 1988). In September 1998, tropical storm Frances created ex-

Table 5.

Mean densities ($m^{-2} \pm 1$ SE) for 3 sciaenid species collected from saltmarsh shorelines at 7 stations in West Galveston Bay, Texas, at progressive distances from the tidal pass. Data are from collections made September–November of 1997 and 1998. Sample sizes are given in parentheses in table header.

Station	<i>Cynoscion nebulosus</i>		<i>Sciaenops ocellatus</i>		<i>Micropogonias undulatus</i>	
	(96)	(56)	(131)	(239)	(423)	(553)
	1997	1998	1997	1998	1997	1998
1	0.00 (0.000)	0.00 (0.000)	0.00 (0.000)	0.32 (0.185)	0.27 (0.227)	0.14 (0.099)
2	0.02 (0.019)	0.01 (0.005)	0.37 (0.223)	0.11 (0.049)	0.42 (0.247)	0.50 (0.161)
3	0.02 (0.015)	0.07 (0.035)	0.02 (0.008)	0.06 (0.022)	0.03 (0.019)	0.05 (0.034)
4	0.13 (0.050)	0.02 (0.012)	0.00 (0.000)	0.12 (0.045)	0.02 (0.009)	< 0.01 (0.004)
5	0.04 (0.022)	0.06 (0.025)	0.02 (0.009)	0.03 (0.010)	0.00 (0.000)	0.14 (0.099)
6	0.08 (0.045)	0.02 (0.008)	0.04 (0.025)	0.24 (0.122)	0.02 (0.008)	0.69 (0.294)
7	0.01 (0.002)	0.01 (0.003)	0.01 (0.002)	< 0.01 (0.001)	0.13 (0.056)	0.08 (0.021)

tremely high tidal levels during the early *S. ocellatus* recruitment period and may have transported larval *S. ocellatus* to interior bay habitats. The tropical storm occurred before peak recruitment of *M. undulatus*; however, meteorological forcing due to frontal boundaries may have affected larval delivery patterns. Without long-term data though, it is impossible to determine the natural variability in recruitment levels within West Galveston Bay.

This research shows that saltmarsh shorelines in West Galveston Bay serve as nursery areas for commercially important sciaenid species. These species may utilize other habitats (i.e., seagrass) as primary nursery areas (Rooker et al. 1998, Stunz 1999); nevertheless, the impact that marsh habitat has on recruitment processes and ultimately stock structure should not be ignored. Although saltmarsh shorelines may be a secondary nursery habitat for these species, seagrass distribution is limited on the upper Texas coast (Adair et al. 1994) and even at lower densities, saltmarsh shorelines may serve as essential habitat and contribute substantially to adult stocks.

ACKNOWLEDGMENTS

We thank F. Gelwick for helping with sampling design and statistical advice. P. Levin allowed time for data collection and provided input on design and analysis while J. Ditty helped with larval identifications. Two anonymous reviewers offered constructive comments on the manuscript, and a special debt of gratitude is owed to C. Yeargan, without whose field support this project could not have been finished.

LITERATURE CITED

- Adair, S.E., J.L. Moore, and C.P. Onuf. 1994. Distribution and status of submerged vegetation on estuaries of the upper Texas coast. *Wetlands* 14:110–121.
- Ayvazian, S.G., L.A. Deegan, and J.T. Finn. 1992. Comparison of habitat use by estuarine fish assemblages in the Acadian and Virginian zoogeographic provinces. *Estuaries* 15:368–383.
- Baltz, D.M., J.W. Fleeger, C.F. Rakocinski, and L.N. McCall. 1998. Food, density, and microhabitat: factors affecting growth and recruitment potential of juvenile saltmarsh fishes. *Environmental Biology of Fishes* 53:89–103.
- Baltz, D.M., C. Rakocinski, and J.W. Fleeger. 1993. Microhabitat use by marsh-edge fishes in a Louisiana estuary. *Environmental Biology of Fishes* 36:109–126.
- Bell, J.D. and M. Westoby. 1986. Variation in seagrass height and density over a wide spatial scale: effects on common fish and decapods. *Journal of Experimental Marine Biology and Ecology* 104:275–295.
- Boesch, D.F. and R.E. Turner. 1984. Dependence of fishery species on salt marshes: the role of food and refuge. *Estuaries* 7:460–468.
- Booth, D.J. and D.M. Brosnan. 1995. The role of recruitment dynamics in rocky shore and coral reef fish communities. *Advances in Ecological Research* 26:309–385.
- Britton, J.C. and B. Morton. 1989. *Shore Ecology of the Gulf of Mexico*. University of Texas Press, Austin, TX, 387 p.
- Caley, M.J., M.H. Carr, M.A. Hixon, T.P. Hughes, G.P. Jones, and B.A. Menge. 1996. Recruitment and the local dynamics of open marine populations. *Annual Review of Ecology and Systematics* 27:477–500.
- Chao, L.N. and J.A. Musick. 1977. Life history, feeding habits, and functional morphology of juvenile sciaenid fishes in the York River Estuary, Virginia. *Fishery Bulletin*, US 75:657–702.
- Cowan, J.H., Jr. and R.S. Birdsong. 1985. Seasonal occurrence of larval and juvenile fishes in a Virginia Atlantic coast estuary with emphasis on drums (family Sciaenidae). *Estuaries* 8:48–59.

- Cowan, J.H., JR. and R.F. Shaw. 1988. The distribution, abundance, and transport of larval sciaenids collected during winter and early spring from the continental shelf waters off West Louisiana. *Fishery Bulletin*, US 86:129–142.
- Day, J.W., JR, C.A. Hall, W.M. Kemp, and A. Yáñez-Arancibia. 1989. *Estuarine Ecology*. John Wiley & Sons, New York, NY, 558 p.
- Deegan, L.A. 1993. Nutrient and energy transport between estuaries and coastal marine ecosystems by fish migration. *Canadian Journal of Fisheries and Aquatic Sciences* 50:74–79.
- Dirnberger, J.M. 1993. Dispersal of larvae with a short planktonic phase in the polychaete *Spirorbis spirillum* (Linnaeus). *Bulletin of Marine Science* 52:898–910.
- Ditty, J.G. and R.F. Shaw. 1994. Preliminary guide to the identification of the early life history stages of sciaenid fishes from the western central Atlantic. NOAA Tech Memo NMFS-SEFSC-349. National Marine Fisheries Service, Miami, FL.
- Ditty, J.G., G.C. Zieske, and R.F. Shaw. 1988. Seasonality and depth distribution of larval fishes in the northern Gulf of Mexico above latitude 26°00'N. *Fishery Bulletin*, US 86:811–823.
- Doherty, P.J. 1991. Spatial and temporal patterns in recruitment. In: P.F. Sale, ed. *The Ecology of Fishes on Coral Reefs*. Academic Press, New York, NY, p. 261–293.
- Gaines, S. and J. Roughgarden. 1985. Larval settling rate: a leading determinant of structure in an ecological community of the marine intertidal zone. *Proceedings of the National Academy of Sciences, USA* 82:3707–3711.
- Hettler, W.F. 1989. Nekton use of regularly-flooded saltmarsh cordgrass habitat in North Carolina, USA. *Marine Ecology Progress Series* 56:111–118.
- Hettler, W.F. and J.A. Hare. 1998. Abundance and size of larval fishes outside the entrance of Beaufort Inlet, North Carolina. *Estuaries* 21:476–499.
- Holt, J., R. Godbout, and C. Arnold. 1981. Effects of temperature and salinity on egg hatching and larval survival of red drum *Sciaenops ocellata*. *Fishery Bulletin*, US 79:569–573.
- Janke, T.E. 1971. Abundance of young sciaenid fishes in Everglades National Park, Florida, in relation to season and other variables. University of Miami Sea Grant Program, Sea Grant Technical Bulletin Number 11, Miami, FL.
- Jenkins, G.P., M.J. Keogh, and P.A. Hamer. 1998. The contributions of habitat structure and larval supply to broad-scale recruitment variability in a temperate zone, seagrass-associated fish. *Journal of Experimental Marine Biology and Ecology* 226:259–278.
- Jenkins, G.P., M.J. Wheatley, and A.G.B. Poore. 1996. Spatial variation in recruitment, growth, and feeding of postsettlement King George whiting, *Sillaginodes punctata*, associated with seagrass beds of Port Phillip Bay, Australia. *Canadian Journal of Fisheries and Aquatic Sciences* 53:350–359.
- Johnson, G.D. 1978. *Development of Fishes of the Mid-Atlantic Bight: an Atlas of Egg, Larval, and Juvenile Stages*. Vol. IV: Carangidae through Ephippidae. United States Fish and Wildlife Service, United States Government Printing Office, Washington, DC, 314 p.
- Kneib, R.T. 1997. The role of tidal marshes in the ecology of estuarine nekton. *Oceanography and Marine Biology: an Annual Review* 35:163–220.
- Kneib, R.T. and S.L. Wagner. 1994. Nekton use of vegetated marsh habitats at different stages of tidal inundation. *Marine Ecology Progress Series* 106:227–238.
- McMichael, R.H., Jr. and K.M. Peters. 1989. Early life history of spotted seatrout, *Cynoscion nebulosus* (Pisces: Sciaenidae), in Tampa Bay, Florida. *Estuaries* 12:98–110.
- Miller, J.M. 1988. Physical processes and the mechanisms of coastal migrations of immature fishes. *American Fisheries Society Symposium* 3:68–76.
- Minello, T.J. 1999. Nekton densities in shallow estuarine habitats of Texas and Louisiana and the identification of essential fish habitat. *American Fisheries Society Symposium* 22:43–75.
- Minello, T.J. and R.J. Zimmerman. 1983. Fish predation on juvenile brown shrimp, *Penaeus aztecus* Ives: the effect of simulated *Spartina* structure on predation rates. *Journal of Experimental Marine Biology and Ecology* 72:211–231.
- Minello, T.J., R.J. Zimmerman, and R. Medina. 1994. The importance of edge for natant macrofauna in a created salt-marsh. *Wetlands* 14:184–198.
- Murphy, M.D. and R.G. Taylor. 1990. Reproduction, growth, and mortality of red drum *Sciaenops ocellatus* in Florida waters. *Fishery Bulletin*, US 88:531–542.
- Nixon, S.W. and C.M. Jones. 1997. Age and growth of larval and juvenile Atlantic croaker, *Micropogonias undulatus*, from the Middle Atlantic Bight and estuarine waters of Virginia. *Fishery Bulletin*, US 95:773–784.
- Nixon, S.W. and C.A. Oviatt. 1973. Ecology of a New England salt marsh. *Ecological Monographs* 43:463–498.
- Olson, R.R. 1985. The consequences of short-distance larval dispersal in a sessile marine invertebrate. *Ecology* 66:30–39.
- Ott, R.L. 1993. *An Introduction to Statistical Methods and Data Analysis*. Duxbury Press, Belmont, CA, 1051 p.
- Peters, K.M. and R.H. McMichael, Jr. 1987. Early life history of the red drum, *Sciaenops ocellatus* (Pisces: Sciaenidae), in Tampa Bay, Florida. *Estuaries* 10:92–107.
- Peterson, G.W. and R.E. Turner. 1994. The value of salt marsh edge vs interior as a habitat for fish and decapod crustaceans in a Louisiana tidal marsh. *Estuaries* 17:235–262.
- Peterson, M.S., B.H. Comyns, J.R. Hendon, P.J. Bond, and G.A. Duff. 2000. Habitat use by early life-history stages of fishes and crustaceans along a changing estuarine landscape: differences between natural and altered shoreline sites. *Wetlands Ecology and Management* 8:209–219.
- Peterson, M.S. and S.T. Ross. 1991. Dynamics of littoral fishes and decapods along a coastal river-estuarine gradient. *Estuarine, Coastal and Shelf Science* 33:467–483.
- Pietrafesa, L.J. and G.S. Janowitz. 1988. Physical oceanographic processes affecting larval transport around and through North Carolina inlets. *American Fisheries Society Symposium* 3:34–50.
- Rakocinski, C.F., D.M. Baltz, and J.W. Fleeger. 1992. Correspondence between environmental gradients and the community structure of marsh-edge fishes in a Louisiana estuary. *Marine Ecology Progress Series* 80:135–148.

- Renfro, W.C. 1963. Small beam net for sampling postlarval shrimp. USFWS Circular 161, United States Fish and Wildlife Service, Washington, DC.
- Rogers, S.G., T.A. Targett, and S.B. Van Sant. 1984. Fish-nursery use in Georgia salt-marsh estuaries: the influence of springtime freshwater conditions. *Transactions of the American Fisheries Society* 113:595–606.
- Rooker, J.R., S.A. Holt, G.J. Holt, and L.A. Fuiman. 1999. Spatial and temporal variability in growth, mortality, and recruitment potential of postsettlement red drum, *Sciaenops ocellatus*, in a subtropical estuary. *Fishery Bulletin, US* 97:581–590.
- Rooker, J.R., S.A. Holt, M.A. Soto, and G.J. Holt. 1998. Postsettlement patterns of habitat use by sciaenid fishes in subtropical seagrass meadows. *Estuaries* 21:318–327.
- Rountree, R.A. and K.A. Able. 1992. Fauna of polyhaline subtidal marsh creeks in southern New Jersey: composition, abundance, and biomass. *Estuaries* 15:171–185.
- Rozas, L.P. 1995. Hydroperiod and its influence on nekton use of the salt marsh—a pulsing ecosystem. *Estuaries* 18:579–590.
- Rozas, L.P. and C.T. Hackney. 1984. Use of oligohaline marshes by fishes and macrofaunal crustaceans in North Carolina. *Estuaries* 7:213–224.
- Rozas, L.P. and T.J. Minello. 1998. Nekton use of salt marsh, seagrass, and nonvegetated habitats in a South Texas (USA) estuary. *Bulletin of Marine Science* 63:481–501.
- Shenker, J.M. and J.M. Dean. 1979. The utilization of an intertidal salt marsh creek by larval and juvenile fishes: abundance, diversity and temporal variation. *Estuaries* 2:154–163.
- SPSS Science. 1988. SYSTAT 8.0. Chicago, IL, USA.
- Stunz, G.W. 1999. Causes and consequences of recruitment patterns in newly settled red drum (*Sciaenops ocellatus*). Ph.D. dissertation, Texas A&M University, College Station, TX, 104 p.
- Texas Department of Water Resources. 1982. Trinity-San Jacinto estuary: an analysis of bay segment boundaries, physical characteristics, and nutrient processes. LP-86 Austin, TX.
- Tolimieri, N. 1995. Effects of microhabitat characteristics on the settlement and recruitment of a coral reef fish at two spatial scales. *Oecologia* 102:52–63.
- Weinstein, M.P. 1979. Shallow marsh habitats as primary nurseries for fish and shellfish, Cape Fear River, North Carolina. *Fishery Bulletin, US* 77:339–357.
- Weinstein, M.P., S.L. Weiss, R.G. Hodson, and L.R. Gerry. 1980. Retention of three taxa of postlarval fishes in an intensively flushed tidal estuary, Cape Fear River, North Carolina. *Fishery Bulletin, US* 78:419–435.
- White, W.A., T.A. Tremblay, E.G. Wermund, Jr., and L.R. Handley. 1993. Trends and status of wetland and aquatic habitats in the Galveston Bay system, Texas. Publication GBNEP-31, Galveston Bay National Estuary Program, Austin, TX.
- Xie, L. and D.B. Eggleston. 1999. Computer simulations of wind-induced estuarine circulation patterns and estuary-shelf exchange processes: the potential role of wind forcing on larval transport. *Estuarine, Coastal and Shelf Science* 49:221–234.
- Zar, J. H. 1984. *Biostatistical Analysis*. Prentice-Hall, Englewood Cliffs, NJ, 718 p.
- Zimmerman, R.J. and T.J. Minello. 1984. Densities of *Penaeus aztecus*, *Penaeus setiferus*, and other natant macrofauna in a Texas salt marsh. *Estuaries* 7:421–433.