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Hydrophone Identification of Spawning Sites of Spotted Seatrout *Cynoscion nebulosus* (Osteichthyes: Sciaenidae) Near Charleston, South Carolina

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HYDROPHONE IDENTIFICATION OF SPAWNING SITES OF SPOTTED SEATROUT *Cynoscion nebulosus* (Osteichthys: Sciaenidae) NEAR CHARLESTON, SOUTH CAROLINA

Spawning male spotted seatrout, *Cynoscion nebulosus*, produce distinctive drumming sounds by compressing the swim bladder with the surrounding muscles to attract mates during their spawning season (Tower 1908, Burkenroad 1931, Fish and Mowbray 1970, Mok and Gilmore 1983). Four distinctive sounds have been described: 1) a "grunt" followed by a series of "knocks", 2) "aggregated grunts", 3) a "long grunt", and 4) a "staccato" (Mok and Gilmore 1983). *Cynoscion nebulosus* spawn about once every 16 to 21 days (Tucker and Faulkner 1987, Brown-Peterson *et al.* 1988) from April through September in South Carolina, USA (Daniel 1988). The initiation, duration, and site of spawning is influenced by environmental and temporal variables (Arnold *et al.* 1978, Hein and Shepard 1979, Brown-Peterson *et al.* 1988, Peebles and Tolley 1988, McMichael and Peters 1989, Saucier 1991). We described the environmental conditions at ten drumming locations by identifying sound producing individuals and aggregations with a hydrophone. We verified spawning activity by collection of recently spawned *Cynoscion nebulosus* eggs in three locations where we recorded drumming activity.

METHODS

We sampled from 1600 to 2400 h EDT, 2 to 6 August 1990, for sound producing *Cynoscion nebulosus* at 13 stations around Charleston Harbor, South Carolina (Figure 1). *Cynoscion nebulosus* drumming sounds were recorded with an Interocean Model 902 hydrophone and a Sony TCS 450 cassette tape recorder. Salinity, water temperature, and dissolved oxygen concentration were measured with Yellow Springs Instrument S-C-T and Model 57 meters, current velocity was measured with a Montedoro-Whitney PVM-2 meter, and water depth was measured with a depth finder at each location. The hydrophone was suspended 1 m below the surface. The pattern and sound level in decibels (standard settings were 132 db re 1 μ pascal) was used to estimate the size of the drumming aggregation on an ordinal scale ranging from 0 to 5 (*i.e.*, 0: no drumming, 1: single drumming individual, 2: two or three drumming individuals, 3: small drumming aggregation, 4: moderate drumming aggregation, 5: large drumming aggregation). Field recordings were verified against known sound recordings of *Cynoscion nebulosus* spawning activity (R. Grant Gilmore, Harbor Branch Oceanographic Institution, Inc., Fort Pierce, Florida, *pers. comm.*). We used a Uniscan II spectrum analyzer to compare frequency and duration patterns (sonograms) with known recordings for further species verification (Mok and Gilmore 1983).

To verify spawning activity, plankton tows were made to capture recently spawned eggs. All tows were made downcurrent of suspected spawning sites with a 0.33 m diameter plankton net constructed with 505 μ mesh and fitted with a 333 μ mesh basket. We made 3 min tows and filtered a mean water volume of 6.6 m^3. Plankton samples were examined at 10× magnification for sciaenid eggs within three hours of sampling. Most eggs were in early stages of development (cell division or morula) indicating that they were captured at the spawning site (Holt *et al.* 1985). Because sciaenid eggs are difficult to identify to species, we reared 10 to 15 buoyant eggs from three sites in 100 ml of filtered seawater in 0.5 L wide-mouth containers. Eggs hatched 16 to 20 h after capture and the yolk sac

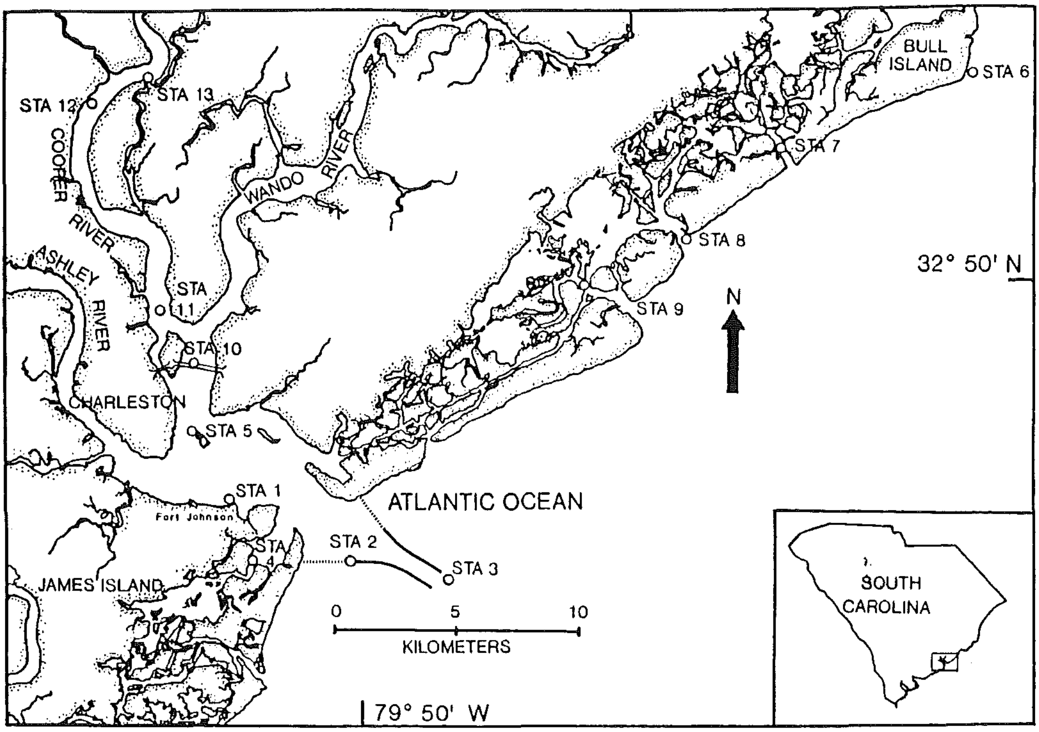

Figure 1. Map of the coastal waters around Charleston, South Carolina, identifying thirteen hydrophone sampling stations.

larvae were identified 18 h after hatching according to Holt *et al.* (1988). The remaining eggs were preserved in 5% seawater-buffered formalin.

RESULTS AND DISCUSSION

We used passive acoustical techniques to locate one large and two moderate drumming aggregations, and 15 smaller groups or individuals of *Cynoscion nebulosus* in the study area during our 5 d survey (Table 1). The spawning activity of the large and two moderate drumming aggregations was verified by rearing newly spawned eggs captured downcurrent of drumming sites. In addition, one female with hydrated eggs was also captured in a gill net set on a drumming aggregation at Fort Johnson (Station 1).

Drumming *Cynoscion nebulosus* were recorded from 2002 to 2331 h. This agrees with Holt *et al.* (1985) and Brown-Peterson *et al.* (1988) who found that *Cynoscion nebulosus* on the Texas coast began spawning about one hour before sunset and continued until 2300 hrs. The most intense drumming activity was located in the Charleston Harbor directly beneath the Cooper River Bridge (Station 10) around the bulkheads to the east and west of the Charleston ship channel. We were able to define the location of a spawning school to within 15 m by observing the sound level. For example, beneath the Cooper River Bridge (Station 10), the sound level was 135 db, but when we moved 20 m to the east or west, the level dropped off quickly to 130 db, a 44% reduction. Forty-three minutes later at 2233 h, the aggregation had shifted position slightly and was not drumming as intensely. Another moderate aggregation was located near Fort Johnson (Station 1) in the vicinity of submerged granite rub-

Table 1. Environmental conditions and *Cynoscion nebulosus* drumming activity recorded at hydrophone listening locations in coastal waters near Charleston, South Carolina, USA.

Date	Time	Station	Location	Drumming Aggregation Size (0-5)	Salinity (‰)	Temp. (°C)	Depth (m)	Velocity (cm/s)	D.O. (mg/l)
Drumming Aggregations									
Aug 2	2055	1	Fort Johnson	4	23.0	27.5	7.6	58	7.9
3	2149	1	Fort Johnson	3	24.0	28.2	7.6	70	6.2
4	2037	1	Fort Johnson	3	27.0	28.0	7.6	7	8.0
6	2017	10	Cooper River	3	25.5	28.8	14.0	——	6.2
6	2129	11	Cooper River	3	24.0	28.4	11.6	——	6.5
6	2150	10	Cooper River	5	25.0	28.6	11.6	6	6.6
6	2233	10	Cooper River	4	25.0	28.2	12.2	35	6.0
Mean				3.6	24.8	28.2	10.3	35.2	6.6
± 1SD				± 0.8	± 1.3	± 0.4	± 2.7	± 29.1	± 0.7
Drumming Individuals									
Aug 2	2242	2	Dynamite Hole	1	26.0	28.2	11.0	73	6.4
3	2002	3	Charleston Ship Channel	2	——	——	9.1	——	6.9
3	2126	4	Schooner Creek	1	——	——	9.1	——	——
3	2251	1	Fort Johnson	1	24.0	28.0	7.6	69	6.9
4	2210	1	Fort Johnson	1	30.0	28.0	5.2	35	7.4
5	2018	6	Bull Island	1	33.0	29.0	——	——	6.6
5	2041	6	Bull Island	1	33.0	29.9	3.1	6	6.3
5	2142	7	Price Inlet	2	33.0	28.5	5.5	——	6.2
5	2231	8	Capers Inlet	2	33.0	28.2	3.7	90	5.7
6	2026	11	Cooper River	2	23.0	28.5	13.4	——	5.3
6	2045	12	Upper Cooper River	2	16.0	29.9	14.0	——	5.3
Mean				1.5	27.9	28.5	8.2	54.6	6.3
± 1SD				± 0.5	± 6.0	± 0.4	± 3.7	± 33.7	± 0.7
No Drumming									
Aug 4	2245	5	Castle Pinckney	0	25.0	28.5	9.5	25	8.2
5	1958	6	Bull Island	0	32.5	29.0	——	——	6.6
5	2314	9	Dewee's Inlet	0	——	——	22.0	——	——
5	2359	1	Fort Johnson	0	25.5	28.5	7.6	130	5.4
6	2100	13	Upper Cooper River	0	13.0	29.0	9.1	——	5.2
Mean				0	24.0	28.8	12.0	77.5	6.4
± 1SD				± 0	± 8.1	± 0.3	± 6.7	± 74.3	± 1.4

ble and pier pilings. Smaller aggregations were also located at Station 1 on the two following nights. Drumming aggregations were located in salinities that ranged from 23 to 27 ppt, dissolved oxygen concentrations that ranged from 6.0 to 8.0 mg l, temperatures that ranged from 27.5 to 28.8 °C, and depths that ranged from 7.6 to 14 m. Observed mean water column velocities for aggregations ranged widely, 6 to 70 cm/s. Focal velocity (*i.e.*, the velocity at the fish's snout) may be a more appropriate variable to characterize spawning habitat selection; nevertheless, all aggregations were located in moving water. The ranges were increased for all variables except temperature when all drumming individuals were included.

In our study, drumming aggregations were not observed in high salinity (>32.5 ppt), beach-front habitats or barrier island passes (Stations 6, 7, 8, and 9) or at low salinity (<16 ppt), up-river locations (Stations 12 and 13). Temperature at non-drumming locations ranged from 28.5 to 29.0 °C. In other studies, spawning salinities selected by *Cynoscion nebulosus* in Texas ranged from 20 to 37 ppt and in Florida salinities ranged from 15.5 to 36 ppt (Arnold *et al.* 1978, Tucker and

Faulkner 1987, Brown-Peterson *et al.* 1988, McMichael and Peters 1989, Rutherford *et al.* 1989). Spawning *Cynoscion nebulosus* select water temperatures above 23°C (Brown-Peterson *et al.* 1988), most often between 25 and 32°C (Arnold *et al.* 1978, Tucker and Faulkner 1987, Holt *et al.* 1988, Rutherford *et al.* 1989). Elsewhere spawning has been reported in barrier island passes (Tabb and Manning 1961), in offshore locations (Jannke 1971), and in channels adjacent to seagrass beds (Brown-Peterson *et al.* 1988). Spawning conditions reported in the literature are highly variable, particularly for salinity and temperature. The wide variance may reflect the species' tolerance, the inaccuracy of indirect methods of spawning site identification, or the unrecognized importance of other variables that influence spawning site selection. Rutherford *et al.* (1989) suggested that current and depth are important variables. In a more extensive hydrophone study of *Cynoscion nebulosus* spawning requirements in Louisiana (Saucier 1991), a combination of temporal and environmental variables and interactions were found to influence drumming aggregation size. In a stepwise regression model, temporal variables were most important followed in order by an interaction between salinity and velocity, velocity, temperature, and an interaction between depth and velocity.

Hydrophones are valuable tools that can aid our understanding of the spawning habitat requirements and behavior of fishes that use sound to aggregate for spawning. Acoustical techniques offer several advantages and can also be used in conjunction with more traditional methods. Acoustical sampling is not labor intensive or destructive. Actual spawning sites can be located with accuracy and studied in detail to describe the suite of environmental and temporal variables associated with spawning. Seasonal and diel patterns of spawning activity can also be studied (Mok and Gilmore 1982, Saucier 1991). In contrast to Johnson and Funicelli (1991), we found that hydrophone listening was an effective technique for locating spawning aggregations of sciaenids when used in a systematic search mode rather than a fixed-station sampling design. Since successful spawning probably takes place in a variety of habitats where salinity, temperature, and other variables are adequate for egg buoyancy and survival, spawning locations for a population may vary seasonally and annually due to climatic factors that influence the spatial patterns of salinity and temperature. Our understanding of the habitat requirements, spawning site selection, and diel patterns of spawning behavior for each species, will be enhanced by examination of variation among years and of several populations in different systems.

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