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# ANALYSIS OF SOUND PRODUCTION IN ESTUARINE AGGREGATIONS OF *POGONIAS CROMIS*, *BAIRDIELLA CHRYSOURA*, AND *CYNOSCION NEBULOSUS* (SCIAENIDAE)

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**Hin-Kiu Mok and R. Grant Gilmore** (1983) Analysis of sound production in estuarine aggregations of *Pogonias cromis*, *Bairdiella chrysoura* and *Cynoscion nebulosus* (Sciaenidae). *Bull. Inst. Zool., Academia Sinica* **22**(2): 157-186. From December 1979 to June 1980 hydrophone recordings were made of sounds produced by the black drum, *Pogonias cromis*, silver perch, *Bairdiella chrysoura* and spotted seatrout, *Cynoscion nebulosus* in the Indian River lagoon, east-central Florida, U. S. A. Species-specific sound qualities were determined and described. *Pogonias cromis* produced two principal sound types characterized as a "loud drum" and a "short grunt", while *B. chrysoura* produced a series of sound combinations all based on a sequence of "knocks". *Cynoscion nebulosus* produced a complex series of sounds characterized as "grunts", "knocks" and "staccato". Diel and seasonal changes in sound production associated with specific recording locations were also determined. Maximum daily sound production for all three species occurred between 1700 and 2200 hr and was coincidental with the appearance of eggs and larvae in the water column at the recording sites. Seasonal peaks in sound production occurred during the winter for *P. cromis*, spring for *B. chrysoura* and spring to summer for *C. nebulosus*. Peak sound production in all species occurred at specific locations and time periods coincidentally with the known principal spawning period for the species. All three species were found to produce sounds of maximum intensity in the deeper portions of the estuary along the Intracoastal Waterway.

Knowledge of temporal and spatial changes in fish aggregations is important in the fishery management of any species. To obtain this knowledge, conventional approaches usually entail trapping and netting of larvae and adults, tagging, and even echo location. However, few studies have been published on the use of hydrophone and other associated equipment to locate and study soniferous fish aggregations for fishery purposes. The objectives of this study are to determine the possibility of using species-specific sound production to locate soniferous fish aggregations and to provide an accurate description of the sounds produced by each species. In addition we investigated the use of the quantity of sound produced by a species aggregation to approximate the size of each aggregation.

In 1968, Breder conducted a survey of fish sounds recorded from a small Florida bay (Lemon Bay, Charlotte County, Florida west coast) by recording sounds at several stations along the coast. The purpose of that study was not to identify the sound producers but to show that sound producers were present and that temporal and spatial changes in sound production take place. The distribution and movement of the soniferous species in the bay, however, were only briefly mentioned. However, Breder was one of few workers who have studied fish movement and distribution by recording the sounds they produce. Takemura *et al.* (1978) studied the temporal variation in sound production of *Nibea albiflora* and *Argyrosomus argentatus* in the Ariake Sound, Japan. However, they did not study spatial change in acoustic activity.

This study was conducted in the Indian River lagoon in east-central Florida where there are numerous soniferous fish species (*e.g.*, carangids, pomadasyids, sciaenids, ariids, and batrachoidids). Recent studies reveal that sixteen soniferous sciaenid species occur in the Indian River lagoon (Gilmore, 1977), thirteen of which are of commercial and sport fishery value. The majority of these species are known to migrate offshore to spawn (Moe, 1972). However, three are known to spawn within the estuary: the black drum, *Pogonias cromis*, the silver perch, *Bairdiella chrysoura*, and the spotted seatrout, *Cynoscion nebulosus* (Günter, 1945; Simons and Breuer, 1962; Tabb, 1966). The spotted seatrout has steadily declined in commercial fishery landings during the past twenty years (*e.g.*, Florida east coast landings went from 1,238,763 lbs. in 1953 to 532,000 lbs. in 1976; Geer and Cohn, 1954; Prochaska, 1976; Snells, 1978; Tabb, 1961). This decline may be due to fishing pressure, habitat destruction or other environmental factors (Tabb, 1961). These factors might also be particularly critical when they affect breeding aggregations during spawning activities at a particular location. Therefore, determination of specific spawning sites and periods are critical for proper management of the estuarine sciaenid fisheries.

Spawning sites of soniferous species may be found by listening for spawning aggregations using hydrophones. Characterization of species-specific sound produced in the spawning season is a necessary preliminary step in localizing these fish aggregations.

The present data set documents sounds produced by *P. cromis*, *B. chrysoura*, and *C. nebulosus* within the Indian River lagoon illustrated in oscillograms, sonograms, and spectrograms which were used to characterize both individual and aggregate sounds of these species. These data were then to utilized to determine the distributional patterns of aggregations of these three species from December 1979 to June 1980.

## STUDY AREAS AND METHODS

We selected a cross section of the Indian River lagoon surrounding our laboratory site (Link Port Study Area, LPSA, St. Lucie County, Florida; Fig. 1) for weekly study of sciaenid sound distribution from December 1979 to June 1980. In addition a larger geographic area, designated as the Intracoastal Waterway Study Area (IWSA), was monitored on a seasonal basis. The IWSA study area was limited to a 28-kilometer section of the Intracoastal Waterway within the Indian River lagoon extending from the Wabasso Causeway (27°45′N, Indian River County, Florida) to Link Port (LP; Fig. 2). Thirty-two recording stations were established at the LPSA and fourty-six in the IWSA. The former area included the Link Port Marina (LPM; maximum depth 5 m), the dredged Link Port Channel (LPC; average depth of 5 m) which joins to the Intracoastal Waterway (average

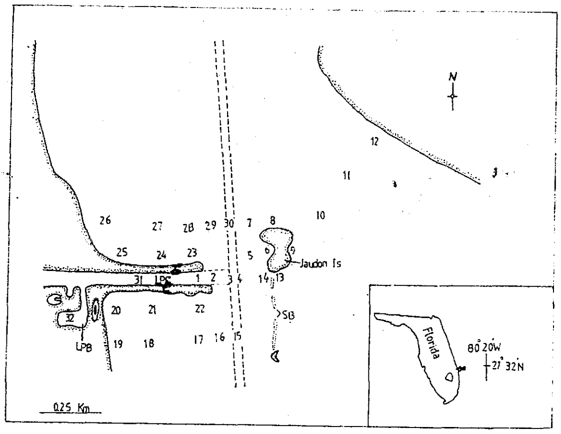


Fig. 1. Locations of the 32 recording stations in the Link Port Study Area. Arrow in the small map points to the location of the study area in Florida State, U.S.A. LPB, Link Port Bay; LPC, Link Pont Channel; SB, sand bar; dash lines, Intracoastal Waterway.

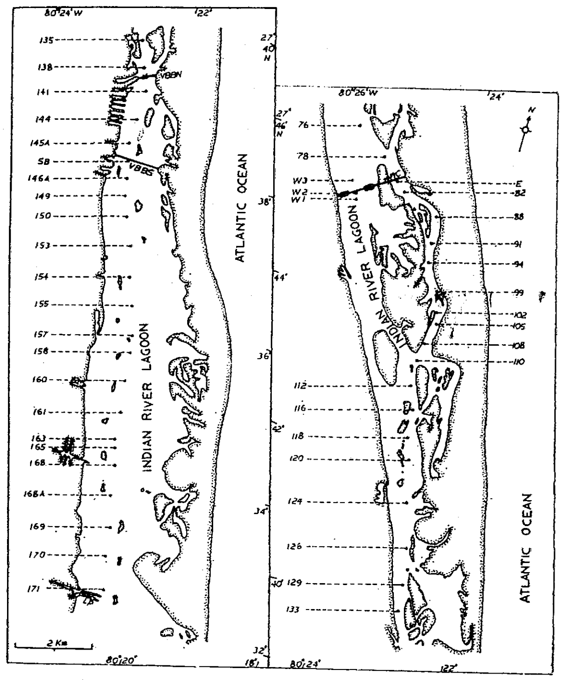


Fig. 2. Locations of the 46 recording stations along the Intracoastal Waterway in the Waterway Study Area. E, east section of the Wabasso Causeway; LP, Link Port; VBBN, north Vero Beach Bridge; VBBS, south Vero Beach Bridge. Numbers along the waterway are numbers of the channel makers.

depth of 5 m) and the shallow flats located east and west of the waterway (average depth of 1.5 m). The Link Port Marina and Channel bottoms were muddy and silty, whereas that of the Intracoastal Waterway bottom consisted of variable amounts of sand, mud and rock. Shallow sand flats ($\leq$1.5 m) were located adjacent to the Intracoastal Waterway while inshore flat regions consisted principally of seagrass beds with occasional small patches of sand. The inshore seagrass beds west of the waterway were larger, denser and extended farther off the shoreline than those east of the waterway.

Most weekly recordings commenced 1.5 hr before sunset and terminated 2 hrs after sunset. Occasional recordings were carried out from 1000 to 1455 hrs. A rigid recording schedule could not be followed from December to February due to poor weather conditions. All stations in the IWSA were surveyed during two consecutive evenings. We covered half of the stations in each evening to minimize the difference in station recording time.

Recordings were made from small motor powered skiffs that were allowed to drift while recordings were made using a Sony TC-158SD cassette recorder (frequency response: 20-14000 Hz) and hydrophone (Inter Ocean System, Inc., Model 902; frequency range: 20-10000 Hz). The recording level of the recorder was set at 1.5, whereas acoustical level of the hydrophonre was set at 140 db re 1 $\mu$ pascal such that sound amplitudes in all recording stations could be compared. The hydrophone was lowered to 1 m below the water surface. A two-minute recording was made at each station during each visit.

An automatic recording system including a hydrophone (Chesapeake Bay Instrument, Inc., Model SH-102; frequency range: 1-20000 Hz) set at 1 m below water surface, a Sony TC-158SD cassette recorder, and a repeat cycle timer (Talley Industries Co.) was installed in the Link Port Marina for 24-hr recording of diel and seasonal acoustic activity in the marina basin. A two-minute recording was made every hour.

Fish sounds were analyzed by using the following equipment: sona-graph (Kay Elemetrics Corp., Model 7029A), analog oscilloscope (Tektronix, 7633), oscilloscope camera (Tektronix C-5A), digital oscilloscope (Nicolet Instrument Co., Model 204) connected to a X-Y recorder (Coulter Electronics, Inc.), stereo frequency equalizer (Realistic 13-1978), and frequency filter (Krohn-hite Corp., Model 3322).

Specimens of *B. chrysoura* and *P. cromis* were kept in a shallow fish pen. Sounds obtained under such condition should provide direct evidence for the verification of sound producer. To find the relation between spawning and acoustic activity and to add information to the identification of sound producer, ichthyoplankton hauls were made irregularly with a 1 m diameter, 200 $\mu$ mesh plankton net. Sciaenid eggs and larvae were identified and their abundances in the collected site were estimated. Plankton samples were taken within 1-1.5 m from the surface between two preselected channel markers (about 15 meters apart) in the Intracoastal Waterway so that quantitative comparisons between hauls could be made.

## RESULTS

### I. Black drum, *Pogonias cromis*

#### Biology

*Pogonias cromis* occurs predominately in inshore neritic waters just outside the ocean littoral zone and in estuarines from southern New England to Argentina (Richard, 1973). This species is one of the largest sciaenids as those caught in the sport fisheries weigh from 20-40 kgs. Among the sciaenids, the black drum ranks third by weight in Florida commercial landings (Florida Department of Natural Resources, Florida Commercial Landings Reports, 1957-1976). Most east-central Florida landings are made in the Atlantic Ocean. However, major sport and commercial catches also occur in the Indian River lagoon between September and April, with the greatest number taken in November (Anderson and Gehringer, 1965).

Adult and juvenile black drums occur most often in unvegetated, mud-bottomed channels in a variety of locations within the Indian River lagoon (Gilmore, 1977). Spawning activity occurs in these locations from early fall to late spring based on sonic observations, and the collection of plankton eggs, early larvae and juveniles (Gilmore *et al.*, in preparation; Youngbluth, *et al.*, unpublished data). The major estuarine sport fishery catch occurs during the peak spawning period as many black drums in spawning condition are caught in deep estuarine channels during the winter months.

#### Description of sounds

When a black drum was hand-held or disturbed in captivity, it produced a "staccato" sound. This sound type was composed of a series of units (Fig. 3A) with energy mainly limited below 400 Hz; repetition rate of the unit reached 14 units/sec. Besides this "staccato" sound, *P. cromis* produced at least two other sound types in natural conditions. One was the "loud drum" sound (Fig. 3B-D) and the other was the "short grunt" sound (Fig. 4). Each sound type was emitted repeatedly. The occurrence of "short grunt" sound varied with seasons (see below). When they occurred, one or two "loud drum" sounds was frequently mingled with a long series of "short grunt" sounds (Fig. 4).

For the "loud drum" sound, the order of harmonics, fundamental frequency, and the energy content at each order of harmonics were variable. In a sample of 194 "loud drum" sounds, the number of harmonics recognizable from the sonograms ranged from 3 to 13 (Table 1). At one extreme, order of harmonics reached 19. Only the high harmonic bands were missing in those sounds with a lower number of harmonics. Frequency of the "loud drum" sound ranged from 100 to 1850 Hz. Frequency ranges of the first five orders of harmonics are listed in Table 2.

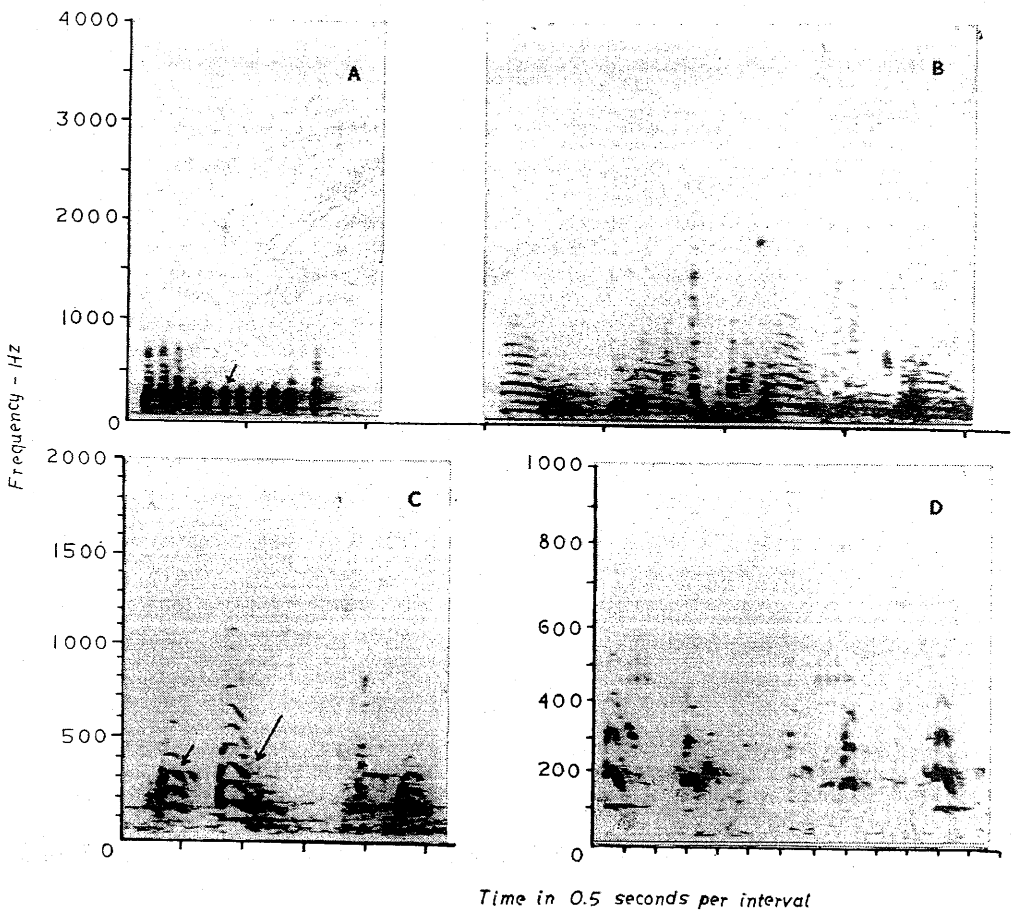


Fig. 3. Sonograms of ***Pogonias cromis*** sounds. A, a "staccato" sound (short arrow indicates a unit of this sound); B, four "loud drums"; C, a "boon loud drum" (indicated by the short arrow) and a "bound loud drum" (indicated by the long arrow); D, four "loud drums" (the first and fourth sounds are "boon" sounds, whereas the second and third are "bound" sounds).

The "loud drum" sound can be divided into two subgroups. The first group sounds like the word "boon" and the second one sounds like the word "bound" (Fig. 3C). The "bound" sound which is usually louder than the "boon" sound has energy spreading to higher frequency range.

Figure 5 presents several oscillograms of "loud drum" sounds. The "boon drum" is shorter than the "bound drum" (*e. g.*, Fig. 5A). The wave form of the "boon drum" (Fig. 5B) differs from that of the "bound drum" in that it consists of a series of paired peaks separated by one to two smaller compressed peaks while the "bound drum" consists of a more symmetrical arrangement of paired peaks of similar amplitude (Fig. 5C, D).

It was difficult to measure the duration of the "loud drum" sound accurately on the sonograms. Ambient noise made it difficult to decipher the termination of the first order of harmonics which is longest in duration among all the orders of harmonics. Estimation of the sound duration was made by measuring the duration of the second harmonics instead. The "loud drum" sound can be put into two subgroups differing in their duration as shown in two normal distributions which peaked in 216 msec and 280 msec, respectively, with an overlapping area at approximately 250 msec (Fig. 6).

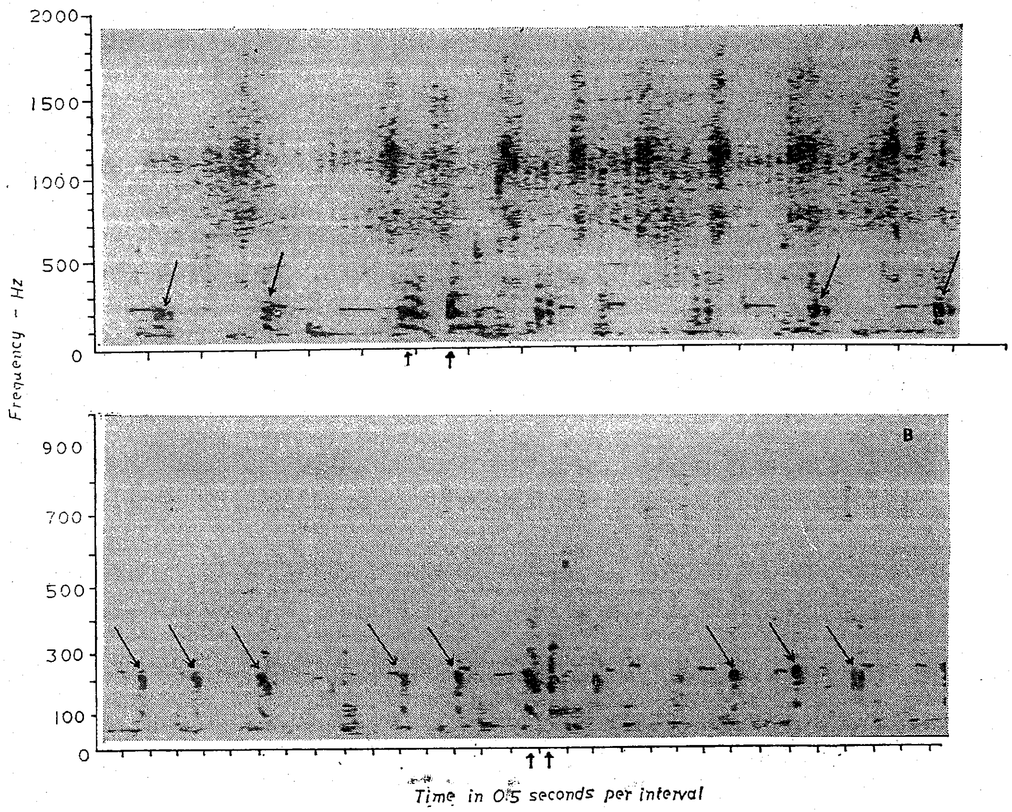


Fig. 4. A series of *Pogonias cromis* "short grunts" mixed with two "loud drums". Long arrows indicate the "short grunts" and the short arrows in the time axis indicate the "loud drums".

TABLE 1
Order of harmonics in 194 "loud drum" sounds of *Pogonias cromis*

| Order of harmonics | Number of recordings |
|---|---|
| 3 | 28 |
| 4 | 35 |
| 5 | 21 |
| 6 | 28 |
| 7 | 32 |
| 8 | 15 |
| 9 | 18 |
| 10 | 5 |
| 11 | 5 |
| 12 | 6 |
| 13 | 1 |

Frequency range on the sono-graph was set at 20 to 2000 Hz.

TABLE 2
Frequency ranges of the first five orders of harmonics of *Pogonias cromis* "loud drum" sound

| Order of harmonics | Frequency band (Hz) |
|---|---|
| 1 | 60, 70, 80, 90 |
| 2 | 140, 150, 160, 200 |
| 3 | 240, 250, 260, 280, 300 |
| 4 | 320, 340, 360, 400 |
| 5 | 440, 500 |

A few series of "loud drum" sounds were interpreted to be emitted by a single fish. In a two-sound series the interval (duration between the beginnings of two immediately adjacent sounds) was 960 msec. In a three-sound series the intervals were 4850 and

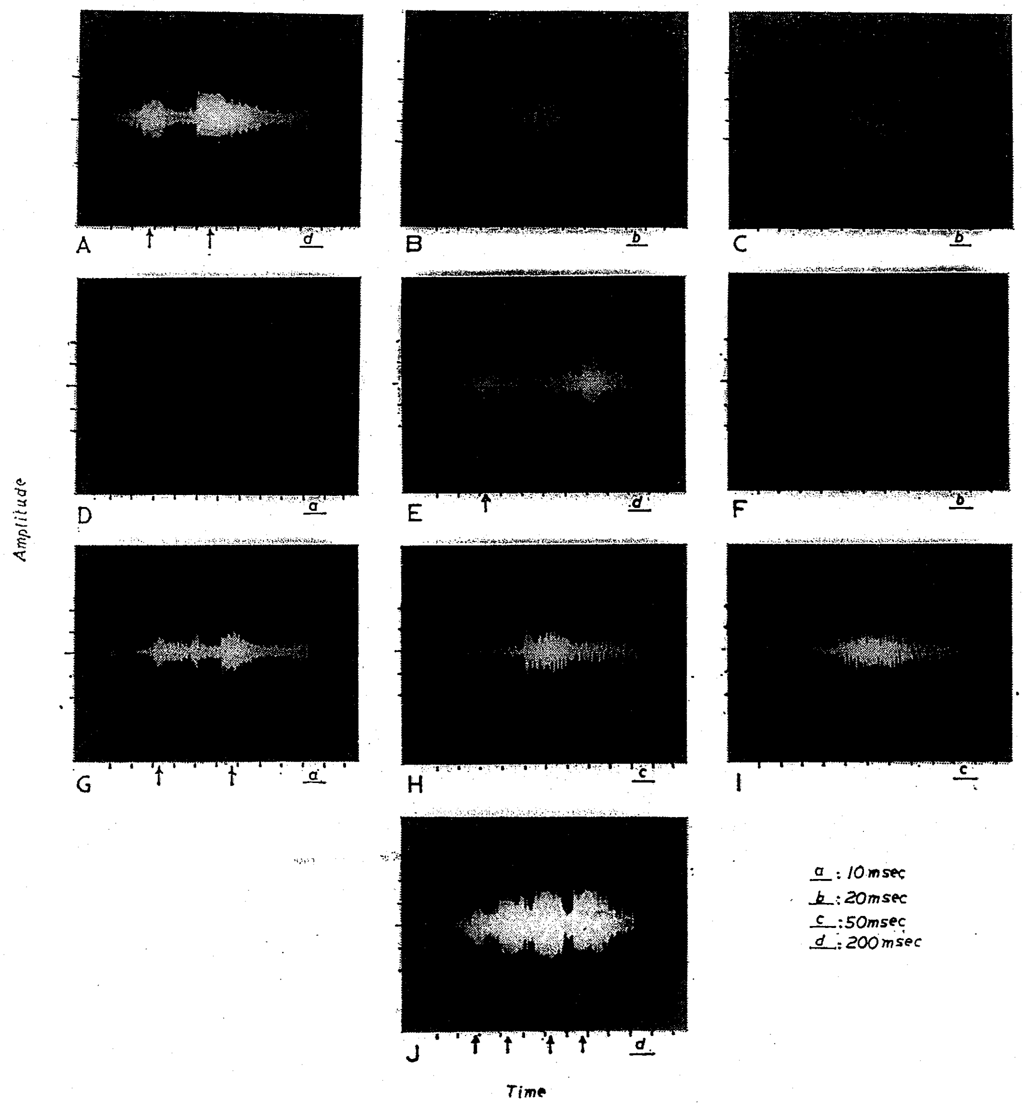


Fig. 5. Oscillograms of some examples of *Pogonias cromis* "loud drums". A, a "boon" and a "bound loud drum" indicated by the left and right arrows in the time axis, respectively; B, a detailed illustration of the waveform of the "boon loud drum" in Fig. 5A; C, a detailed illustration of the waveform of the "bound loud drum" in Fig. 5B; D, another detailed illustration of the waveform of a "bound loud drum"; E, two adjacent "loud drums"; F, detailed illustration of the first "loud drum" in Fig. 5E indicated by the arrow in the time axis; G, two "loud drums"; H–I, detailed illustrations of the left and right "loud drums" in Fig. 5G indicated by the arrows in the time axis; J, four "loud drums".

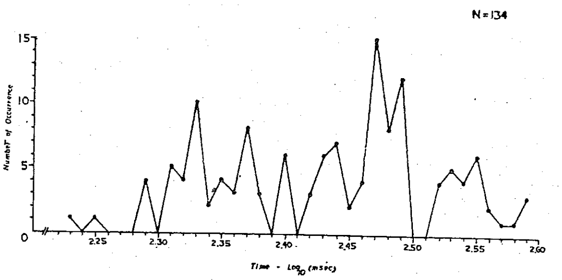


Fig. 6. A plot of the duration of *Pogonias cromis* "loud drums".

1000 msec, respectively (listed from the beginning interval to the last interval). In a five-sound series the intervals were 1750, 2280, 610, 2700 msec, respectively. These sounds revealed a pattern of alternating long and short intervals. Due to the small number of sound series available, a detailed study of sound intervals was not possible.

In the "short grunt" sounds most sound energy were restricted to a band at about 200 Hz (Fig. 4A, B), although some energy was contentrated near 140 Hz (Fig. 4B). Very little energy was found at higher frequencies. This sound lasted about 300 msec.

**Spatial and temporal sound distributions**

*Seasonal variation:* Recordings made in January, 1980, showed *P. cromis* "loud drum" sounds dominating all other sounds recorded within the Intracoastal Waterway both in number and intensity at water temperatures of 18 to 20°C. These loud sounds did not include the "short grunt" sounds. During February and early March, *P. cromis* "loud drum" sounds were completely absent in the Link Port Study Area when the water temperatures had dropped to 13–15°C. During this cold period, the long and harmonic sounds of the *Opsanus tau* were the only fish sounds produced at a significant level. As the water temperature increased to 18–20°C on 22 February, the "loud drum" sounds of *P. cromis* were recorded again. When water temperatures reached 20°C or higher in March, April and May, the "loud drum" sounds were present but were fewer in number and intensity compared to recordings made in January. In late April and early May "loud drum" sounds were much weaker and "short grunt" sounds occurred much more often than the "loud drum" sounds. One or two of the latter sound type were mixed in series with "short grunt" sound. Complete absence of *P. cromis* sounds was noted in our overnight recording session made on 14 May and also in recordings of 18 June at 1800 hr. The decline in drum sound production during the spring coincides with a decline in spawning activity. The intensity of sound production recorded in the Intracoastal Waterway during the winter and the capture of eggs and larva (also see below) isolates both this location and time period as the location and period of maximum aggregation of spawning black drum.

*Diel acoustical variation:* On 30 January we made recordings at Station 3 in the Link Port Study Area (Fig. 1) at 0930, 1430, and

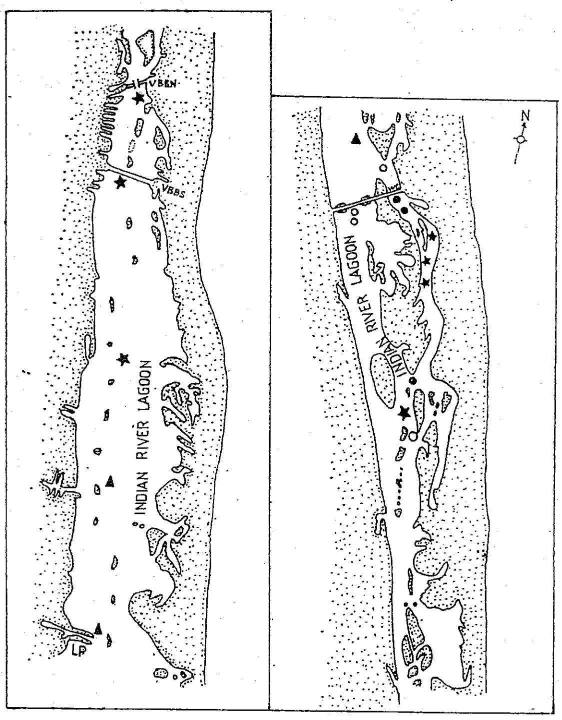


Fig. 7. Distribution of the *Pogonias cromis* "loud drums" in the Intracoastal Waterway Study Area. Triangle represents scattered individual sounds; white circle represents small group sound; asterisk represents median group sounds; black circle represents large group sound.

1630 hr. *P. cromis* "loud drum" sounds only appeared in the last recording made after sunset. On 25 March, several sequences of drum sounds were recorded at Station 3 in the Link Port Study Area at 1400 hr. This was the only instance when "loud drum" sounds appeared during the day. In the diel survey conducted on 30 April we recorded many "short grunt" sounds with a few interspersed "loud drum" sounds only in the 1930 and 2030 hr recording sessions.

*Spatial distribution:* During January, "loud drum" sounds recorded at stations located off the deep Intracoastal Waterway (Stations $W_1$ and $W_2$) were usually weak and thought to be emitted from a distant source (Figs. 2, 7; Table 3). Loud group sounds appeared primarily in the north section of the Waterway Study Area where the waterway winds among numerous small mangrove-lined islands (Fig. 7). The loudest group sound was associated with Stations E, 82, and 110 (Figs. 2, 7; Table 3). Little variation in sound type was observed among stations during April and most of the sounds recorded were either weak sounds from scattered individuals or small groups (Table 3). Acoustical activity further decreased in May. During May, Stations $W_1$, $W_2$, and $W_3$, located

TABLE 3
Appearance of the *Pogonias cromis* "loud drum" sound in the Waterway Study Area in January, April and May, 1980

| Station | Date | | | Station | Date | | |
|---|---|---|---|---|---|---|---|
| | January | April | May | | January | April | May |
| $W_1$ | FSG | — | — | 135 | | FSI | — |
| $W_2$ | FSG | FSI | — | 138 | | FSI | — |
| $W_3$ | | FSI | — | 141 | CMG | FSI | — |
| 76 | CSI | M | — | 144 | | FSI | — |
| 78 | CSG | M | FSI | 145A | | FSI | — |
| E | CLG* | CSG | FSI | VVBS | CMG | FSI | CSI |
| 82 | CLG* | FSG | FSI | 146A | | FSI | — |
| 88 | CMG | FSG | — | 149 | | CSI | — |
| 91 | CMG | FSG | — | 150 | | CSI | CSI |
| 94 | CMG | FSI | FSI | 153 | | M | — |
| 99 | | FSI | FSI | 154 | | FSI | — |
| 102 | | FSI | — | 155 | | FSI | — |
| 105 | | FSI | CSI | 157 | CMG | FSI | CSI |
| 108 | | CSI | FSI | 158 | | FSI | FSI |
| 110 | CLG | FSI | FSI | 160 | | FSI | — |
| 112 | CMG | FSI | — | 161 | | FSI | — |
| 116 | CSG | FSI | FSI | 163 | | FSI | FSI |
| 118 | | FSI | — | 165 | FSI | CSI | FSI |
| 120 | | FSI | — | 168 | | FSI | FSI |
| 124 | | FSI | FSI | 168A | | FSI | — |
| 126 | | FSI | — | 169A | | FSI | — |
| 129 | | CSI | — | 170 | | FSI | FSI |
| 133 | | FSI | — | 171 | CSI | FSI | FSI |

CLG, close-by large group sound; CLG*, close-by extremely large group sound; CMG, close-by medium group sound; CSG, close-by small group sound; CSI, close-by scattered individual sound; FLG, far (or weak) large group sound; FMS, far (or weak) medium group sound; FSI, far (or weak) scattered individual sound; M, *P. cromis* sounds masked by the loud background sound from the aggregations of *Bairdiella chrysoura*; (—), absence of sound; blank, no data.

far off the waterway, lacked black drum sounds, as did the area from Station 126 to 145A (Figs. 2, 7; Table 3). Only weak scattered individual sounds were recorded at these locations during April (Table 3).

Close-by individual and group sounds were almost exclusively limited to the deep Intracoastal Waterway and immediately adjacent deep areas (Fig. 8). In contrast to the other sciaenid species studied no seasonal dispersal of any drum sound type from the deep waterway into adjacent shallow seagrass-bed areas was noted. During the evening, we recorded black drum sounds only twice in the shallow area—on 22 February at Station 10 and on 26 March at Station 20 (Fig. 8). In both instances, only one to a few drum sounds were heard.

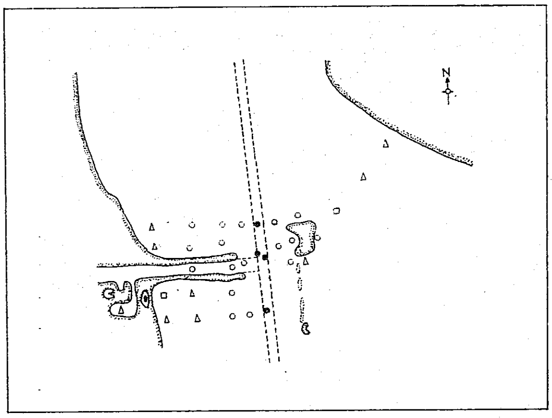

Fig. 8. Distribution of the *Pogonias cromis* "loud drums" in the Link Port Study Area during January, 1980. White circle represents far group sound; black circle represents close-by group sound; square represents close-by individual sound recorded only once; triangle indicates absence of "loud drums".

## II. Silver perch, *Bairdiella chrysoura*

### Biology

*B. chrysoura* is primarily a shallow water nearshore estuarine inhabitant ranging from the Gulf of Maine to Mexico. It occurs commonly in seagrass beds and over open, sandy bottoms (Johnson, 1978) and throughout much of its temperate range, migrates to offshore continental shelf waters during the winter. However, it remains inshore through most of the year in east central Florida (Gilmore *et al.*, in preparation).

Spawning activity occurs throughout the year in the Indian River lagoon with most spawning taking place from March to June (Gilmore *et al.*, in preparation). Spawning adults occur most abundantly in the deeper water of the estuary (Tabb and Manning, 1961).

### Description of sounds

The calls of *B. chrysoura* were composed of various numbers of "knocks" (Figs. 9A, 10A, B). For a majority of calls, the number of "knocks" ranged from 2 to 26 (mode=8, N=60). "Knocks" belonging to the same call were usually equal in duration (Fig. 9A). The duration of each "knock" ranged from 34 to 70 msec, with a frequency peak near 53 to 56 msec (Fig. 11A). No clear association between the number of "knocks" per call and the duration of the "knock" was noted (Fig. 11A). Intervals between the two nearest "knocks" (measured from the end of one "knock" to the beginning of the following "knock") within the same call were usually similar. However, in many cases this interval was shorter between those "knocks" in the early part of the call (Fig. 9A). The mean duration of this interval was estimated to be 80 to 90 msec with the lower and upper ranges to be 42 and 204 msec, respectively (Fig. 12). No obvious association was observed between the number of "knocks" per call and the duration of the interval (Fig. 11B).

Frequency composition of the calls was variable. On the basis of sound energy distribution within their frequency range, the calls were classified into three types:

Type 1. Sound energy is spread almost continously from about 330 to 2900 Hz (Fig. 13A).

Type 2. Most sound energy is limited to a particular frequency and can be sorted into two sub-types:

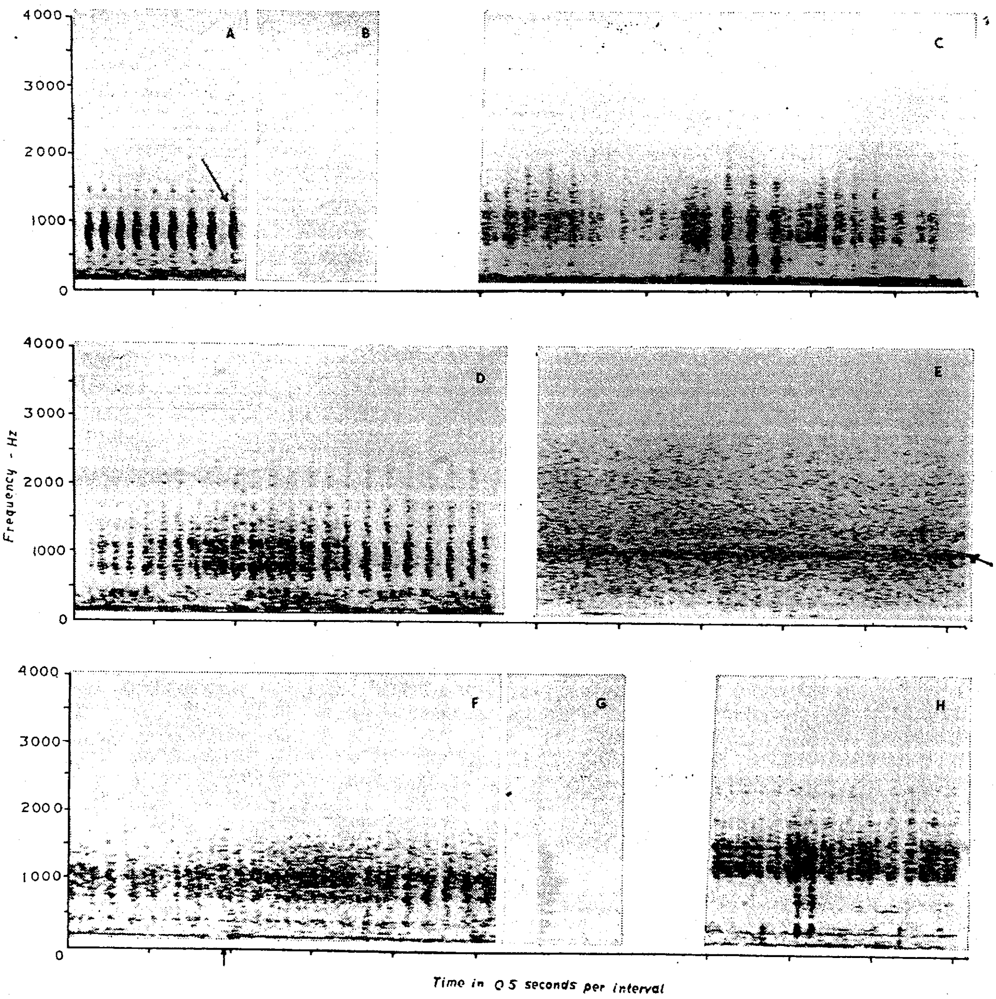


Fig. 9. Sonograms of the various sound types of ***Bairdiella chrysoura***. A, a nine-knock call; the arrow points to one of the "knocks" or the notes of the call; B, a spectrograms of a "knock"; C, scattered individual sound; D, close-by small group sound. E, close-by extremely large group sound; arrow indicates the high energy band; F, close-by large group sound; G, spectrogram of a close-by large group sound; section was made at the point indicated by the arrow in the time axis in F; H, far large group sound with two "knocks" produced by a close-by silver perch.

(A) Sound energy is limited between 200 and 1900 Hz (Fig. 13B).

(B) Most energy is distributed in a narrower and lower frequency range in comparison to (A), *i.e.*, from 500 to 1200 Hz (Figs. 13C, D and 9A, B).

Type 3. Sound energy is reduced in some frequency ranges such that distinguishable narrow high energy bands appear at particular frequencies (*e.g.*, at 700, 1000, 2000 Hz or at 400 and 700 Hz; Fig. 13E, F).

For the purposes of studying the spatial and temporal changes in the distributions of *B. chrysoura* sounds within the lagoon, we have classified their sounds into six categories:

*Individual sound* (*I*): It represents the distinctive calls of an individual located close to the hydrophone. The "knocks" of the same call are clearly distinguished from the ambient

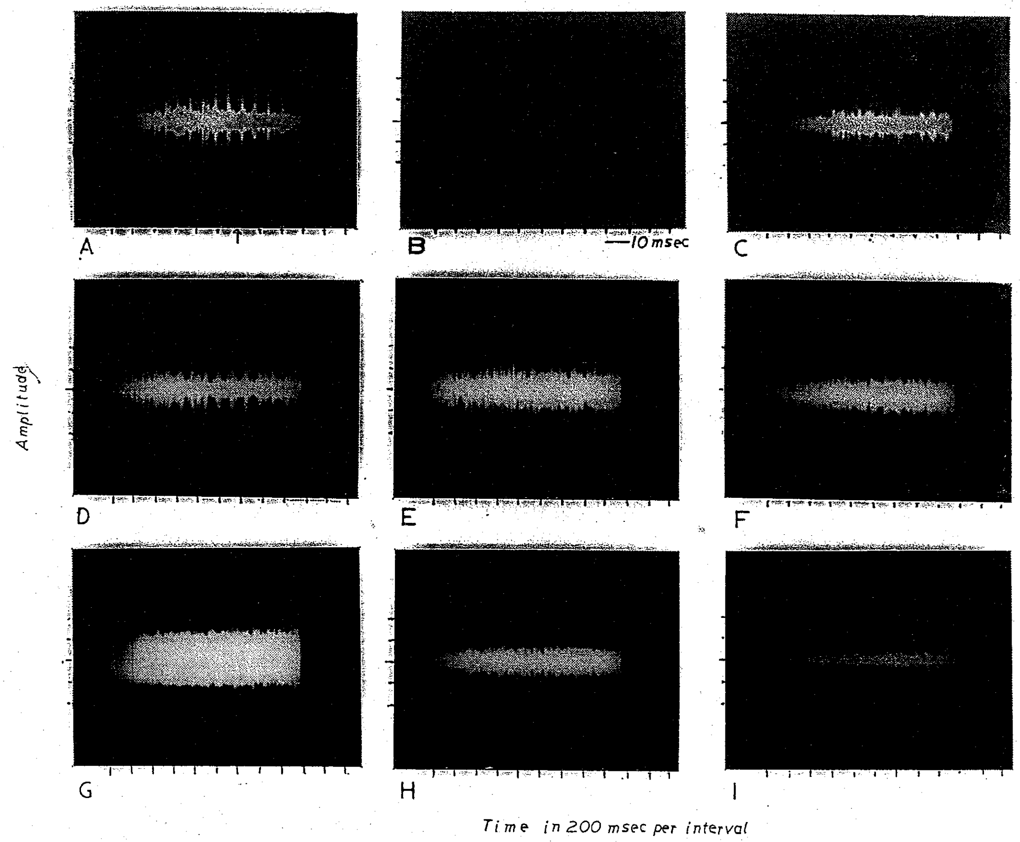


Fig. 10. Oscillograms of the various *Bairdiella chrysoura* sound types. A, a series of "knocks" of a call as shown by the vertical high spikes; B, a more detailed waveform of the "knock" indicated by the arrow in the time axis of oscillogram A; C, scattered individual sound; D, close-by small group sound; E, close-by small group sound; F, far small group sound; G, extremely large group sound; H, far (or weak) large group sound; I, reduction of sound intensity of a far large group sound as shown in oscillogram H.

noise (Figs. 9A, 10A, B). Due to the apparent close position of the sound producer, amplitudes of the calls are high.

*Scattered individual sound* (*SI*): It represents the calls of a few sound-producing individuals located near the hydrophone. "Knocks" of the call are recognizable (Figs. 9B, 10C). Because several fishes are emitting sounds at about the same time, the distribution of "knocks" as shown by the spikes in the oscillograms usually becomes random, making recognition of all the "knocks" in a particular call difficult. The number of "knocks" per unit time shown in the oscillograms and sonograms are higher in this category (SI) than the first one (I) (Figs. 9B, 10C).

*Close-by small group sound* (*CSG*): This sound category is composed of a higher number of knocks per unit time in comparison with SI sounds. Sounds amplitude is also higher. Because some fishes may have been very close to the hydrophone, a particular call may be distinguished in some cases (*e.g.*, Figs. 9D, 10D, E). In some cases, due to the high number of "knocks" presented, the sonograms showed a dark band (high energy band) at a particular frequency range (Fig. 9D).

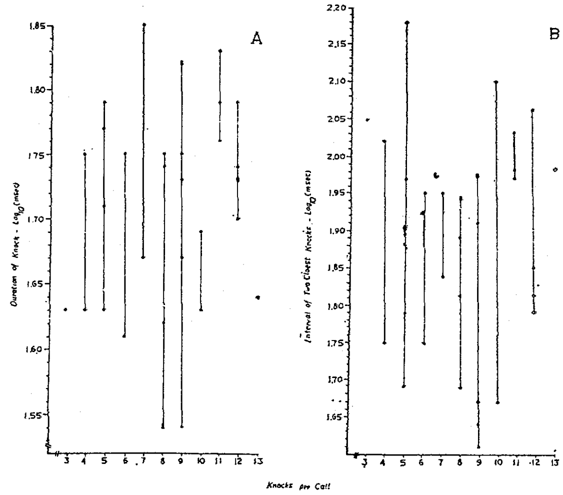

Fig. 11. Relations of "knocks" per call and duration of "knock" (A) and "knocks" per call and interval of two closest "knocks" (B) in *Bairdiella chrysoura* sounds.

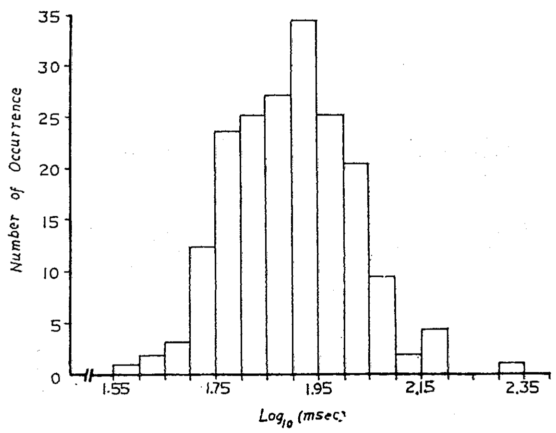


Fig. 12. A plot of the duration of the interval between two closest "knocks" in the same call of *Bairdiella chrysoura.* 190 intervals were measured.

*Far small group sound (FSG):* This category is similar to the CSG sound category except that the sound amplitute is lower. Individual calls have a lower chance of being recognized clearly in the oscillogram (Fig. 10F).

*Close-by large group sound (CLG):* The number of "knocks" per unit time and sound amplitude are very high. Individual knocks as shown by spikes in an oscillogram can hardly be distinguished from one another. Due to the similarity of sound amplitude among the "knocks" and the large number of "knocks", the oscillogram shows a wide band with the upper and lower edges slightly serrated (Fig. 10G). Figure 9E illustrates the sonogram of CLG sounds characterized by a dark band of high sound energy around 1000 Hz.

*Far large group sound (FLG):* This category shares the characteristics of the CLG sound except that its amplitude is lower (Figs. 9H, 10H). A FLG sound recorded near Station 12 (Fig. 10H) reduced its amplitude during the recording period (Fig. 10I). This could have been simply due to the reduction of sound amplitude or to the departure of the sound producing group.

Because group sounds are assumed to be associated with fish aggregations, it is important to learn more about the characteristics of group sounds such as the frequency range of the high energy band. This knowledge is useful in distinguishing the *B. chrysoura* group sound from those of other species when both species having a species-specific energy band are producing sounds at the same time and at the same location. Three sonograms of CSG sounds showed a high energy band ranging from 600 to 1200 Hz, 650 to 1100 Hz, and 550 to 1300 Hz. Two CLG sounds had a band ranging from 620 to 1150 Hz, and one from 900 to 1000 Hz. A FLG sound had a band ranging from 1000 to 1800 Hz (Fig. 9H). It can be concluded that the width of this band and its lower and upper frequency ranges were variable and for *B. chrysoura,* it may best be defined from 550 to 1800 Hz.

### Spatial and temporal sound distributions

*Seasonal variation:* Our recordings made in late January showed that *B. chrysoura* CSG and CLG sounds were produced in the northern section of the Intracoastal Waterway Study Area (Stations 76 to 94; Fig. 2). As we proceeded southwards, only SI sounds were recorded and sounds were completely absent from the central and southern portions of the study area (Station 116 south).

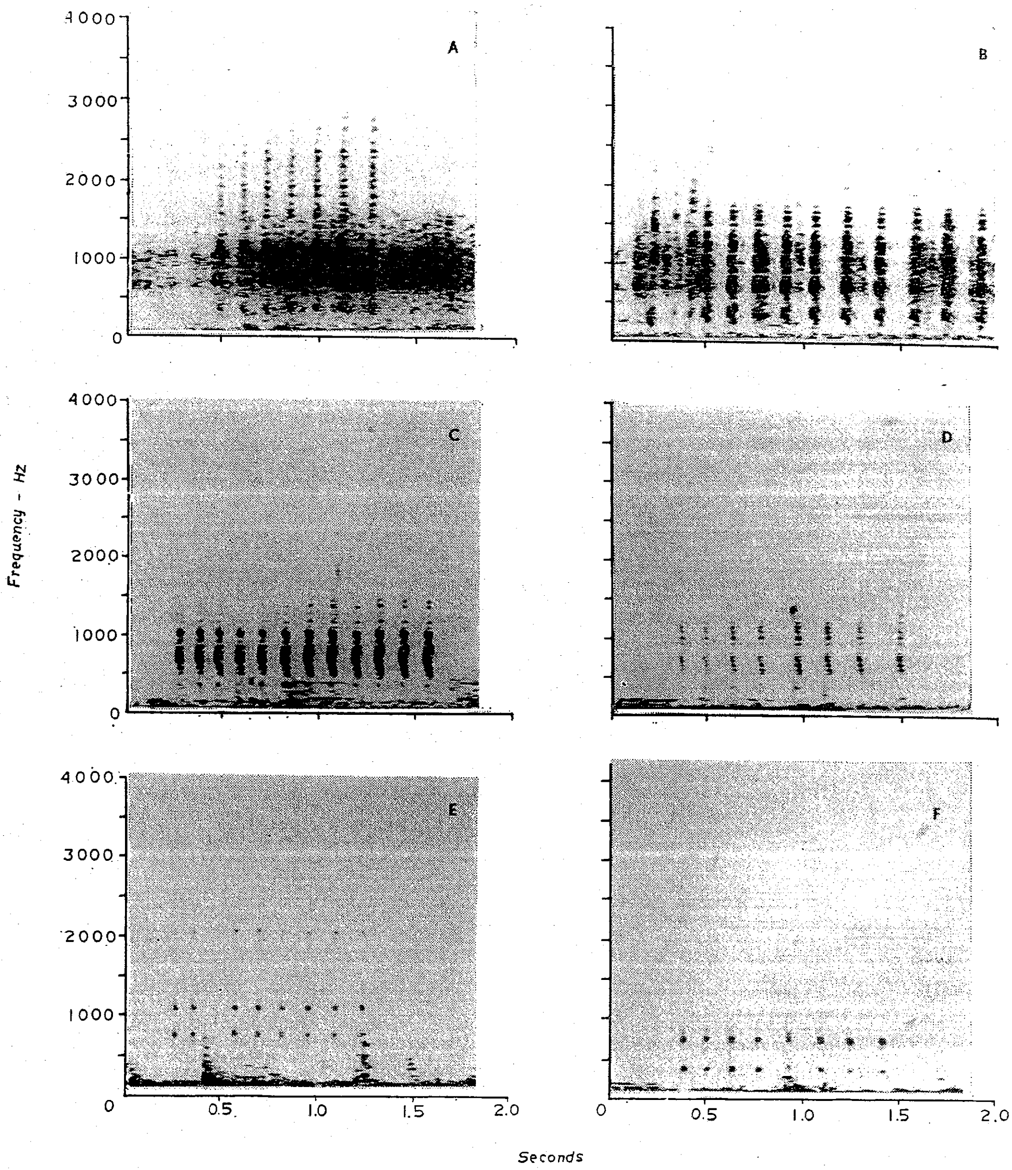


Fig. 13. Variation of the *Bairdiella chrysoura* calls in the distribution of sound energy.

Most evening recordings conducted in the Link Port Study Area from December and mid February revealed little *B. chrysoura* acoustic activity; only SI and CSG sounds were recorded at some stations within this area (SI at Stations 12, 22, 27 ,and CSG at Station 16). In late February sound production increased as CLG sounds were recorded at four stations within the Link Port Study Area (Stations 3, 4, 5, and 11). In March and April *B. chrysoura* sounds were common in the Link Port Study Area with acoustic activities peaking in March. There was a reduction in sound production (*i.e.*, in maximum intensity of group sound) from April to June throughout all study areas (Fig. 16 and Table 4).

*Diel acoustical variation:* From late February to April, *B. chrysoura* sounds were significant compared to those in December and increased in intensity about 1.5 hours before sunset. At some stations in the Link Port Study Area (*i.e.*, Station 3) SI and small group

TABLE 4.
Occurrence of the *Bairdiella chrysoura* sound types in the Intracoastal Waterway Study Area

| Recording station | Sound type: Scattered individual | | Small group | | Large group | | Recording station | Sound type: Scattered individual | | Small group | | Large group | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $W_1$ | | + | | | | | 135 | | + | + | | | |
| $W_2$ | | | + | + | | | 138 | + | + | | | | |
| $W_3$ | | | + | + | | | 141 | + | + | | | | |
| 76 | | | | | 1.62 | 1.10 | 144 | + | + | | | | |
| 78 | | | | + | 1.36 | | 145A | | + | + | | | |
| E | | | | + | 1.60 | | SB | + | | | | | |
| 82 | | | | | 1.60 | 1.04 | 146A | | + | + | | | |
| 88 | | | | | 1.66 | 1.14 | 149 | | + | | | 1.84 | |
| 91 | | | | | 1.64 | 1.10 | 150 | | + | | | 1.76 | |
| 94 | | | | | 1.60 | 1.10 | 153 | | | | | 1.90 | 0.88 |
| 99 | | | | | 1.64 | 1.08 | 154 | | | | | 1.64 | 0.09 |
| 102 | | | | | 1.58 | 1.12 | 155 | | | | | 1.92 | 1.14 |
| 105 | | | | | 1.66 | 1.12 | 157 | | | | | 2.00 | 1.22 |
| 108 | | | | | 1.64 | 1.08 | 158 | | | | | 1.86 | 1.16 |
| 110 | | | | | 1.60 | 1.10 | 160 | | | | | 1.96 | 1.14 |
| 112 | | | | | 1.62 | 1.10 | 161 | | | | | * | 1.08 |
| 116 | | | | | 1.62 | 1.16 | 163 | | | | | 1.88 | 1.22 |
| 118 | | | | | 1.56 | 1.12 | 165 | | | | | 1.96 | 1.08 |
| 120 | | | | | 1.62 | 1.14 | 168 | | | | | 1.90 | 1.20 |
| 124 | | | | | 1.56 | 1.18 | 168A | | | | | 1.82 | 1.16 |
| 126 | | | | | 1.62 | 1.12 | 169 | | | | | 1.94 | 1.10 |
| 129 | | | | + | 1.62 | | 170 | | | | | 1.80 | 1.14 |
| 133 | | + | + | | | | 171 | | | | | 1.76 | 1.10 |

Left column of each sound type represents data of April 8 and 10, whereas the right column represents data of May 5 and 6. Numbers under the large group sound type are measurements of sound amplitude in volt.

sounds preceded the appearance of CLG sounds. However, individual sounds (or I) had been recorded, although rarely, at shallower depths (*e. g.*, Station 24) during the afternoon (1500 hr in this particular case).

Overnight recording from 1630 to 0730 hr on 30 April showed that acoustic activity peaked around 2130 hr (Fig. 14). The amplitudes of CLG sounds at 2030 and 2130 hr were 0.660 and 0.704 volts, respectively. Another recording session from 1630 to 0230 hr made on 19 May showed that CLG sounds appeared only at 2230 hr. No *B. chrysoura* sound was noted before this period. The recording periods of 2330, 0130, and 0230 hr documented only

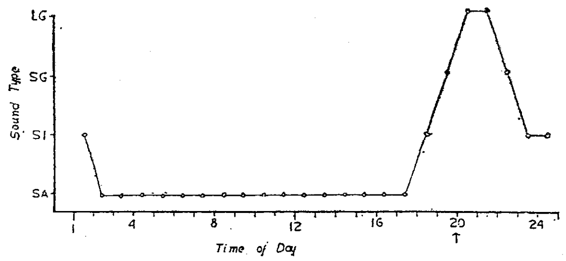


Fig. 14. Diel acoustic activity of *Bairdiella chrysoura*. LG, large group sound; SA, sound absent; SI, scattered individual sound; SG, small group sound; o, presence of a particular sound type; •, highest sound amplitude of the evening. Arrow in the time axis points to the sunset time.

SI sounds at both Stations 3 and 7. Also on 19 May CLG sounds of *Cynoscion nebulosus* were the most prominent sounds recorded before 2230 hr. The peak acoustic activity of *B. chrysoura* was delayed and it occurred later in the evening during May than in April. The reason of this delay may be related to the presence of the CLG sounds of *C. nebulosus* earlier in the evening (also see below).

*Spatial distribution:* The distribution of *B. chrysoura* sound types in the Indian River lagoon (*e. g.*, in the Link Port Study Area) from March to April showed a highly predictable pattern (Fig. 15). CLG sounds consistently occurred within the Intracoastal Waterway and expanded eastward as far as Station 10 located in the shallower area. Small group sounds would occasionally reach Station 12 where the water is very shallow (about 1 m). It was noted that Stations 7 and 8 were more often occupied by CLG sounds, whereas Stations 4, 6, and 14 were not (Fig. 15). Stations 13 and 14 were close to each other, but were separated by a sand bar and a beach with a single narrow pass joining them (Fig. 2). CLG sounds frequently occurred at Station 13 but seldom were heard at Station 14 (Fig. 15). On the west side of the waterway, CLG sounds were limited to the vicinity of Stations 27 and 16. Some CSG sounds expanded northward from Station 27 for a limited distance. Sounds were much lower in number and occurred more infrequently for all the stations located west of the waterway (except Stations 1, 2, and 27), when compared to those east of the waterway. The primary spawning aggregation occurred in the Intracoastal Waterway and eastward beyond Jaudon Island. The east and west boundaries of the CLG were not stationary as the west boundary expanded westward to Station 16 while the east boundary fluctuated daily between Stations 11 and 10. A smaller secondary aggregation occurred in the shallow seagrass region near Station 27 and expanded northward (Fig. 15).

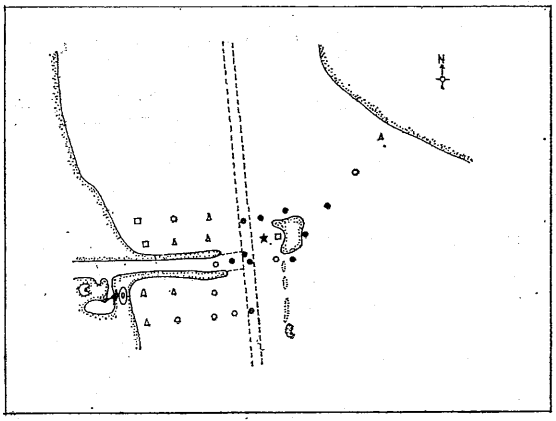

Fig. 15. Distributions of the *Bairdiella chrysoura* sound categories in the Link Port Study Area from March to April. Black circle, close-by large group sound; white circle, close-by small group sound; asterisk, occurrence of either large or small group sounds; triangle, scattered individual sound; square, absence of *B. chrysoura* sound.

When comparing data recorded in the Intracoastal Waterway Study Area in mid April and early May with other adjacent areas, we noted that shallow water stations near the west section of the Wabasso Causeway were lower in number of sounds than stations located inside the waterway. During April numerous stations throughout the northern and southern halves of the study area (Stations 76 to 129 and 153 to 171) were occupied by CLG sounds. CLG sounds were never recorded from the stations in the vicinity of the City of Vero Beach (Stations 138 to SB; Fig. 16 and Table 4). This area of low sound activity expanded northward and southward in May so that it also included Stations 129 to 135 and 146A to 150 (Fig. 16 and Table 4). Low acoustic activity seemed to be associated with areas of high boat activity (*e. g.*, Indian River lagoon at City of Vero Beach).

Amplitude of the CLG sounds did not vary significantly among stations where this sound type was recorded in the Intracoastal Waterway (Table 4). This observation suggested that the densities of aggregations were similar among the various stations in the waterway.

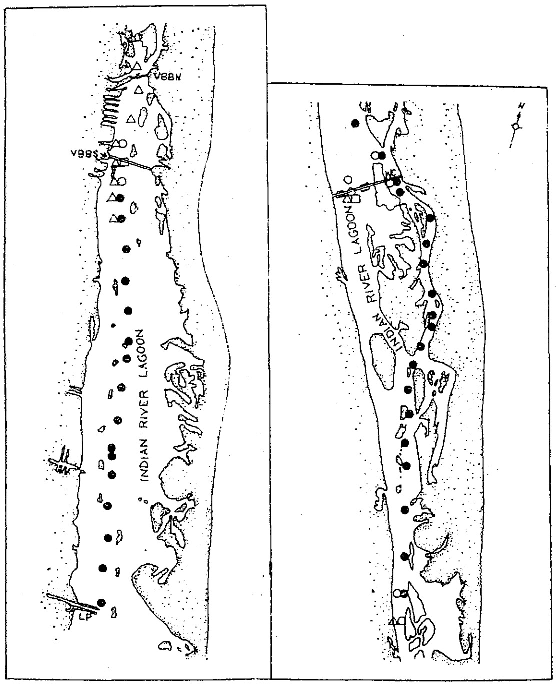


Fig. 16. Distribution of *Bairdiella chrysoura* sounds in the Waterway Study Area. Black circle represents close-by large group sound; white circle represents closeby small group sound; triangle represents scattered individual sound; square indicates absence of sound. The left symbols denote the sound types in April (8 and 10); the right symbols denote the sound types in May (5 and 6). When sound types in both months are similar, only one symbol is shown in the map.

## III. Spotted seatrout, *Cynoscion nebulosus*

### Biology

The spotted seatrout occurs in estuaries from Cape Cod to Mexico with greatest abundance in Florida and the Gulf States (Johnson, 1978). Throughout this range this species is of sport and commercial fishery value.

Adult seatrout migrate little with most movements occurring seasonally associated with thermal and salinity tolerance levels and spawning activities (Tabb, 1966). This species prefers locations within the lagoon where tidal fluctuations are minimal (Tabb, 1966). Juvenile and adult *C. nebulosus* occur in several estuarine habitats including seagrass beds, mangrove-lined depressions and in relatively deep channels and canals.

According to fishery data, spawning takes place in the Indian River lagoon from February to September with principal activity occurring from April to September (Gilmore *et al.*, in prep.). Adults show a preference for deep water (2.5 to 5 m depths) during spawning periods and in periods of potential hypothermal stress (Tabb, 1961). Spawning takes place in groups in deeper channels adjacent to vegetated shallow areas (Tabb, 1961). Spawning activity includes side-to-side body contact, accompanied by soft croaking by the males (Tabb, 1966).

### Description of sounds

Four types of *C. nebulosus* sounds were recorded in the lagoon. They are designated as (1) a "grunt" followed by a series of "knocks", (2) "aggregated grunts", (3) "long grunt", and (4) "staccato".

The first sound type was recorded in the Link Port Study Area (slightly north of Station 7; Fig. 17) and was composed of a train of calls each of which was led by a single "grunt" followed by a series of "knocks" (Figs. 17, 18A; long arrow indicates this leading grunt). The duration of the leading grunt ranged from 70 to 140 msec with a mean of 114 msec (N=69). The "knocks" were shorter than the leading grunts, ranging from 51 to 97 msec with a mean of 75 msec (N=120). In 71 calls analysed durations of all "knocks" within the same call were similar. Most calls contained two "knocks". The occurrence of various numbers of "knocks" (k) per call are listed in an increasing order as follows: 1k=20, 2k=34, 3k=8, 4k=2, 5k=1 and "rapid staccato" =6. The last category represents a series of closely placed "knocks" ($k \geq 6$; Fig. 18A; short arrow indicates these knocks). The intervals between two closest "knocks" in a "rapid staccato" were shorter than other calls with 2k (or two

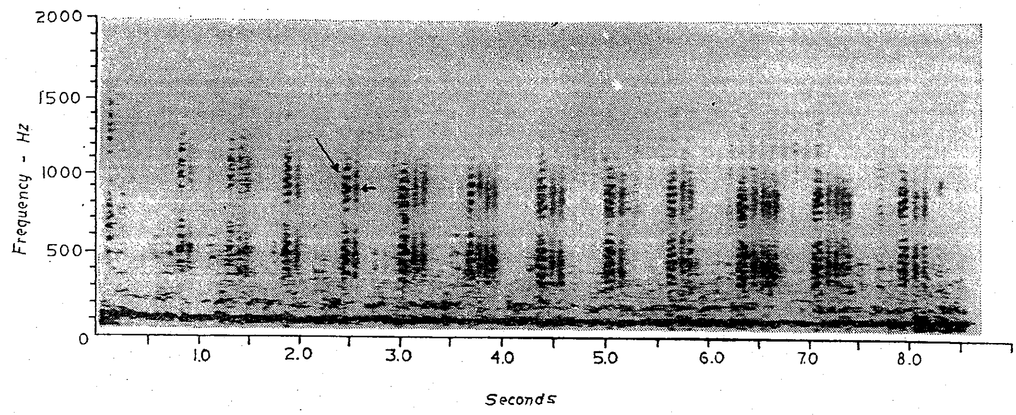


Fig. 17. A sequence of the Type-1 *Cynoscion nebulosus* sound. Long arrow points to a leading "grunt"; short arrow points to a following "knock".

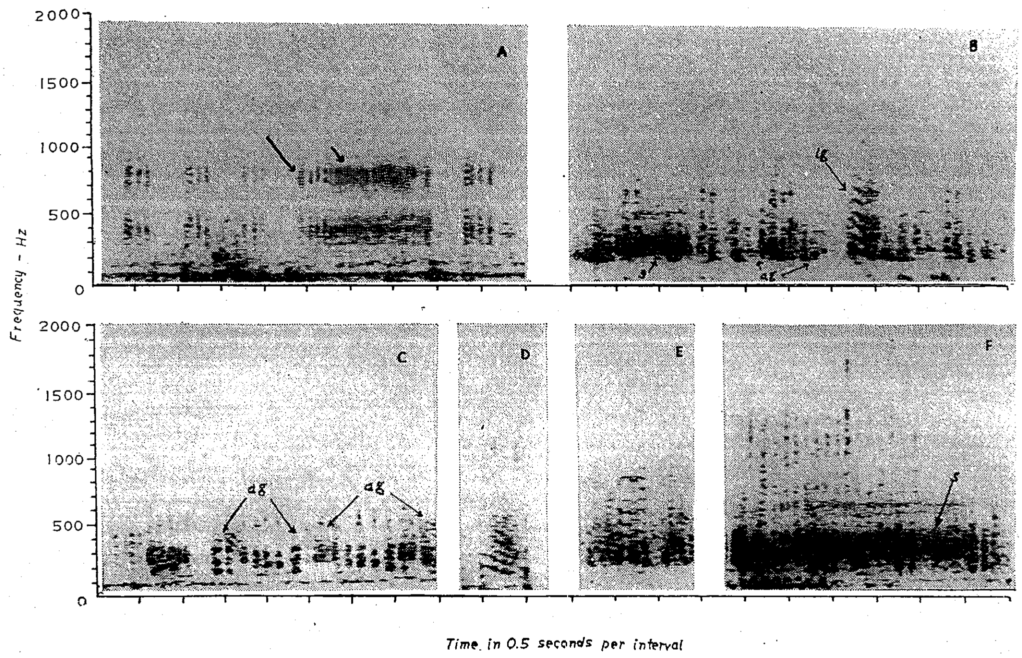


Fig. 18. The *Cynoscion nebulosus* sound types. A, type 1 (long arrow, leading "grunt"; short arrow, closely-placed "knocks"); B, a sequence of sounds including the "staccato" (s), "aggregated grunt" (ag), and "long grunt" (lg); C, a series of "aggregated grunt" (ag); D-E, variation of the "long grunts"; F, a long "staccato" (s) mixed with some "aggregated grunts".

knocks) to 5k. As a result, individual "knocks" could not be easily distinguished by examining the sonogram (*e.g.*, Fig. 18A). Durations of a sample of "rapid staccatos" were measured and found to have a mean of 365 msec. (185 to 1180 msec). Interval between two adjacent calls as measured from the end of one call to the beginning of the leading "grunt" of the following call peaked at a mean value of 335 msec (305 to 380 msec; Fig. 19). This interval was subjected to rather high variation.

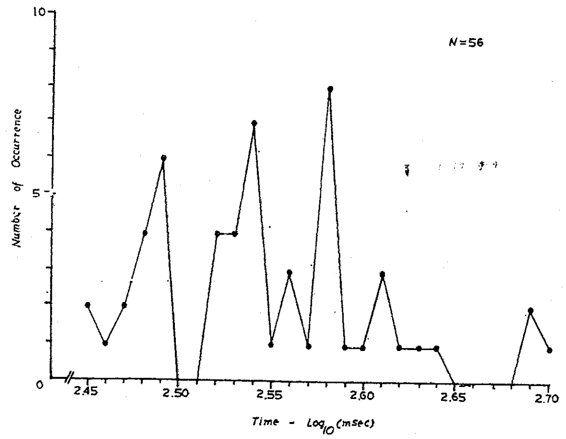


Fig. 19. A plot of the occurrence of the various durations from the termination to the beginning of two adjacent type-1 *Cynoscion nebulosus* sounds.

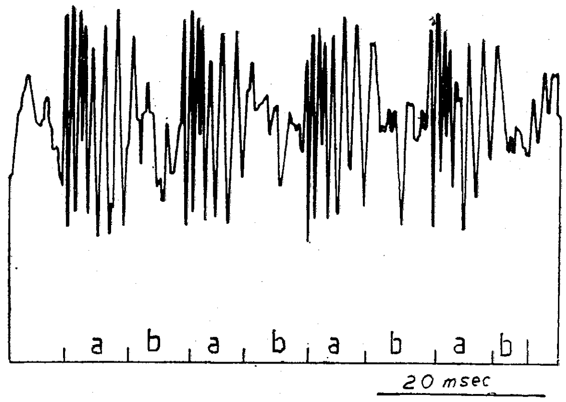


Fig. 20. Oscillogram of a leading "grunt" from the type-1 sound of *Cynoscion nebulosus.* The leading "grunt" was composed of four wave groups. "a" and "b" represent the two sub-groups forming a single wave group.

Frequency composition of the leading "grunt" and the following "knocks" were quite similar (Fig. 17). The frequency ranged from 300 to 1350 Hz and there was a discontinuous frequency band or low energy band around 500 to 900 Hz (Fig. 17). Most of the calls examined had the lower and upper frequencies located at 300 and 1000 Hz, respectively (Fig. 17). For the discontinuous frequency band, the lower and upper frequencies were 600 and 700 Hz, respectively (Fig. 17). Frequency range and amplitude of adjacent calls were similar in most cases. However, changes in these characters were noted in some instances (Fig. 17). The calls recorded earlier in the series were higher in frequency range but lower in amplitude, whereas those appeared later in the series were lower in frequency range but higher in amplitude (Fig. 17). Oscillograms of a single leading "grunt" showed three to four wave groups, each similar in temporal amplitude change (Fig. 20). In the early part of a wave group sound intensity changed rapidly and significantly (Fig. 20; "a" represents this part of the wave group). Rate and degree of intensity change reduced toward the end of a wave group (Fig. 20; "b" represented this part of the wave group).

Among other sound types of *C. nebulosus*, "aggregated grunts" occurred most frequently, whereas the "staccato" and "long grunt" were occasionally mixed in a chain of "aggregated grunts". The "long grunt" appeared more often than the "staccato". These sounds can best be distinguished by their time-amplitude wave forms (see below).

"Aggregated grunts" were composed of several closely placed grunts (2 to 7, mostly 2 grunts; Fig. 18C). Individual grunts lasted a mean of 110 msec (Fig. 21). Duration of the "aggregation grunts" was variable; it ranged from 206 to 845 msec (mean 440 msec; Fig. 22). Most sound energy was distributed from 220 to 600 Hz with some energy dispersed to the higher frequencies (Fig. 18B, C; Fig. 23A–C). The loud group-sound of "aggregated grunts" is characterized by an energy band from 150 to 650 Hz (Fig. 23D, E). No consistent time-amplitude waveform of the "aggregated grunts" was noted except that the middle wave group consistently showed three peaks of amplitude change (Figs. 24B, 25; dotted line in the later figure indicates these peaks).

In the "long grunt" peak wave amplitudes did not vary significantly throughout the sound (Fig. 24A, C). Two wave groups appeared alternatively at the mid portion of the "long grunt". The first wave group consists of one to two peaks followed by a much longer peak

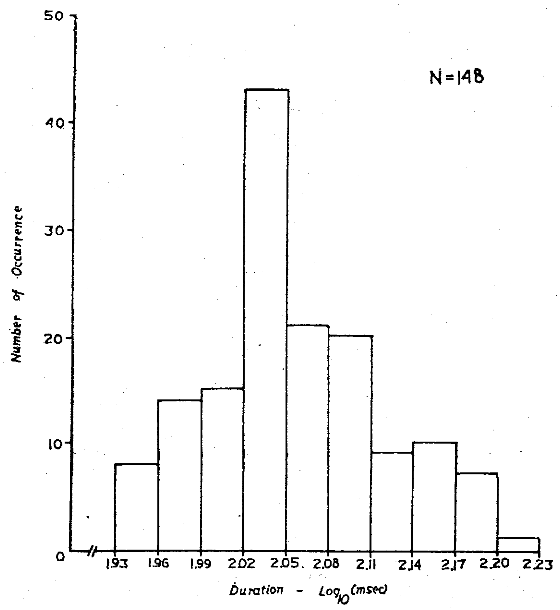


Fig. 21. Variation of the duration of individual grunts composing the "aggregated grunt" or the type-2 *Cynoscion nebulosus* sound. N is the total number of individual grunts measured.

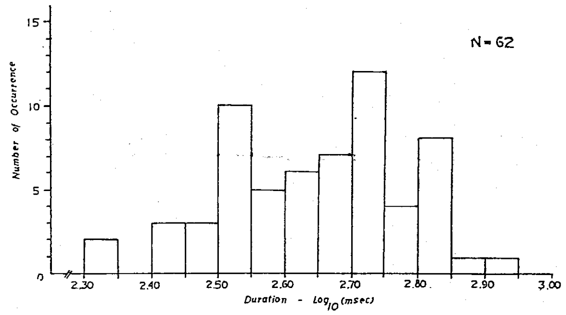


Fig. 22. Variation of the duration of the *Cynoscion nebulosus* "aggregated grunts". N is the total number of "aggregated grunts" measured.

(Fig. 26B, C, F; section "a"). The second wave group is composed of two (rarely three) long peaks (Fig. 26B, C; section "b"). No predictable waveform was seen at the beginning and end of the sound (Fig. 26A, D, and E). Durations of the "long grunts" ranged from 400 to 500 msec. Sound energy was spread to several narrow bands (harmonic sound) from 200 to 1400 Hz (Fig. 18B, D, E). The frequencies of the "long grunt" were higher than those of the "staccato" and "aggregated grunts" (Fig. 18B).

The "staccato" consisted of a chain of similar components, each representing a series of rapid amplitude change (Figs. 24D, E, 27A; arrows in the latter figure point to three of the wave groups composing a "staccato"). Peak amplitude increased and reached its maximum value in the mid section of the component wave group and then decreased (Figs. 24D, E, 27A). Duration of these wave groups ranged around 30 msec. Intervals between two adjacent wave groups were variable but were usually less than 10 msec (Fig. 27A). Maximum amplitudes of these wave groups in the same "staccato" sound did not vary much (Fig. 27A). No specific pattern of intensity change at any particular part of the "staccato" was observed (Fig. 27B–D). Energy in the "staccato" was distributed from 200 to 600 Hz; most of this energy was limited to a broad band ranging from 200 to 350 Hz and a narrow band at a higher frequency of 500 to 600 Hz (Fig. 18B, F). Reduction in energy content was observed in the frequencies between these bands and also above the upper narrow band (between 500 and 600 Hz). The energy distribution pattern of the "staccato" differed from that of the first sound type of *C. nebulosus*, *i.e.*, the leading grunt plus a succeeding series of "knocks", by having two recognizable broad bands with no energy between them.

**Spatial and temporal distributions**

*Seasonal and spatial variations:* Recordings made from January through March in both the Link Port and Waterway Study Areas did not contain spotted seatrout sounds. Our first record of spotted seatrout sounds occurred on 14 March (Fig. 28A–D) and became more common during the following months (data only extended to May; Fig. 28E, F). Evening recordings made in March and April in the Link Port Study Area showed only scattered individual sounds at shallow locations in the lagoon away from the Intracoastal Waterway (Fig. 28A–E). However, recordings made in

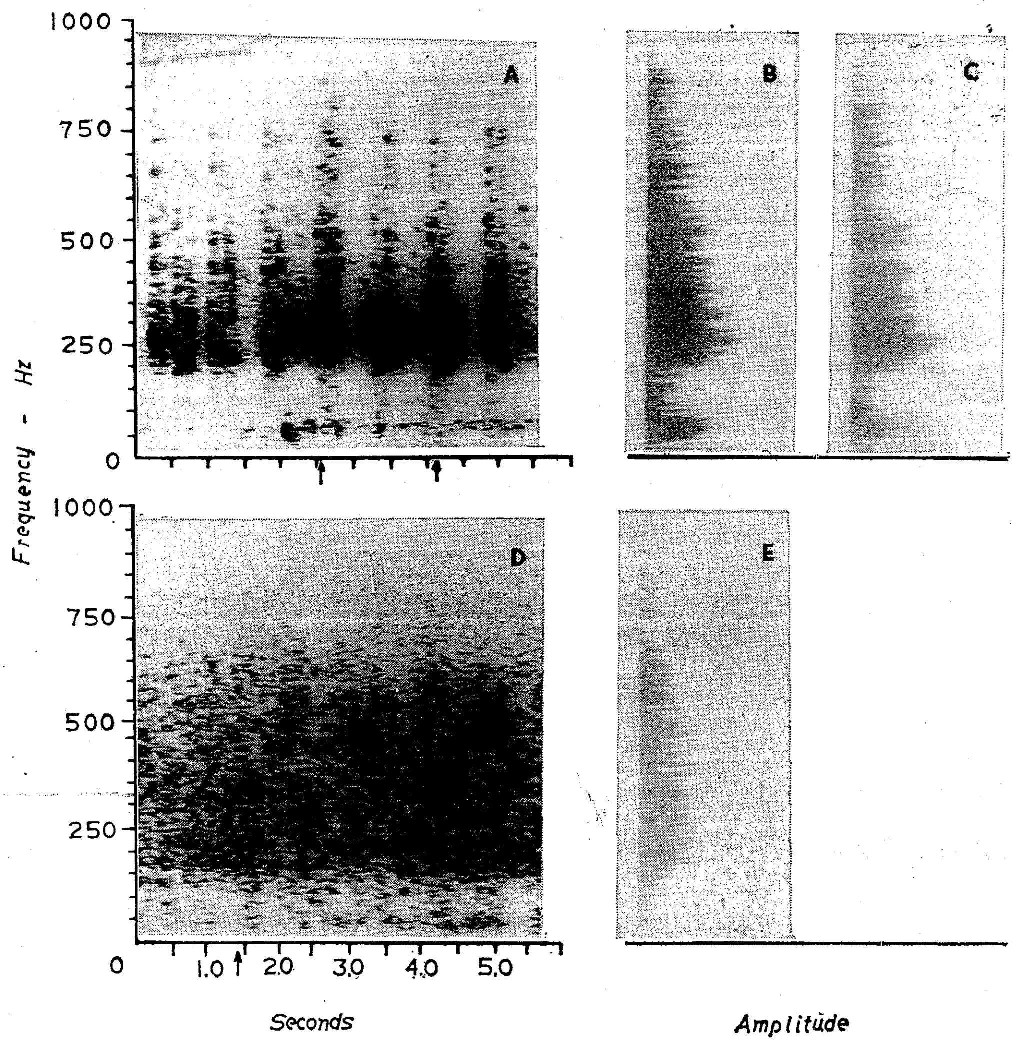


Fig. 23. A, sonograms of eight "aggregated grunts" of *Cynoscion nebulosus*. B-C, spectrograms of the section made at the points indicated by the arrows in the time axis of sonogram A, respectively; D, sonograms of the group sound of "aggregated grunts" noted that individual "aggregated grunts" were indistinguishable; E, spectrogram of the section made at the point as indicated by the arrow in the time axis of oscillogram D noted that the distinguishable peak at the 250 Hz as shown in spectrograms B and C becomes obscure.

the Intracoastal Waterway on 8 and 10 April revealed scattered individual sounds at some stations principally in the northern portion of the study area (Fig. 30). These sounds did not appear at stations in the southern half of the study area. Therefore, during March and April, spotted seatrout sounds in the Waterway Study Area were limited to its northern section and were recorded only in the shallow seagrass bed areas and the Link Port Channel in the southern section of the waterway (Fig. 28). The appearance of spotted seatrout sounds in the deep Link Port Channel suggests that their absence in the Intracoastal Waterway was not due to the avoidance of deeper water.

Large group sounds were first recorded in the Intracoastal Waterway on 14 and 19 May (Figs. 28F, 29). Acoustic activity measured by the numbers of sounds recorded per unit time increased during May.

During May the highest intensity of large group sounds was limited to the Intracoastal Waterway and adjacent deeper parts of the seagrass flats (Figs. 28F, 29). Small group and individual sounds appeared on both sides of the Intracoastal Waterway extending even into the shallow seagrass areas (Figs. 28F, 29). This spatial pattern resembled that of *Bairdiella chrysoura* as the highest acoustic activity took place in the Intracoastal Waterway and acoustic activity was high near Stations 9 and 10 located east of Jaudon Island (Fig. 28F). However,

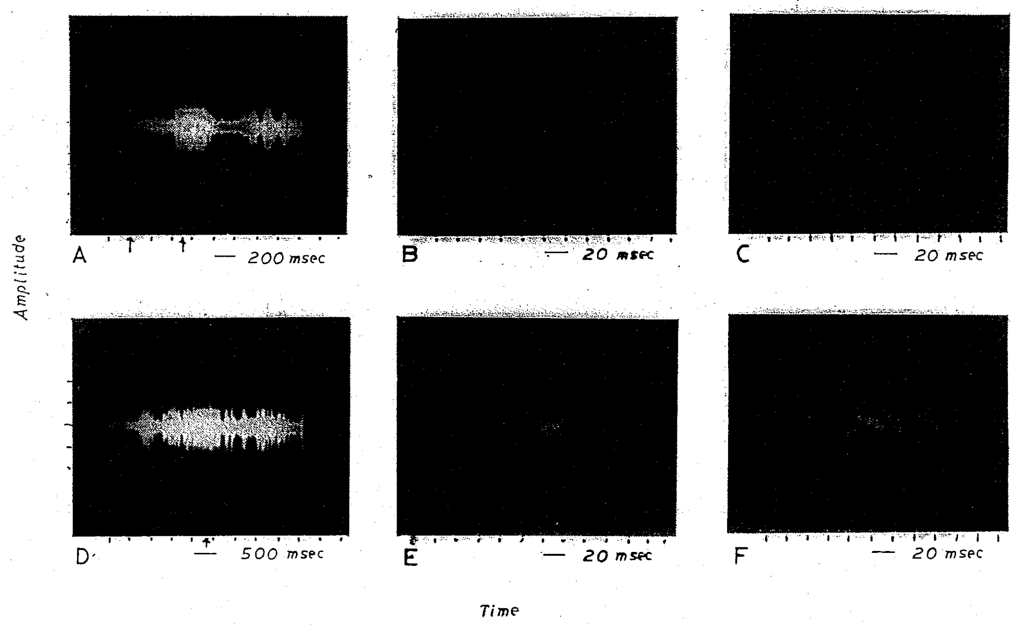


Fig. 24. Oscillograms of three types of *Cynoscion nebulosus* sounds illustrated at various time units. A, a series of sound includes six "aggregated grunts" and one "long grunt"; B, a closer look at the waveform of an "aggregated grunt" at the point as indicated by the left arrow in oscillogram A; C, a closer look at the waveform of the front portion of the "long grunt" as indicated by the right arrow in oscillogram A; D, oscillogram of a series of sound composing of "aggregated grunt" and a "staccato" sound; E, a close look at the waveform of the portion of the "staccato" sound as indicated by the arrow in oscillogram D; F, the waveform of the large group sound composing mainly of "aggregated grunts"

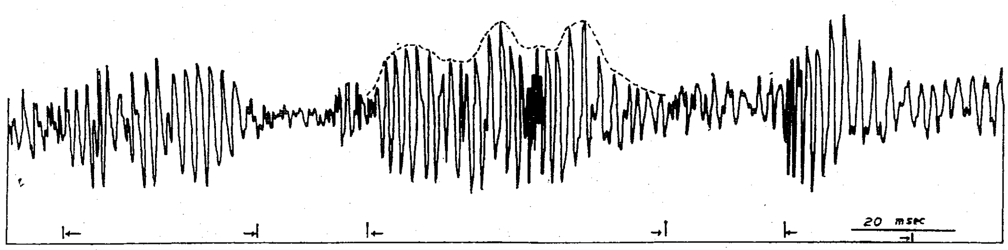


Fig. 25. Oscillogram showing three wave groups of an "aggregated grunt", each is defined by the area between two opposite arrows. Notice the three peaks of high amplitude in the middle wave group under dotted line.

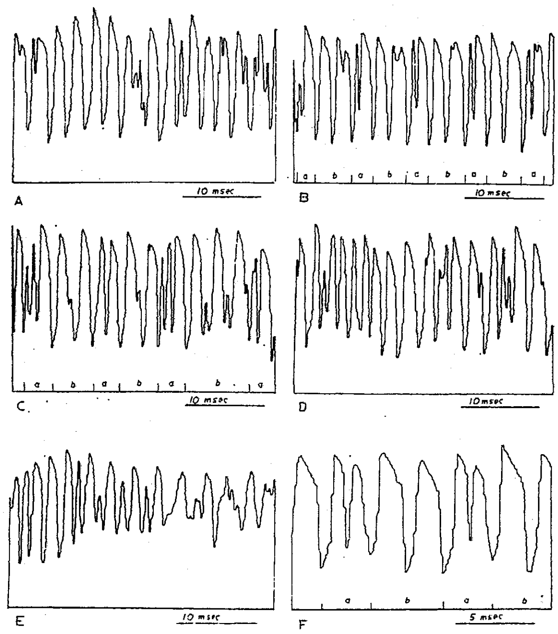


Fig. 26. Detailed waveform or time-amplitude changes at various portions of a *Cynoscion nebulosus* "long grunt". A, anterior portion; B–C, middle portion; D, posterior portion; E, tail portion; F, a further detailed waveform at the mid portion of the grunt. "a" and "b" are two subgroups of wave forming the mid portion of groups forming the wave of the "long grunt".

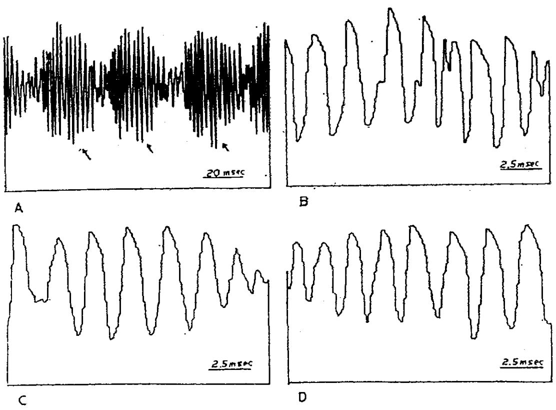


Fig. 27. A, waveform of a section of a *Cynoscion nebulosus* "staccato". B–D, oscillograms showing the waveforms at various portions of the wave groups located at various parts of the wave chain of the "staccato" sound. Arrows point to the wave groups forming the wave chain of a "staccato" sound.

during March and April, spotted seatrout sounds did not show a highly predictable distribution pattern in the Link Port Study Area. We recorded close scattered individual sounds at various stations (Fig. 28A–E). An area with high acoustic activity near Station 27 overlapped with that of a group of *B. chrysoura* (Fig. 28). Spotted seatrout and silver perch showed similar spawning group distribution. The distribution pattern of the spotted seatrout sounds in the Link Port Study Area suggested that major spawning activity began in May in the Intracoastal Waterway, although some small isolated aggregations occurred on the seagrass flats and appear earlier than May.

On 8 and 10 April, acoustic activity of scattered individuals took place mostly between the Wabasso Causeway and Station 124 (or the northern section of the Waterway Study Area; Figs. 30, 2). Spotted seatrout sounds were mostly absent in the central and southern sections (*i. e.*, south of Station 126; Figs. 30, 2). However, close-by scattered individual sounds were recorded at Stations SB and 154 (Figs. 30, 2). A similar pattern was seen on 5 and 6 May. Group sound significantly increased at the southern stations (Station 165 to 171) during May. The area north of Station 126 was occupied mainly by scattered individual sounds while area between Stations 138 and 153 lacked sounds (Figs. 30, 2). The north and south ends of this low-sound area seemed to vary with season. Unlike *B. chrysoura*, close-by spotted seatrout group sounds tended to occupy smaller areas within the waterway.

*Daily and diel variations:* Spotted seatrout croaking was generally heard approximately one to two hours before sunset. A 15-hour recording session from 1630 to 0730 hr made on 30 April documented no group sounds in the Intracoastal Waterway. However, croaking sounds were recorded during a 10-hour recording session from 1630 hr on 19 May to 0230 hr on 20 May. On 19 May, scattered individual sounds appeared at 1630 and 1830 hr, while large group sounds made their first appearance at 1930 hr and remained at a similar intensity

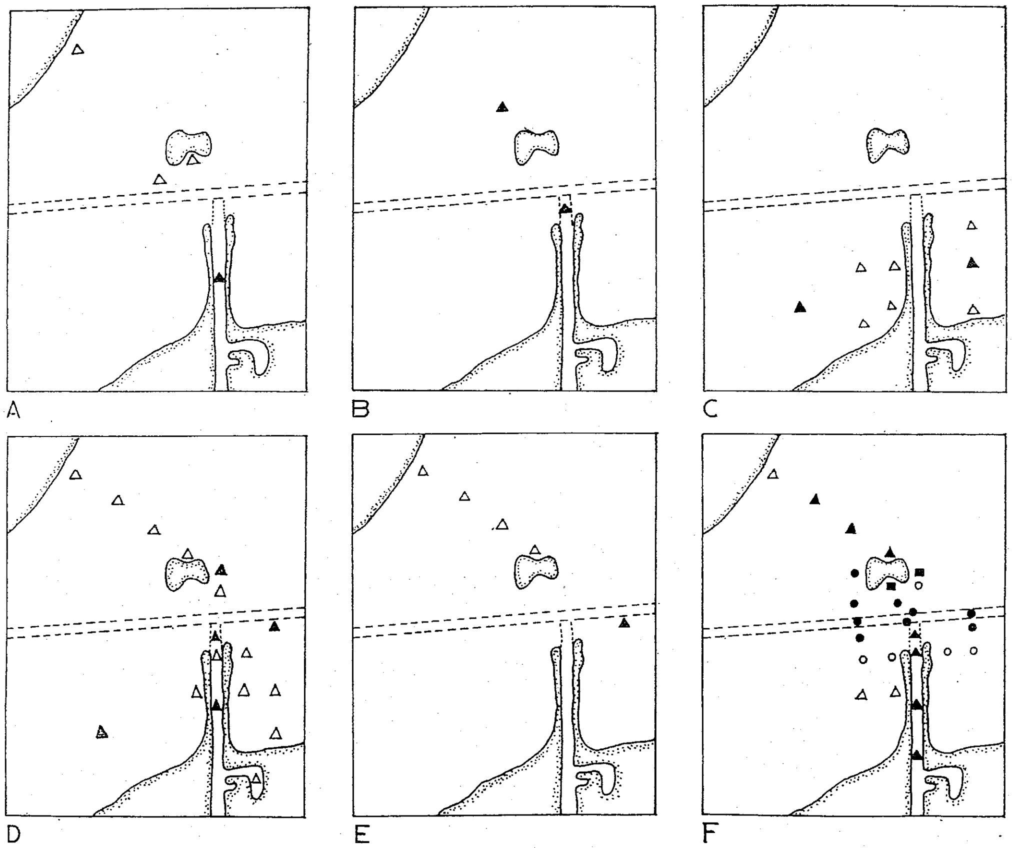


Fig. 28. Monthly variation in the distribution of the *Cynoscion nebulosus* sounds in the Link Port Study Area. A, data collected on 16 March; B, data collected on 20 March; C, data collected on 25 March; D, data collected on 26 March; E, data collected on 4 April; F, data collected on 5 May. Black triangle, close-by scattered individual sound; white triangle, far (or weak) scattered individual sound; square, close-by small group sound; black circle, close-by large group sound; white circle, far (or weak) group sound.

until 2030 and 2130 hr. Group sounds disappeared after 2130 hr and only scattered individual sounds were heard at 2230, 2330, and 0030 hr. On this same evening the group sounds of the *B. chrysoura* reached its peak in intensity at 2300 hr and dominated the Intracoastal Waterway.

**Identification of sound producers**

No fish sounds were recorded in the fish pen where a few silver perch and black drum were kept. As a consequence, the fish producing the isolated sound types discussed above could only be identified by indirected evidence, *i.e.*, by the co-occurrences of sound types and fish specimens collected at the vicinity of high acoustic activity, and of particular prevailing sound types during spawning season of specific soniferous species at particular location within the Indian River lagoon. In April 1978 and 1979 we were able to locate an aggregation of *B. chrysoura* near the Wabasso Causeway by using a hydrophone; there was a large sport fishery catch of silver perch at the same site where we recorded a loud groupsound which was believed to be produced by this species. We identified the *P. cromis* sound types by the same method. In addition, ichthyoplankton

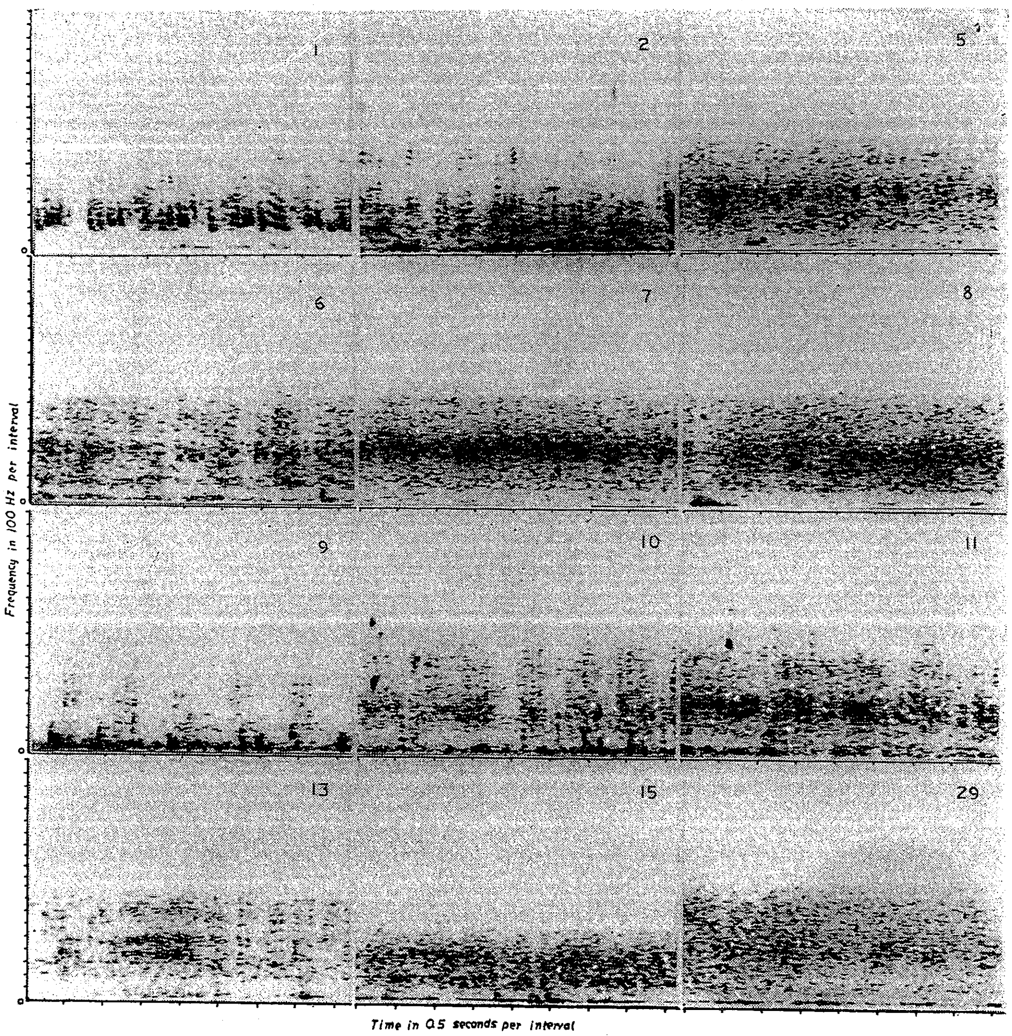


Fig. 29. Sonograms showing the acoustical patterns of 12 recording stations in the Link Port Study Area where *Cynoscion nebulosus* sounds dominated. Data were recorded in the evening of May 14. Numbers on the right hand corner of the sonograms represent station numbers as defined in Fig. 1.

samples taken in the waterway in late winter showed that *P. cromis* eggs were much more numerous than other egg types in the lagoon during that period. The dominant sound type in that period was then believed to be emitted by *P. cromis*. Sounds emitted by other species present were principally from the toadfish, *Opsanus tau* and the catfish, *Arius felis*. Characteristics of their sounds are well documented (*e.g.*, Gray and Winn, 1961; Fish and Mowbray, 1970).

On 19 May, plankton tows taken in the day time (at 1630 hr) in the waterway collected a small amount of fish eggs (93 *C. nebulosus* eggs and 6 *B. chrysoura* eggs). Conversely, tows taken later in that day (at 2130 hr) and at 0230 hr on 20 May collected a much larger number of fish eggs (2812 *C. nebulosus* eggs, 650 *B. chrysoura* eggs, and 3013 *C. nebulosus* eggs, 375 *B. chrysoura* eggs, respectively). Because loud large group sounds of these species were heard at 2130 and 0130 hr but were absent during the day, acoustic activity and egg number (or spawning) were

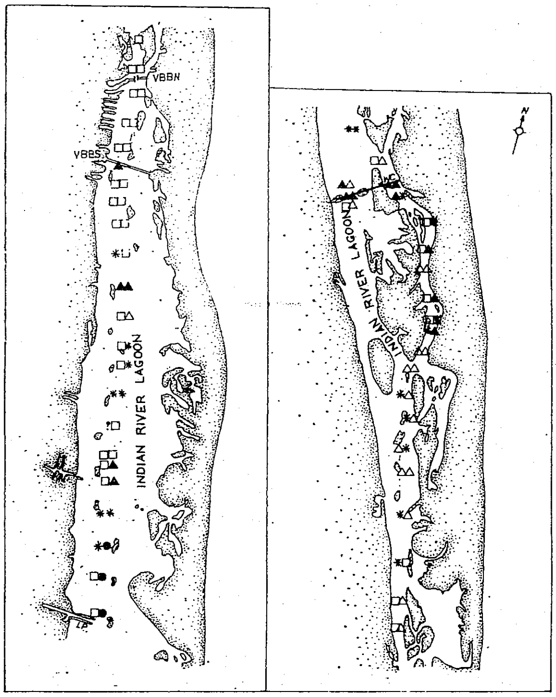


Fig. 30 Distribution of *Cynoscion nebulosus* sounds in the Waterway Study Area in April (left symbols) and May (right symbols). Square, sound absent; black triangle, close-by scattered individual sound; white triangle, far (or weak) scattered individual sound; black circle, close-by large group sound; asterisk, *C. nebulosus* sounds masked by the group sound of *Bairdiella chrysoura*; ?, lacking in data.

positively correlated. Since *C. nebulosus* was the dominant spawning species at that period, the major sound type was therefore believed to be produced by this species.

## DISCUSSION

The present study demonstrates that by recording sounds from various specific locations and time periods, the temporal and spatial changes in distribution and relative density of soniferous fish aggregations can be detected. Problems associated with the acoustical technique we used in the present study are (1) resolution of in situ sound recordings, (2) identification of sound producer, (3) recognizing sound characteristics, (4) localizing the sound source, and (5) estimating the fish aggregation size.

Resolution of species-specific sounds was difficult under various field conditions. When operating a small boat in rough sea, wave impact and motor noise produce acoustic interference. This interference can be minimized by stopping the motor and allowing the boat to drift. If the present acoustical technique is applied to coastal or open-water fishery studies, ship generator and the running propeller will also create acoustic interference. To improve the in situ recording resolution in such situations, an electronic filtering system blocking generator and propeller noise would be helpful. It may also be feasible to install the recording equipment on a buoy and either tow it at a very slow speed or release the buoy and recover it after recording. Row or sailing boats may be practical under certain research or field recording conditions. Ambient biological sounds produced by various invertebrates including alpheid shrimp also produced ambient sound interference. A filter was developed to exclude alpheid shrimp sounds. We were fortunate that the great intensity or level of sound production in the sciaenids studied was greater than most ambient sound sources and therefore permitted adequate study of these species-specific sounds.

To identify the sound producer, the following approaches may be practical depending on field conditions and the species concerned. Two direct methods of observation can be used. (1) In situ simultaneous observation by diving or other observational tools (*e.g.*, underwater TV system and underwater submersile) and sound recording. This method is limited by water clarity and accessability of the species studied. (2) Recording sounds emitted by captive fishes caught from the recording area in the field. These approaches, the latter in particular, can provide direct evidence for the identification of the sound producer. Unfortunately, sound production may be atypical or may not even occur under captive conditions due to the absence of a proper releaser or the inherent stress of captivity. We did not record sounds from adult black drum and silver perch placed in a large fish pen and floating fish cage. However, Guest and Lasswell (1978) successfully recorded the reproductive sound of redfish acclimated under laboratory conditions.

Because sciaenids usually produce sounds in the evening during the breeding season, it is difficult to identify the sound producer by underwater observation due to poor water visibility. We failed to observe silver perch nor any other species in several evening dives made in the presence of silver perch large group sounds. Under these circumstances, only indirect evidence was available in this study.

A sound producer is considered recognizable by indirect evidence if one of the following relationships is observed. (1) An association of a dominant group sound and presence of a dominant species from fish captures made at the recording site. (2) An association of a dominant group sound and an overwhelming majority of freshly spawned eggs of a particular species in the water column. (3) An association of a particular group sound and the specific spawning location and spawning season of a particular species determined by catch data at the recording location. The latter two conditions also assume that sound production is associated with reproductive behavior. The three indirect observation methodologies given above were utilized to identify sound producers in this study.

The characteristics of species-specific sounds can be described fully if a large sample of sounds of various intensities produced by a known species at various distances from the hydrophone was analysed. Analysis of a large sample of sounds can minimize the bias caused by individual variation and variation due to distance of the sound source from the hydrophone. Propagating sound attenuates its energy at different rates according to the frequency composition; high frequencies are associated with a high attenuation rate. Due to attenuation, the relative amount of energy will be lower in the high frequency range in the sound produced by a remote fish. The same sound produced near the hydrophone should preserve more energy in the high frequency spectra. Therefore, in a series of recordings made while moving toward the sound source, the number of sounds with higher relative energy in the upper frequency range is likely to increase within the sample. Variation of sound characteristics in a large sample of sounds belonging to the same sound type but differred in sound intensity provides additional information for an accurate description of the "real" sound. This analysis can also be achieved by comparing high intensity sounds. Temporal features such as note duration, inter-note duration, and repetition rate (*e.g.*, Narins and Capranica, 1977) and detailed waveform features of the sounds can also be used for sound identification. This is typically observed in analyses of sounds produced by single isolated individuals. However, our recordings were made from aggregates with occassional isolated individuals nearer the hydrophone. It is significant that aggregate sound production was often emitted in unison, therefore, making sound characteristic determinations somewhat easier.

Spatial isolation of a vociferous fish aggregation occurs when a major sound intensity change is detected as one approaches and crosses a high intensity sound boundary associated with a high intensity sound aggregation. Major increases in sound intensity preceed the movement over the aggregate boundary. Intensity may reach a maximum value at the boundary and then fluctuate around this maximum intensity at various locations within the aggregation. These expectations are grounded on the assumption that the aggregation is a compact one and fish density varies very little in different parts of the aggregation (also see below). Simultaneous recordings made at several adjacent points in relation to the aggregation boundary provide data on spatial differences in sound intensity valuable in isolating the sound source location or soniferous fish aggregation. If this cannot be done due to the lack of additional vessels or recording apparatus, recordings could be made at various locations with a high speed vessel moving over various recording sites within a short time period. This method can minimize the sound variation caused by temporal variation in station visitation. Our soniferous species were more active acoustically later in the evening and all recording stations had to be maintained in a relatively short period of time.

In order to locate effectively the sound producer or sound source, we also need to know the original sound intensity, sound intensity at the recording site, and attenuation rate of the sound at a particular frequency or as a whole. A special case was noted in *B. chrysoura* as the intensities of the group sounds produced along the north section of the Waterway Study Area occupied by a narrow channel were similar among the recording stations. We made the practical assumption that fishes under similar external stimulation and internal motivation will emit sounds in their maximum intensity at the peak of the daily acoustic activity. The average maximum intensity was used as an estimation of the maximum intensity for *B. chrysoura*. We then used these recordings of *B. chrysoura* and the sounds of *P. cromis* and *C. nebulosus* to perform field experiments by playing the various specific sound types in the Link Port Channel and a 1.5-m depth adjacent to the Intracoastal Waterway. The low frequency sounds of *C. nebulosus* attenuated very gradually and propagated a longer distance than the sounds of either *P. cromis* and *B. chrysoura*. However, the high intensity and high frequency sounds produced by nearby alpheid shrimp and other ambient sounds made accurate measurement of the intensity of detectable far group sounds difficult. Laboratory study under controlled conditions should provide a more accurate method to estimate the attenuation rates of fish sounds. When the original sound intensity, recorded sound intensity, and attenuation rates are known, one can estimate the radius within which the producer was most likely to be located. Simultaneous recording at three or more locations, or consecutive recordings made from these locations within very short time intervals, should provide sufficient data for the direction and location of the sound producer as long as the producer is relatively stationary.

When using the "listening" principle to study the aggregation density, the interpretation was based on the assumption that high acoustic activity (or large numbers of sound per unit time) is positively correlated with the density of the aggregation. However, since it is commonly known that in most soniferous species only the male produces sounds (Fish and Morbray, 1970), sex ratio becomes an important population parameter for a better understanding of the aggregation density. However, in the absence of sex ratio information we can use this acoustical technique to study the spatial and temporal changes in aggregation density and to locate the area of greatest relative density of male sciaenids.

This "listening" technique can only provide information about the distribution of sound within an area at a particular time. We were unable to tell exactly what causes a particular temporal-spatial pattern of sound distribution. For instance, the increase in acoustic activities in the Intracoastal Waterway does not imply that the fish migrate to this area during the later afternoon or that they actually have been there throughout the entire diel period, but only that they emit sound during crepescular periods and at night. The data only lend support to the hypothesis that the Intracoastal Waterway is preferred as the spawning ground and that large numbers of fish occur there as they produce sound while spawning.

The present data on ichthyoplankton and previous fishery studies indicate segregation of the major peak of spawning of black drum, silver perch, and spotted seatrout. The Indian

River lagoon was dominated by a particular sound type in each of the major spawning periods of these species. In May, the time of highest acoustic activity of *B. chrysoura* and *C. nebulosus* did not occur at the same time. Also during May, *C. nebulosus* acoustic activity appeared earlier in the evening than that of *B. chrysoura*. In the earlier part of the spawning season of *B. chrysoura* (*i.e.*, March and April) the peak of sound production occurred approximately one hour after sunset. However, the time of highest acoustic activity in May represented a delayed peak of sound intensity for *B. chrysoura* (about three hours after sunset). The appearance of the dominating group sound of spotted seatrout earlier in the evening might account for this delay although other endogenous and exogenous factors not affected by the presence of the spotted seatrout sounds might have an equal effect. If the sound has a communicatory function in reproductive behavior, *i. e.*, it affects the receivers either behaviorally or physiologically, resulting in actual spawning or physiological readiness for reproduction, it should be adaptive for temporal segregation of their peak acoustic activities. Such segregation will lead to better sound reception conditions for this important acoustical stimulation.

During the spawning season, evening aggregations of these species were mostly found in the deep Intracoastal Waterway. There are, however, some differences in their group distributions within the waterway. Aggregations of *B. chrysoura* seem broadly distributed in the waterway. Those of *P. cromis* tend to be distributed in the northern section of the Waterway Study Area where the waterway winds among numerous small mangrove-lined islands. The aggregations of *C. nebulosus* were distributed mostly in the southern section of the Waterway Study Area and aggregation size estimated by the intensity of group sound was smaller than that of the other two species. As far as the spawning grounds of these species are concerned, we do not see any immediate threat to them, especially to *B. chrysoura*. This interpretation is grounded on the fact that this species is not restricted to a small spawning ground. The northern and southern sections of the Intracoastal Waterway Study Area where the majority of the spawning aggregations of *P. cromis* and *C. nebulosus* were isolated should be recognized as vital spawning locations for these species.

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# 美國印第安河瀉湖石首魚類 (*Pogonias cromis, Bairdiella chrysoura, Cynoscion nebulosus*) 魚羣聲音之分析

莫 顯 蕎 R. GRANT GILMORE

本報告主旨在探討自 1979 年 12 月至次年 6 月間，美國沸羅里達州東岸之印第安河瀉湖 (lagoon) 中三種石首魚類聲音之特徵，其時空分佈，和各種聲音與繁殖之關係。*Pogonias cromis* 發出兩種聲音，一爲强的鼓聲，一爲短之喉聲 (grunt)。*Bairdiella chrysoura* 能發出連串的敲擊聲 (knocks)。*Cynoscion nebulosus* 的聲音則爲喉聲，敲擊聲及振動聲 (staccato) 單獨或組合成的。魚羣聲音發生最多的時間在 1700～2000 小時間，此段時間恰好和水層中最高含卵量相符合。因此石首魚類發聲與產卵可能有直接之關係。在生殖季節時，此三種石首魚類在夜間，大都羣集於較深的河道中。