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Do Striped Cusk-Eels *Ophidion marginatum* (Ophidiidae) Produce the "Chatter" Sound Attributed to Weakfish *Cynoscion regalis* (Sciaenidae)?

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Weakfish *Cynoscion regalis* and striped cusk-eels *Ophidion marginatum* both produce sounds, but there has been confusion in the literature on a particular sound, the "chatter." It has been stated that this sound is produced by weakfish using their pharyngeal teeth. Striped cusk-eels make a similar sound (but not identified in the literature as a chatter) using sonic muscles associated with the swim bladder and vertebral components. The striped cusk-eel identifications were based on captive fish sound recordings, whereas the weakfish identifications were based on recordings made in situ where weakfish were visually observed but other sound-producing organisms could have been present. Based on new signal analysis of striped cusk-eel sounds made in captivity, we identify that species as the source of the chatter sound in our field recordings. The dominant frequency of the sounds increased while the pulse period decreased over the temperature range 18.0–27.5 C. The acoustic characteristics presented here will aid researchers in their identification of these sounds.

THERE has been renewed interest in identifying soniferous fishes by the sounds they produce to record their presence in an area (Mann and Lobel, 1995; Lugli et al. 1995) and to delimit spawning locations for management purposes (Mok and Gilmore, 1983; Saucier and Baltz, 1993; Luczkovich et al., 1999). If sound alone is used to identify a species in a survey, then the sounds must be species specific and clearly linked to a species by means of sound recordings made in captivity or under controlled conditions. Confusion can occur if species identifications are based solely on field recordings, because the source of the sound often cannot be identified with certainty.

In the past, we and others have identified a particular sound, which has been called the "chatter" and is commonly heard in Delaware and North Carolina estuarine waters during hydrophone surveys, as being produced by weakfish, *Cynoscion regalis* (Fish and Mowbray, 1970; Connaughton and Taylor, 1995). These papers suggested that weakfish of both sexes produced this sound using stridulation of their pharyngeal teeth. Fish and Mowbray (1970) attributed the chatter sound to weakfish because they recorded the sound in the vicinity of weakfish aggregations, but they never recorded the sound from captive weakfish.

Striped cusk-eels *Ophidion marginatum* occur in North Carolina (Schwartz, 1997) and also produce sounds (Courtenay, 1971; Mann et al., 1997). Mann et al. (1997) recorded sounds produced in captivity by spawning striped cusk-eels and analyzed their signals. We provided our recordings and signal analysis of the chatter sound to those authors and other researchers. One of the authors (RAR) suggested that the chatter sound was possibly not produced by a weakfish but by a striped cusk-eel. In this study, we compare our field recorded chatter sounds to a recording of captive striped cusk-eel sounds. We also characterize the spectral and temporal variation in the chatter sounds as a function of temperature.

MATERIALS AND METHODS

Sound recording.—We recorded fish sounds in the Pamlico and Bogue Sounds of North Carolina using an InterOcean Model 902 Acoustic Listening and Calibration System (frequency range: 20 Hz to 10,000 Hz; sensitivity: 100 dB re 1 μPa RMS pressure) consisting of an InterOcean Model T-902 hydrophone (omnidirectional with sensitivity−195 dB re 1 V/μPa) and amplifier (gain 15–95 dB). Amplifier output was recorded to a portable battery-operated digital audio tape (DAT; Sony TCD-D8) with 16 bits of resolution and a sampling rate of 48 kHz, reduced to 24 kHz prior to analysis. Data were resampled using a National Instruments NB-2150F analog-to-digital board with antialiasing filters in a Power Macintosh computer. The recording of a captive striped cusk-eel was made as described in Mann et al. (1997) and was sent to us by one of the authors (DAM). We digitized the captive striped cusk-eel recording with sampling frequency 24 kHz using the same analog-to-digital equipment as used for the field recordings.

Signal analysis.—We analyzed the recorded sounds using oscillograms, sonograms, and av-

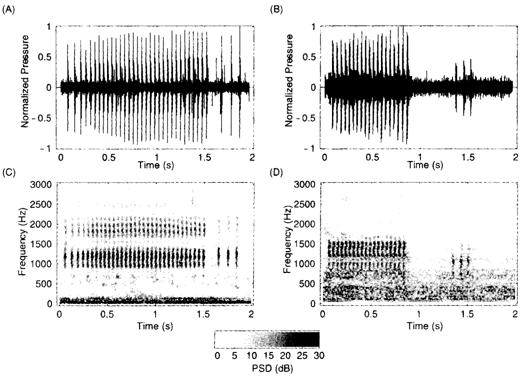

Fig. 1. (A) Oscillogram of chatters recorded at 1810 on 25 August 1997 near Hatteras Inlet in Pamlico Sound, North Carolina (35°11′33.758″N, 75°46′42.129″W). (B) Oscillogram produced by a captive striped cusk-eel recorded in air by Mann et al. (1997). (C) A sonogram of same sound as in (A) using 1024-point Hanning windowed Fast Fourier Transforms with 7/8 overlap; power spectral densities (PSDs) on a relative scale with 0 dB set to background level. (D) Sonogram of same sound as in (B) produced using the same techniques as in (C).

erage power spectra using the signal analysis techniques outlined in Sprague et al. (2000) and those used by Mann et al. (1997). Because both the field recordings and the captive fish recordings contained low frequency artifacts that were not part of the fish sound, we filtered all low frequencies (< 750 Hz) using a Fast Fourier Transform (FFT) filter (Press et al., 1992) before plotting and analyzing oscillograms. This low-frequency filtering is routine in analyzing recordings from noisy environments and did not change the higher frequency fish sounds in the signal. We used sonograms to compare time variations of the frequency content of each recording. We plotted each sonogram using relative power spectral densities adjusted so that the background level in each sonogram (the lightest region) was 0 dB. The average power spectrum emphasizes the frequency components that occur continually in a recording segment and is useful for analyzing a sound that does not change rapidly. We computed average power spectra by averaging the spectral components of power spectra computed from successive 1024-sample windows in the signal. All power spectra used for sonograms and average power spectra were produced from unfiltered data because each power spectrum separated the unwanted low frequency noise from the higher frequency fish sounds.

Sound characteristics.—We measured three characteristics of each sound: the number of pulses, the pulse period, and the dominant frequency. We determined the number of pulses in a sound by counting the pulses in each filtered oscillogram. Often, there were several sound sources present in field recordings causing difficulty in determining which oscillations in the oscillogram corresponded to the pulses of the chatter sound. For noisy recordings, we used sonograms with short time-windows (10.7 ms) and large overlaps (7/8) to distinguish the chatter pulses from other noise with different frequency and time characteristics. The short time-windows insured that several consecutive time-windows in the sonogram contained each pulse followed by several consecutive time-windows containing the interval between the pulse and the subsequent pulse. The resulting separation of pulses in the short-time-windowed sonogram allowed us to accurately count the number of pulses in the train. The pulse period (equivalent to the inverse of the pulse repetition rate) is the time interval between the beginning of a pulse, or click, to the beginning of the next pulse, determined for a train of pulses by measuring the time interval from the beginning of the first pulse to the beginning of the final pulse and dividing by the total number of pulses minus one (Mann et al., 1997). We determined the beginning of the pulse by the time of the zero-crossing in the oscillogram immediately preceding the pulse. The dominant frequency is the frequency peak in the average power spectrum with the largest power spectral density, estimated by calculating the expectation value of the peak frequency using a weighted average method of power spectral densities associated with a range of sampled frequencies around the peak (Sprague et al., 2000).

Fish collection.—Striped cusk-eels were collected using a semiballoon trawl with 5.5-m head rope and 6.35-mm stretched mesh bag. Repeated trawls were towed for 5 min at speeds of 4.0–4.5 km/h from 0200–0430, 23 May 2000. We towed in areas where we previously had recorded chatters, notably Teaches Hole Channel (35°05′45.920″N, 75°59′37.218″W). The water depth was 3.0–5.2 m, bottom temperature was 21 C, and the salinity was 35.2 ppt. Acoustic recordings were made at the end of the trawl track.

RESULTS

The field recordings of chatters showed very similar spectral and temporal characteristics to the calls of captive striped cusk-eels. Oscillograms of the field recorded chatter (Fig. 1A)

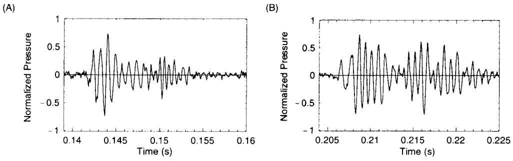

Fig. 2. Oscillograms showing single pulses. (A) Oscillogram of pulse in the field recorded chatter shown in Figure 1A. (B) Oscillogram of pulse in the captive striped cusk-eel sound shown in Figure 1B.

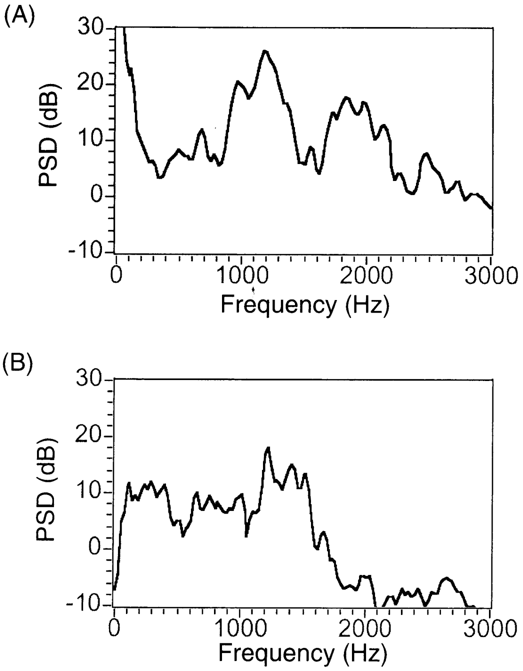

Fig. 3. Average power spectra of the long calls from Figure 1 produced using consecutive 1024-point Hanning windowed Fast Fourier Transforms. The power spectral densities (PSDs) are on a relative scale with 0 dB set to the background level. (A) Average power spectrum of the same field recorded chatter as in Figure 1A. The low-frequency components in this sonogram were a result of 60 Hz noise and were not part of the fish sounds. (B) Average power spectrum of the same captive striped cusk-eel sound as in Figure 1B.

and the captive striped cusk-eel call (Fig. 1B) revealed that both sounds consisted of a long train of pulses followed by a shorter train of three pulses. Although long pulse trains often preceded short pulse trains in both field recordings and captive striped cusk-eel sounds, this did not occur in all cases in either group of recordings. The field-recorded long chatter (Fig. 1A) consisted of 32 pulses with pulse period 46.7 ms (equivalent to a pulse repetition rate of 21.4 pulses/sec), and the captive striped cusk-eel long call (Fig. 1B) consisted of 19 pulses with pulse period 43.5 ms (pulse repetition rate 23.0 pulses/sec). The sonogram of the chatter recording (Fig. 1C) consisted of a series of rapid broad-frequency pulses of 1–2 kHz. The sonogram of the captive striped cusk-eel recording (Fig. 1D) also consisted of rapid pulses with sound energy between 1 and 2 kHz. The pulses of the chatter recording and the captive striped cusk-eel recording are shown in detail in Figure 2. The average power spectra of the same two sounds indicated that the dominant frequency of the field-recorded long chatter (Fig. 3A) was 1.182 kHz, whereas the dominant frequency of the captive striped cusk-eel long call (Fig. 3B) was 1.218 kHz.

We recorded 97 separate chatters in the field during May through September of 1996 and 1997 at various times of the day (presunset, night time, and postsunrise, 1600–1000 DST). The maximum sound pressure levels of recorded chatters ranged from 110–123 dB re 1 μPa (averaging meter, time constant 100 ms). The number of pulses in each chatter ranged from 1 to 73, with median 31 and standard deviation 15.2. We found 16 short chatters with four or fewer pulses, and the next shortest chatter had 14 pulses. We omitted the short chatters from our regression analysis because they were clearly representative of a different class of sounds than the longer chatters (Mann et al., 1997). Regression analysis revealed no significant dependence of the number of pulses on the temperature (Fig. 4A). There was a significant decrease in pulse period (Fig. 4B) and a significant increase in dominant frequency (Fig. 4C) as the temperature increased from 18 to 27 C at our study sites.

In an attempt to document the presence of the striped cusk-eel in an area where we had previously made chatter recordings, we captured two striped cusk-eels, one juvenile (80 mm SL) and one female (208 mm SL) in Teaches Hole Channel, Pamlico Sound, North Carolina on 23 May 2000. In that location, we recorded a series of loud chatter sounds, similar to those described above, in 4 m of water after the final trawl in which a cusk-eel was captured.

DISCUSSION

Signal analysis performed in this study is consistent with the striped cusk-eel sounds described by Mann et al. (1997). Based on this similarity, we identify the source of the chatter sound in our field recordings as striped cusk-eels—not weakfish. The captive striped cusk-eel

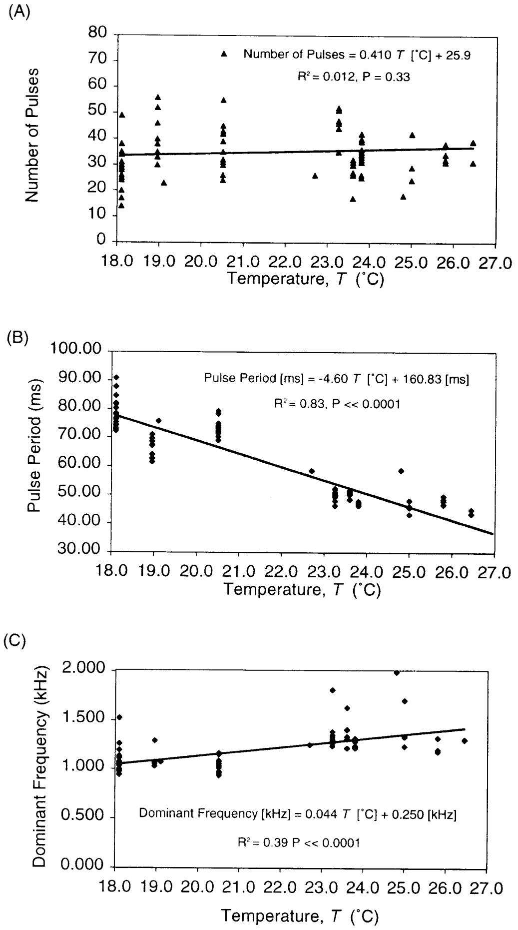

Fig. 4. Regression analyses of sound characteristics of field-recorded chatter sounds as a function of temperature. $n = 81$ pulses. (A) Number of pulses versus temperature. (B) Pulse period versus temperature. (C) Dominant frequency versus temperature.

and field recordings had similar pulse periods and similar dominant frequencies. In addition to the acoustic similarity, we captured striped cusk-eels in a location where we immediately recorded chatter sounds. Although entirely circumstantial, this capture of striped cusk-eels in the location where we recorded the sounds supports our identification.

Although weakfish have been held in captivity by us and others and have produced sounds in a captive environment, they have never produced a chatter in such an environment (Fish and Mowbray, 1970; Connaughton and Taylor, 1995; Sprague et al., 2000). We based the identification of the chatter sounds on Fish and Mowbray's (1970:93) description of weakfish sounds from field investigations in which they reported "... prolonged bursts of croaking sounds ... often producing a steady chattering chorus [with] predominant frequencies usually 1.2–1.8 kHz." Their figure 154, identified as a field recording of weakfish sounds, has frequencies in this 1.2–1.8 kHz range and is remarkably similar to our Figure 1C–D. We believe that Fish and Mowbray (1970) were in error, causing a series of misidentifications over the years.

We observed a significant decrease in the pulse period and a significant increase in the dominant frequency of striped cusk-eel calls as a function of temperature. This is the first demonstration that the pulse period varies with temperature in any fish. Fine (1978) demonstrated that the fundamental frequency increased with temperature in oyster toadfish *Opsanus tau*. Also, the frequency of the central nervous system pattern generator increases with temperature in the oyster toadfish, plainfin midshipman *Porichthys notatus*, longhorn sculpin *Myoxocephalus scorpius*, Pacific staghorn *Leptocottus armatus*, and northern searobin *Prionotus carolinus* (Bass and Baker, 1991). The increase in dominant frequency with temperature that we observed in striped cusk-eel sounds is consistent with the frequency increases observed in these other species. Although the dominant frequency varied directly with temperature, it may have been influenced by other behavioral, ecological, and physiological factors as well, accounting for some of the variation in our data.

The pulse periods of field-recorded chatters were similar to those of captive striped cusk-eel sounds. When applied to the temperature range (21.5–27.5 C) over which the captive striped cusk-eel sounds were recorded (Mann et al., 1997), the regression relationship for field-recorded chatters yielded pulse periods from 34.4–62.0 ms. The median temperature for the captive cusk-eel recordings was 24.5 C, which gave a pulse period of 48.2 ms from our regression equation. This is similar to the measured mean pulse period of 43.0 ± 1.2 ms for long cusk-eel calls (Mann et al., 1997).

The dominant frequencies of our field-recorded chatters are close to the dominant frequencies of the cusk-eel sounds recorded by Mann et al. (1997). When applied to the median temperature for the captive cusk-eel recordings, our regression equation for dominant frequency produces 1.334 kHz, which is remarkably similar to the 1.218 kHz dominant frequency of the captive striped cusk-eel call shown in Figure 1D. Differences in the dominant frequencies of our chatter sounds and captive striped cusk-eel sounds could be a result of differences in fish sizes, associated with variations in swim bladder size and sonic muscle characteristics (Connaughton et al., 2000; Sprague, 2000). In addition, these differences could have occurred as a result of distortions introduced by the acoustic environment of the aquarium and the air recording method used by Mann et al. (1997). Despite these factors, the dominant frequency of the captive striped cusk-eel sounds is within the range of dominant frequencies in our field-recorded chatters.

The number of pulses in our field-recorded long chatters was higher than the number of pulses produced in the captive striped cusk-eel recordings of Mann et al. (1997). Those authors observed three classes of sounds in their recordings: 1–5, 6–14, and 16–27 pulses. Sixteen of our field-recorded chatters fell into the 1–5 pulse category and one into the 6–14 pulse category. The rest of our chatters (80 total) were in the 16–27 pulse category or longer. These differences in the numbers of pulses could be a result of influences of the tank environment on striped cusk-eel behavior.

Although we did not observe striped cusk-eels producing our field-recorded chatters, Mann et al. (1997) recorded similar sounds during courtship activity. Therefore, it is likely that the striped cusk-eels in our field recordings were involved in courtship and mating behavior at our study sites. Our capture of striped cusk-eels and subsequent recording of chatter sounds in the same location confirmed the presence of that species in the study area during the same season (May) as we recorded chatters in previous years, suggesting that striped cusk-eel reproduction occurs in North Carolina estuarine waters. Another species of cusk-eel, the crested cusk-eel *O. welshi,* occurs in our study area, but we did not collect it in our trawls. It is possible that the chatters we recorded were produced by the crested cusk-eel accounting for some of the differences between our chatters and the captive striped cusk-eel sounds recorded by Mann et al. (1997). However, the crested cusk-eel is rare in North Carolina (M. Fahay, pers. com.).

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