The onset of synchronization of calls in a Sciaenidae mating chorus

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Introduction

In many fish, males use nocturnal mating calls to attract females, resulting in characteristic mating choruses dominating estuary and ocean soundscapes. Just before and after sunset, when fish call for mates, they initially compete to attract them. They call during a space between other conspecific fish calls (anti-phase synchronization). Full synchronization (simultaneous calls) can also occur when there are thousands of calling individuals so that they cooperate in a lek, as has been hypothesized for sound-producing codfish[1]. Synchronous calling will maximize the range, serving as an "acoustic beacon", with the characteristic period of the call repeated[2]. Here, we describe the onset before and after sunset of calling synchronization in weakfish *Cynoscion regalis* Sciaenidae. Hydrophone recordings were made from sunset into the night and analyzed using power spectral band sums (power spectra summed across the weakfish's dominant call frequencies, 300 Hz to 600 Hz). Power spectral band sum (PSB sum) is a technique developed to isolate and plot the variations in power spectra over time in a frequency band associated with a given fish species[3]. We used the band 300 Hz to 600 Hz in the case of weakfish. In this frequency band, we summed the power spectra derived from a spectrogram of time windows (4096-point Fast Fourier Transform, FFT, with 50 % overlap, using a sliding FFT window) and plotted the PSB sum versus time. PSB sums showed a periodic variation before, during, and after sunset. The period of the variation in PSB sums of the weakfish calls was 2.6 s before sunset, when few fish were calling, and decreased to 2.3 s in a post-sunset chorus as more weakfish began to call.

Observations of Synchronous Weakfish Chorusing

We have previously documented that weakfish call nocturnally during May and June near the inlets of coastal North Carolina estuaries in Pamlico Sound[4]. Anecdotally, we have noticed that weakfish choruses seem to increase in amplitude, then fade, and then become louder again in a pulsing rhythm. We hypothesize here that this phenomenon is due to the synchronous calls of male weakfish.

Individual Male Synchronizing

We observed a male exhibiting anti-phase synchronization initially, which became synchronized during sunset. In Figure 1, the Power Spectral Band Sum (PSB sum) is shown for a series of recordings made June 17, 1997. These sounds were recorded at Hatteras Inlet, NC, just before and after sunset (20:20 EDT).

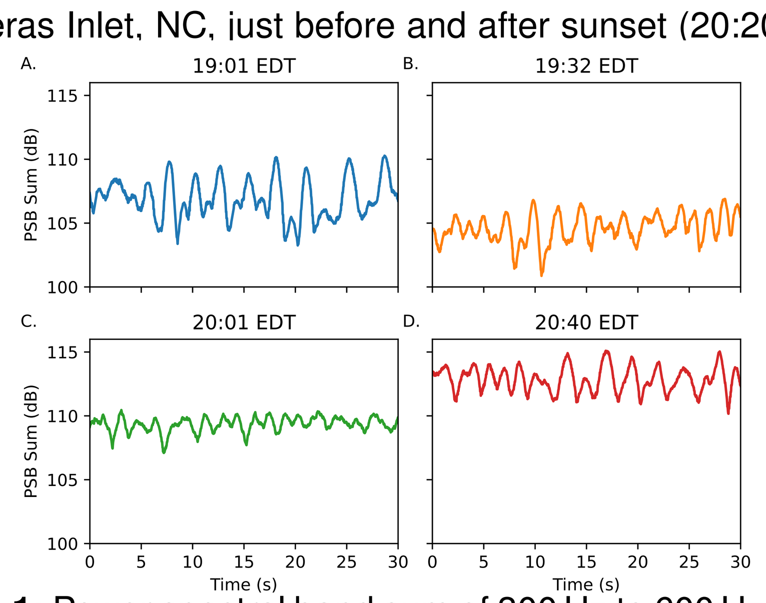

Figure 1: Power spectral band sum of 300 Hz to 600 Hz associated with a weakfish chorus before and after sunset (20:20 local Time) at Hatteras Inlet, North Carolina, USA. A. Blue line: Anti-phase calling with a male in foreground and an aggregation in the background recorded 19:01 EDT before sunset; B. orange line: synchronization of the individual and the same chorus recorded at 19:32 EDT; C. green line: chorus recorded at 20:01 EDT; D. red line: the fully synchronized chorus is audible as a pulsing of the sounds after sunset (20:40 EDT)

Before sunset (Fig. 1A, 19:01 EDT), a single male began calling near our hydrophone. As sunset approached (Fig. 1B, 19:32 EDT) that male became synchronized with the chorusing males in the background. Synchronization was less apparent just before sunset (20:01 EDT), perhaps due to more males joining in. After sunset (Fig. 1D, 20:40 EDT), synchronization became apparent again as the chorus became loudest (i.e., most fish were calling). We believe that additional males were joining the chorus at 20:01 EDT, but some were out of phase with the others. In theory, when more oscillators (calling fish) enter a population, the coupling between oscillators can decrease, leading to less synchronization[5]. Anti-phase synchronization occurred first with one fish and a chorus of multiple fish; individuals gradually became synchronized 30 min later. The synchronization of males in a chorus should attract females at a greater distance. We hypothesize that synchronized chorusing occurs first in males that are nearby a calling fish, but distant males may compete with the male near our hydrophone and exhibit anti-phase synchronization or non-synchronous behavior, depending on how well they were coupled by their hearing of other calling males.

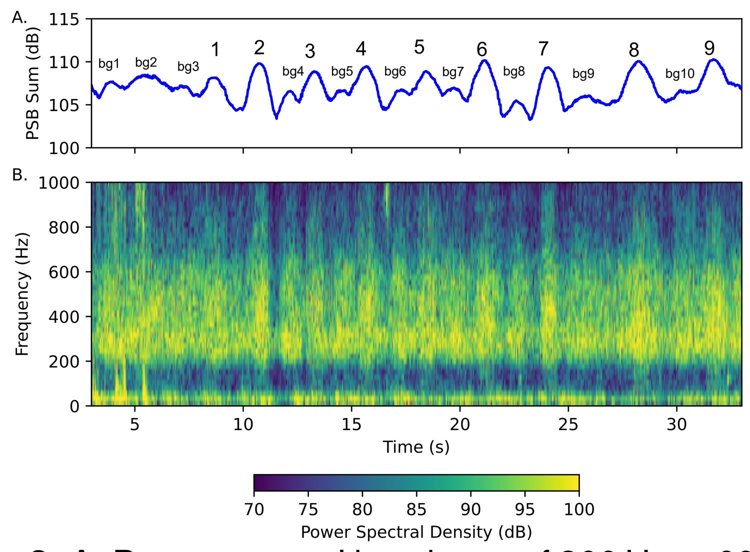

Figure 2: A. Power spectral band sum of 300 Hz to 600 Hz associated with a weakfish chorus before sunset (19:01 EDT) at Hatteras Inlet, North Carolina, USA. Anti-phase calling with a male in foreground (peaks 1–9) and an aggregation in the background (peaks bg 1– bg 8). PSB sum levels are referenced to 1 μPa^2. B. Spectrogram of the sound recorded with reference level 1 μPa^2/Hz.

A closer view of the single male calling and the subsequent transition to synchronization can be observed in the following analysis of peaks in the PSB signal and associated spectrograms. Figure 2 shows that at 19:01 EDT, before sunset, when a chorus was forming, there was a single male weakfish calling close to our hydrophone (Fig. 2 top, PSB sum peaks associated with that male's pulses are numbered 1–9). A chorus of male weakfish, which are more distant from the hydrophone, can be heard in the background of the recording (Fig. 2 top, PSB sum peaks are labeled as bg 1–10). The background peaks have lower PSB sums ($<$ 108 dB) than the individual calling in the foreground ($>$ 108 dB). The male in the foreground is not in sync with the chorus, being 180 degrees out of phase with the chorusing males in the background. The frequency of the pulses are 0.3 Hz (9 calls in 30 s). Figure 3 shows the next recording in the sequence in Figure 1, made just before sunset at 19:32 EDT. Here, the male weakfish previously shown to produce purring pulse sounds at a frequency of 0.3 Hz has synchronized with the background chorus and is making pulses at 0.5 Hz (15 peaks in the PSB sum in 30 s). The chorus previously was $<$ 108 dB, but now all peaks exceed 105 dB. The earlier background chorus 2 also may have been at 0.5 Hz, but alternate peaks were obscured by the individual fish calling $>$ 105 dB in the foreground. The 0.5 Hz rate exhibited by an aggregation (or a lek of calling fish) may be a pulsing rate that is most attractive to females, serving as a synchronized "acoustic beacon" for the lek.

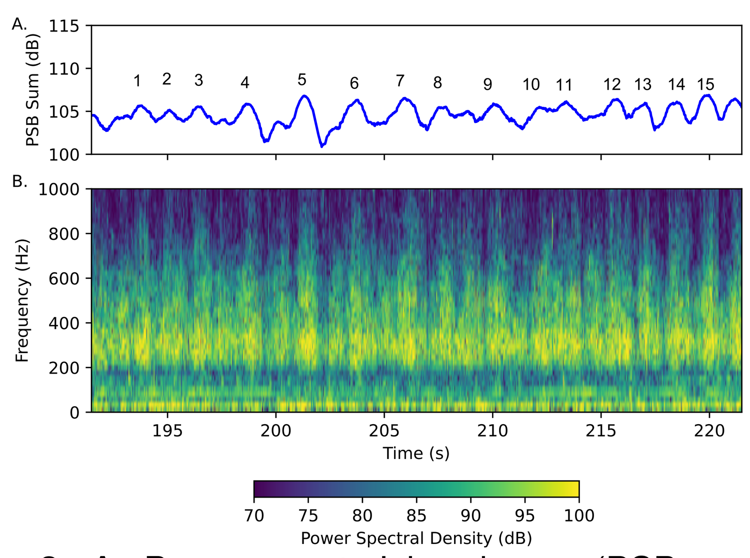

Figure 3: A. Power spectral band sum (PSB sum) of 300 Hz to 600 Hz components associated with a weakfish chorus just before sunset (19:32 EDT) at Hatteras Inlet, North Carolina, USA. The single calling male near the hydrophone has synchronized with the chorus of the fish in the background (peaks 1–15). PSB sum levels are referenced to 1 μPa^2. B. Spectrogram of the sound recorded with reference level 1 μPa^2/Hz.

Onset of the Synchronized Weakfish Chorus

We deployed a hydrophone on May 04, 2001 in Wallace Channel in Ocracoke Inlet, North Carolina before and after sunset. Digital audio tape recordings were made at the times indicated in Figure 4. The plot shows an increasing intensity of the weakfish power spectral band sum (dB) after sunset. The PSB sum fluctuates, demonstrating the synchronous calling of the males, which starts before sunset and continues after sunset. The period of the synchronized calls is shown in Table 1.

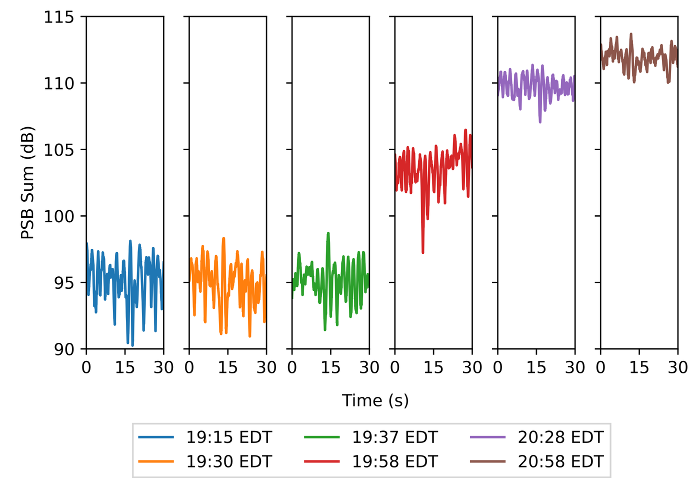

Figure 4: Power spectral band sum of 300 Hz to 600 Hz associated with a weakfish chorus after sunset (19:52 EDT) at Ocracoke Inlet, North Carolina, USA. Blue line: recorded 19:15 EDT before sunset; orange line: the same chorus recorded at 1930 EDT; green line: recorded at 19:37 EDT; red line: recorded at 19:58 EDT (after sunset); purple line: recorded at 20:28 EDT; brown line: recorded at 20:58 EDT

Table 1: Estimate of the period of the fluctuations in the weakfish PSB sums. The period estimates are based on an average power spectrum, calculated using a Welch's method[6], of the power spectral band sums of a 120 s interval beginning at the time specified in the first column. Call period uncertainties are based on the precision of power spectrum frequency: $\Delta f = \Delta f_{\text{power spectrum}}/2 = 0.004$ Hz.

Time (EDT)	Period (s)
19:15	2.55 ± 0.03
19:30	2.55 ± 0.03
19:37	1.90 ± 0.02
19:58	1.84 ± 0.01
20:28	2.14 ± 0.02
20:58	2.26 ± 0.02

Conclusions

1. The weakfish *Cynoscion regalis* population studied is hypothesized to use synchronized calling during spawning, forming an "acoustic beacon".
2. Initially, anti-phase synchronization occurs, then full synchronization occurs as an individual male switches to match others calling nearby.
3. The pulsing frequency after synchronization centers on a 2 s period between peaks.
4. When more fish join the chorus at sunset, non-synchronous or anti-phase synchronous calling occurs, then the chorus becomes synchronous again. The period of the pulsing in synchronous calling can change slightly before and after sunset, varying between 1.8 s and 2.6 s.
5. The period of the synchronized calling may be important for attracting females; the females may pay more attention to males singing in together at the same pulse period ($\sim$ 2 s) than males that are not in sync.
6. The synchronous calling in a chorus of weakfish may be an acoustic beacon attracting females over a greater distance than non-synchronous calling.
7. Further experiments with hydrophone arrays to localize individual males calling and playbacks at different pulsing frequencies are required to confirm this hypothesis of synchronization of mating calls.
8. A model of synchronization onset in weakfish[7] is presented elsewhere in the Aquatic Noise 2025 poster sessions.

References

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