

Sexual Dimorphism in Sound Production and Call Characteristics in the Striped Weakfish *Cynoscion guatucupa*

Javier S. Tellechea^{1,*} and Walter Norbis^{1,2}

¹Instituto de Biología, Departamento de Biología Animal, Laboratorio de Fisiología de la Reproducción y Ecología de Peces, Facultad de Ciencias, Universidad de la República, Iguá 4225, Montevideo, Uruguay

²Departamento de Biología de Poblaciones, Dirección Nacional de Recursos Acuáticos (MGAP); Constituyente 1497, Montevideo, Uruguay

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Javier S. Tellechea and Walter Norbis (2012) Sexual dimorphism in sound production and call characteristics in the striped weakfish *Cynoscion guatucupa*. *Zoological Studies* 51(7): 946-955. Within the family Sciaenidae, the genus *Cynoscion* is composed of 25 species, but sound production in the striped weakfish *C. guatucupa* has not been documented. The striped weakfish possesses sexually dimorphic bilateral sonic muscles used for sound production which is associated with spawning and disturbance calls. The bilaterally paired muscles lie on the inner body wall of the male, surrounding the swimbladder. Positive identification of advertisement calls in captivity were identified with spawning activity in the field. We found that advertisement calls recorded in the field were similar to voluntary calls recorded in tanks during the spawning season. In captivity, advertisement calls had an average pulse duration of 28.8 ± 7.04 ms, an inter-pulse interval of 219.1 ± 83.7 ms, and a dominant frequency of 457 ± 19.6 Hz in the spawning season. Striped weakfish advertisement calls were not detected in the non-reproductive season, but fish did produce disturbance calls when exposed to disturbance stimuli. Disturbance calls consisted of a burst of pulses produced at short intervals with an average pulse duration of 7.35 ± 1.63 ms, an inter-pulse interval of 20.2 ± 1.75 ms, and a dominant frequency of 484 ± 38.6 Hz. The number of pulses produced for disturbance calls was significantly greater (Mann-Whitney test, $p < 0.05$) than those for advertisement calls. The pulse duration and inter-pulse interval increased as the dominant frequency decreased with fish size. The relationship between the dominant frequency (of disturbance calls) and total length (TL) showed a breaking point at 17 cm TL and corresponded to sexually immature individuals of 1-2 yr old. This break point value was related to the size-age spatial segregation of the species in the study area, whereby juveniles (< 2 yr old) inhabit brackish, warmer waters in the shallowest portion of the Uruguayan coast. <http://zoolestud.sinica.edu.tw/Journals/51.7/946.pdf>

Key words: Sound production, Bioacoustics, Sonic muscles, Sciaenidae, *Cynoscion guatucupa*.

Many fish produce species-specific sounds (Fish and Mowbray 1970, Fine et al. 1977, Myrberg 1981) associated with aggression, aggregation, fright, and reproductive behavior (Winn 1964). The Sciaenidae (drums and croakers) is one of the largest families of sound-producing teleosts, including 270 species within 70 genera (Chao 1986). Sound production has been associated with sciaenids since before the turn of the 20th century (Smith 1905, Tower 1908), often in association

with spawning activity (Guest and Lasswell 1978, Mok and Gilmore 1983, Saucier and Baltz 1993, Rountree et al. 2006, Luczkovich et al. 2008, Gannon 2008).

Sciaenid males produce species-specific courtship “drumming” sounds at spawning sites (Fish and Mowbray 1970, Mok and Gilmore 1983, Connaughton and Taylor 1995 1996, Luczkovich et al. 1999, Tellechea et al. 2010 2011). Well-developed extrinsic sonic muscles that surround

*To whom correspondence and reprint requests should be addressed. E-mail: jstellechea@gmail.com

the swimbladder stimulate sound production (Tavolga 1964). Sonic muscles are often found in close association with the swimbladder, which vibrates with the contraction of these muscles, thereby producing sound. These spawning-related sounds and use of passive acoustics (Rountree et al. 2006, Lowerre-Barbieri et al. 2008, Walters et al. 2009) have been used by scientists and fisheries managers to delineate areas where spawning occurs (Luczkovich et al. 2008). Sonic muscles fall into 2 categories: intrinsic, which originate and insert on the swimbladder wall; and extrinsic, which may be associated with the swimbladder but are not part of the bladder wall (Tavolga 1964).

The striped weakfish, *Cynoscion guatucupa* (Sciaenidae; Cuvier 1830), is a demersal coastal marine species (found in conditions of 27-33 psu and 11-17°C), distributed along the western Atlantic Ocean from Rio de Janeiro, Brazil (22°S), to the San Matias Gulf, Argentina (43°S), (Menezes et al. 2003, Cousseau and Perrota 2004). This nectopelagic species is one of the most important coastal Uruguayan-Argentinean and Brazilian fishing resources captured by bottom trawlers throughout the year (Ruarte et al. 2004, Norbis et al. 2006, Villwock and Haimovici 2007). The annual catch in Argentina and Uruguay was approximately 12,000 tons in 2010 with an estimated average annual catch of approximately 14,600 tons for 2001-2010 (www.ctmfm.org). This species spawns multiple times during its reproductive season, which occurs between Oct. and Apr. and peaks in spring and early autumn (Cassia 1986, Viera and Haimovici 1997, Militelli and Macchi 2006). Total length (TLs) at 1st maturity of 30.66 cm in Dec. and 27.20 cm in Mar. were estimated among both sexes (Militelli and Macchi 2006). The age-class distribution pattern of striped weakfish is influenced by a combination of physical conditions (salinity and temperature) and biological characteristics (migration and reproduction). During spring, individuals of older age-classes inhabit deeper zones of the marine coastal area (more saline), while younger individuals inhabit shallower outer estuarine areas (Jaureguizar et al. 2006).

Within the family Sciaenidae, the genus *Cynoscion* is composed of 25 species. Several authors reported and analyzed sound produced by a few of these species (Fish and Cumming 1972, Mok and Gilmore 1983, Connaughton and Taylor 1995, Connaughton et al. 2000 2002b, Locascio and Mann 2008), but sound production

in the striped weakfish has not been documented. The aim of this study was to characterize sound production by the striped weakfish in relation to fish size and sex and to examine the gross structure of the swimbladder muscle.

MATERIALS AND METHODS

Sound recording

Sounds from the striped weakfish were recorded between Sept. 2008 and June 2009, including the spawning season (27 d in the spawning season and 34 d outside the reproduction season). We analyzed sounds recorded from captive fish ($n = 385$ sounds) and from 9 stations in the field ($n = 92$ sounds). At each recording station, we recorded sounds at different times of the day (2 d per station): morning (07:00-11:00), midday (12:00-16:00), and late afternoon-night (18:00-24:00). We also collected temperature and salinity data at all stations. Recordings in the field were taken with a mobile hydrophone at the fishing ground in the Rio de la Plata estuary and in the Atlantic Ocean at likely spawning areas on board the *R/V Aldebaran*, operated by Dirección Nacional de Recursos Acuáticos (DINARA), Uruguay, on the inner continental shelf (at a depth of < 30 m) at different points along the Uruguayan coast (Solymar, Parque del Plata, Punta del Este, and La Paloma; Fig. 1). Once recordings were taken at selected points in the field, we conducted fishing trawls to verify that the species recorded was the striped weakfish.

Sounds from captive fish were recorded on board the research vessel with the engine off. Captured fish were kept alive on board in 3000-L canvas tanks (3 × 1.5 × 0.60 m) with in situ estuarine water from the Rio de la Plata or ocean water from the coastal zone, inside and outside the reproductive season (reproduction season, at Rio de la Plata, 23°C and 20 psu salinity; in the Atlantic Ocean, 23°C and 20 psu salinity; non-reproductive season, at Rio de la Plata, 13°C and 15 psu salinity, in the Atlantic Ocean, 11°C and 22 psu salinity). For recording, individual fish were transferred to 1000-L canvas tanks (1 × 1 × 1 m) using a hand net, and the hydrophone was placed 1 m from the fish. Striped weakfish emit disturbance calls when held in the hand as do other sciaenids, i.e., weakfish *C. regalis* (Connaughton et al. 2000) and whitemouth croaker *Micropogonias furnieri* (Tellechea et al.

2010). Each individual was exposed to 2 stimuli that evoked disturbance calls 1) grabbing them by the tail or otherwise handling them, and 2) casting a shadow over the surface of the tank. For each individual recorded, sex was determined by dissection, and total length (TL) was measured to the nearest 1 cm. In addition, the maturity stage was determined macroscopically according to a maturity key adapted from Vizziano (2002) for sciaenid fishes. Animal care protocols were approved by the Comisión Honoraria de Experimentación Animal (CHEA), Univ. de la República, Montevideo, Uruguay.

Sound analysis

Recordings were made with a hydrophone built in the laboratory (with a sensitivity of -40 dB re: 1 μ Pa and linear from 20 Hz and 60 kHz). Recordings were made on a digital TASCAM HD-P2 recorder at a sampling rate of 44.1 kHz. The sound was analyzed using Audacity free software, vers. 1.2.3 (Mazzoni 2006). Power spectra were calculated using a 1024-point fast Fourier transformation (FFT) with a Hanning window. The pulse duration, dominant frequency, and inter-pulse interval (time between the end of a pulse and beginning of the next pulse) were also measured.

Statistical analysis

Throughout the text, results are presented as the mean with the standard deviation (\pm S.D.). The pulse duration, inter-pulse interval, and dominant frequency for calls emitted by fish in captivity and in the field were compared using Student's *t*-tests, Student's paired *t*-tests, or nonparametric Mann-Whitney tests if parametric assumptions were met (Sokal and Rohlf 1995). Relationships among the mean pulse duration, pulse interval, and TL were analyzed using linear regressions (Sokal and Rohlf 1995), while the relationship between the dominant frequency and TL was analyzed using a segmented linear regression with 1 breakpoint (BP) using the free software, Segreg (Oosterbaan 1994). This model can be used when datasets exhibit 2 or more different linear relationships within 2 or more ranges of the same dataset (Neter et al. 1990). We also fit logarithmic and exponential models to the same data and compared model fits. We tested the null hypothesis of no significant differences between the induced stimuli for the 3 variables that characterized sound with Student's *t*-test (Sokal

and Rohlf 1995). For this analysis, we used PAST (vers. 2.04), a free statistical software package (Hammer et al. 2001). In all tests, the significance level used was $p = 0.05$.

RESULTS

Sound production

Calls were recorded from 45 captive males obtained from 9 stations in the field, with 16 males recorded outside the spawning season (disturbance calls), and 29 males recorded during the spawning season, of which advertisement calls were recorded from 9 males as well. Female striped weakfish did not emit sounds. Dissection of the 45 males recorded and 45 females indicated that only males possessed sonic muscles and produced sound.

During Jan. (spawning season) a voluntary train of pulses was recorded only for mature spawning individuals ($n = 9$) in tanks. We verified that individuals of ≥ 25 cm TL were mature spawning (running-ripe) by the release of sperm when stripped. These 9 fish were acclimatized on board for 12 h in tanks, after which we began recording sounds. The water temperature and salinity in the tanks were the same as those at the site of field recordings. Advertising calls were heard when fish swam freely, alone or in groups, in experimental tanks with females, as males continued producing advertisement calls when females were near. After 2 h of recording captive fish, the 2 sexes were in spawning condition (running-ripe, i.e., males release sperm and females release hydrated oocytes when stripped). Advertising calls consisted of a series of individual pulses that occurred at an average of 219.1 ± 83.7 ms (Fig. 2A). The average pulse duration was 28.8 ± 7.04 ms, the dominant frequency was 457 ± 19.6 Hz, and the number of pulses was 4.44 ± 1.66 (Table 1).

Field and captivity studies indicated a close link between male voluntary drumming behavior and reproductive activity. In the Rio de la Plata coastal estuary (Parque del Plata and Solymar, at 23°C and 20‰ salinity) and on the Atlantic coast (Punta del Este and La Paloma, at 18°C and 30‰ salinity) striped weakfish were recorded during part of their spawning season (from Jan. to Mar.) in shallow inshore waters (at depths of < 15 m; Fig. 2B). Outside of the spawning season, we did not detect this call in the field or in captivity, while

choruses of advertisement calls were heard and recorded in the night (20:00-24:00) in captivity and in the field. After each recording session, we verified the presence of *C. guatucupa* by netting. No significant differences in the pulse duration (pulses $n = 40$ $p = 0.81$) or dominant frequency ($p = 0.58$) occurred between advertisement calls in captivity and in the field (Table 1). The pulse interval and number of pulses could not be distinguished in field recordings due to overlapping sounds (Fig. 2).

Confirmation of sounds recorded in the field and the role of these sounds in spawning were examined among captive striped weakfish. Advertisement calls were emitted naturally by males only during the spawning season. Outside the spawning season, males did not emit this

sound naturally, and disturbance calls were emitted only when subjected to the aforementioned stimuli. The striped weakfish was the dominant fish (> 80% of the catch with respect to other fish species) caught in trawls after field sound recordings.

Disturbance calls were produced when fish were exposed to the 2 stimuli. This call was recorded among males under such stimuli in the non-reproductive season ($n = 36$) and in the spawning season ($n = 9$). We analyzed a total of 128 calls, with a total of 1350 pulses from 45 fish. The disturbance call is a train of pulses, and the number of pulses per burst varied from 12 to 47, with each specimen emitting 1-4 bursts per call (Fig. 3). No significant differences in the pulse duration ($p = 0.63$), pulse interval ($p = 0.93$), or dominant frequency ($p = 0.35$) were

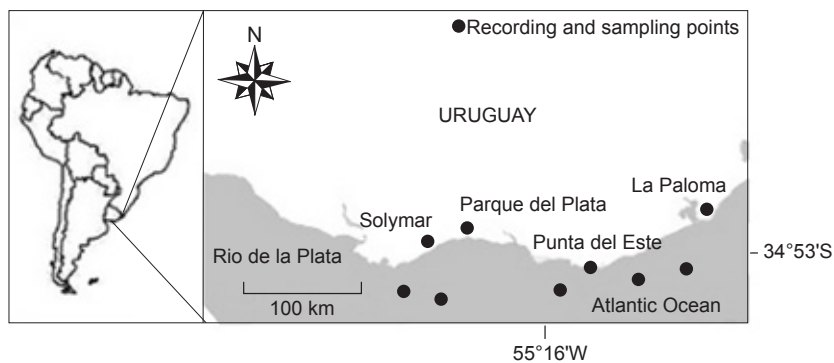


Fig. 1. Map of the study area showing locations where sounds from fish aggregations were recorded and where trawls took place along the Uruguayan coast.

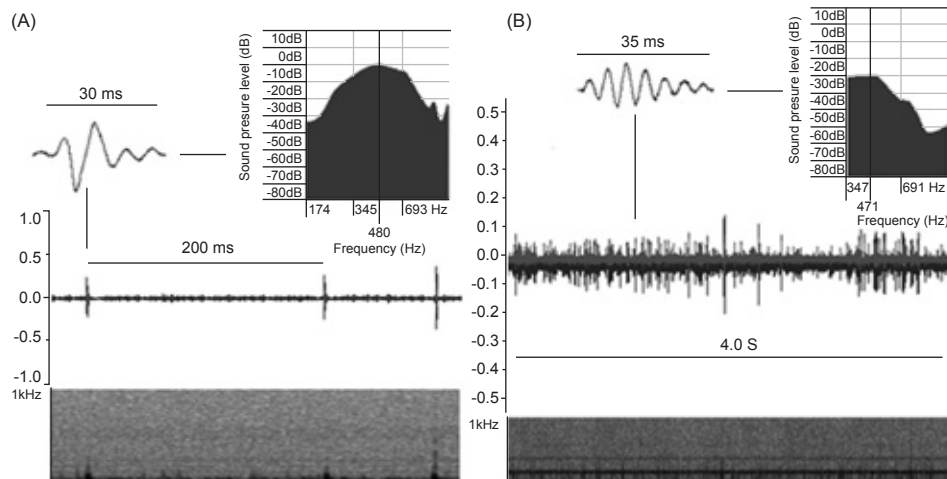


Fig. 2. (A) Oscillogram of the advertisement call of a captive male (24 L_T) and a typical spectrum of a single pulse indicating the dominant frequency (with a Hanning window and a fast Fourier transformation size of 1024 points). (B) Oscillogram of a drumming chorus recorded in the Atlantic Ocean, and a single expanded pulse indicating the duration and dominant frequency (with a Hanning window and a fast Fourier transformation size of 1024 points).

found between the 2 stimuli (*t*-test). Pulse trains consisted of approximately 4 cycles with the most energy occurring in the 2nd and 3rd cycles, and the 4th and 5th cycles were often greatly attenuated (Fig. 3C). The average duration was 7.35 ± 1.63 ms, the interval was 20.2 ± 1.75 ms, and the dominant frequency was 484 ± 38.6 Hz for fish recorded in captivity on board the vessel (Table 2). No significant differences in the pulse duration ($p = 0.06$), pulse interval ($p = 0.08$), or dominant frequency ($p = 0.52$) were found between fish that emitted disturbance calls in the non-spawning

season ($n = 16$) versus during the spawning season ($n = 29$). However, the number of pulses produced by disturbance calls ($n = 45$ fishes) were significantly greater (Mann-Whitney test, $p < 0.0001$) than those produced by advertisement calls ($n = 9$ fishes; Fig. 4).

Relationships of TL with the pulse duration and TL with the pulse interval both showed linear tendencies (Fig. 5). However, the relationship between the dominant frequency (Df) and TL indicated that 2 phases were separately fit by segmented linear regressions with a BP at

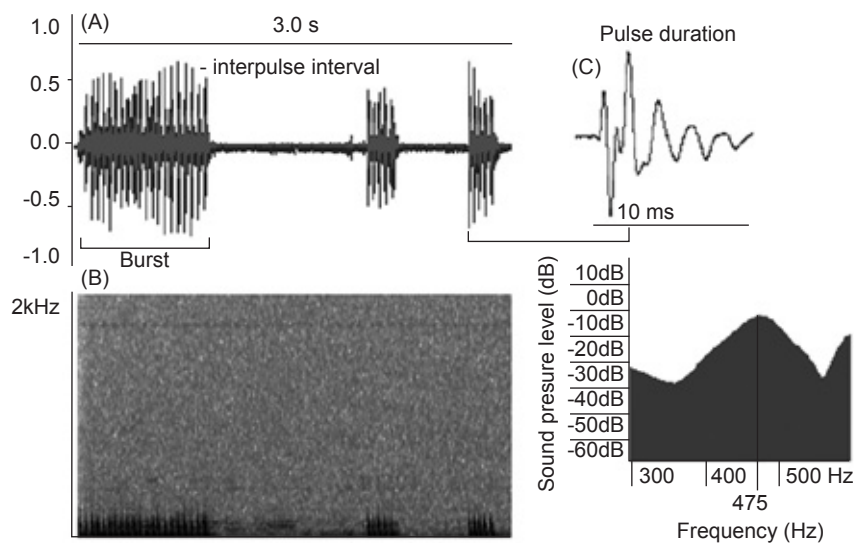


Fig. 3. A disturbance call oscillogram (A) of a 28 L_T male with the uncalibrated relative amplitude on the Y-axis, (B) sonograms using the Hanning window function and a fast Fourier transformation of size of 1024 points, and frequency on the Y-axis; with a single expanded pulse (C) indicating the duration and dominant frequency at 475 Hz.

Table 1. Average, standard deviation and range of call characteristics for the advertisement call (* : impossible to obtain data by the overlap of the pulses in the field)

Male captive recordings ($n = 9$)				
Pulses ($n = 40$)	Average	S.D.	Minimum	Maximum
Pulse duration (ms)	28.8	7.04	14	35
Interpulse interval (ms)	219.1	83.7	97	344
Dominant frequency (Hz)	457	19.6	423	476
Number of pulses	4.44	1.66	3	8
Field recordings				
Males ($n = 40$ pulses)	Average	S.D.	Minimum	Maximum
Pulse duration (ms)	28.6	4.72	12	37
Interpulse interval (ms)	*	*	*	*
Dominant frequency (Hz)	434.4	31.8	366	489
Number of pulses	*	*	*	*

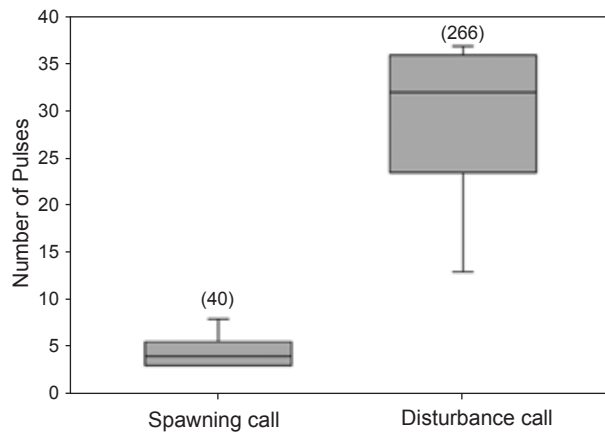


Fig. 4. Pulse number box plot (mean + standard deviation) by call, either an advertisement call or disturbance call. Sample sizes are indicated above the bars in parentheses.

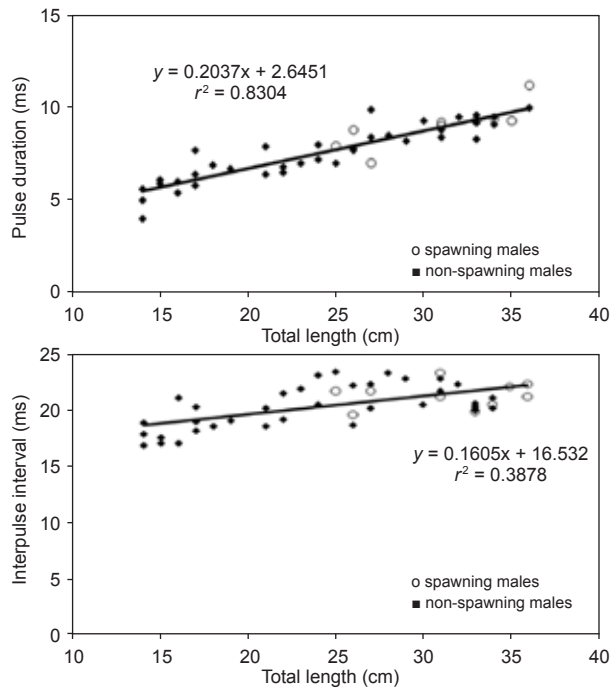


Fig. 5. Relationships among the pulse duration, interpulse interval, and total length (L_T) for disturbance calls.

17.08 cm TL (Fig. 6). The Df decreased from 575 to 478 Hz ($r_1 = -0.82$; $p < 0.05$) before the BP (17.08 cm TL) and then decreased at a slower rate among larger individuals ($r_2 = -0.83$, $p < 0.05$; Table 3). The relationship between Df and TL was fit by the logarithmic model $Df = -116.39 \ln(TL) + 855.67$ ($r^2 = 0.81$) and by the exponential model $Df = 619.36 e^{-0.0098(TL)}$ ($r^2 = 0.78$). The relationship between Df and pulse duration (Pd) was fit by a logarithmic model $Df = -146.35 \ln(Pd) + 780.85$ ($r^2 = 0.68$) and an exponential model $Df = 65786 e^{-0.039(Pd)}$ ($r^2 = 0.67$). We only discuss results from the segmented linear regression as the error distributions in the logarithmic and exponential models showed a BP and a clear change in trends delineated by data points.

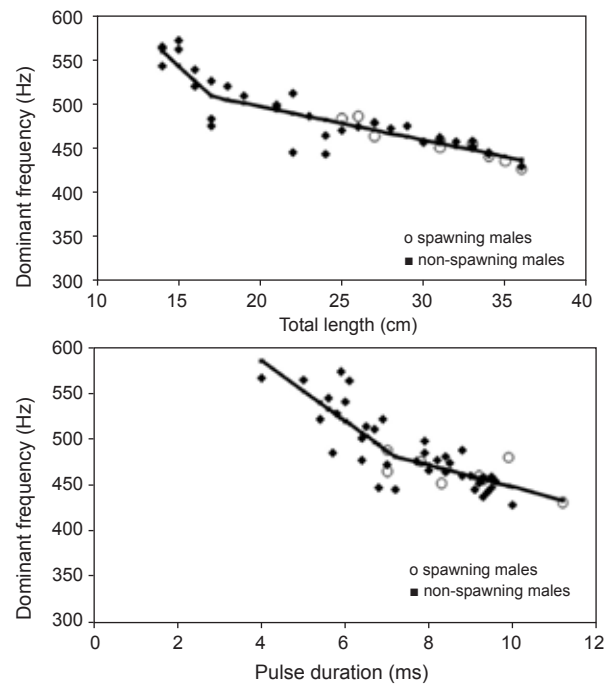


Fig. 6. Relationships of the dominant frequency with the total length (L_T), and of the dominant frequency with the pulse duration (see text and table 2) of disturbance calls.

Table 2. Average, standard deviation and range of call characteristics for the disturbance call

Pulses ($n = 1350$)	Average	S.D.	Minimum	Maximum
Pulse duration (ms)	7.35	1.63	4	11
Interpulse interval (ms)	20.2	1.75	17	23
Dominant frequency (Hz)	484	38.6	429	575
Number of pulses	27.2	8.6	12	47

Sonic muscles

The striped weakfish possesses sexually dimorphic extrinsic sonic muscles. Bilaterally paired muscles were observed on the inner body wall of males, surrounding the swimbladder. They extended nearly the entire length of the body cavity and attached to the lateral body wall musculature by connective tissue (Fig. 7). We noted that the color of the muscle changed seasonally, increasing

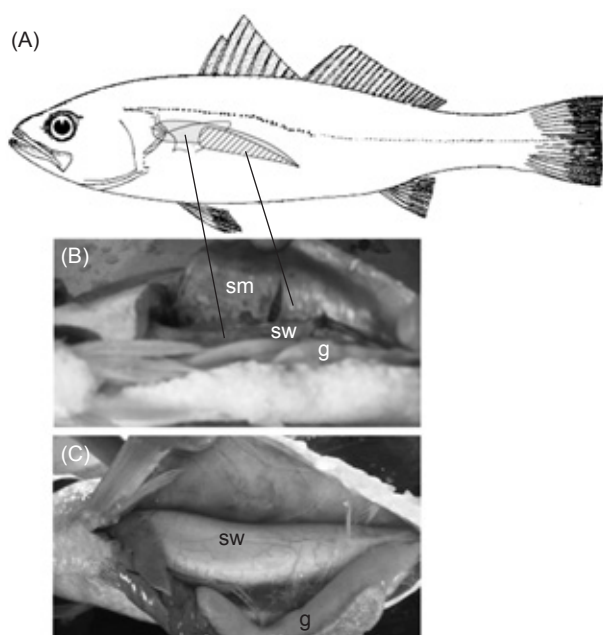


Fig. 7. (A) Illustration of the location and sexual dimorphism of sonic muscles in the striped weakfish (drawing of a fish taken from Menezes and Figueiredo 2003); (B) photograph of the body cavity of a sperm-producing male, showing the dark-red sonic muscle during the spawning season; (C) photograph of the right body wall of a pre-spawning female without sonic muscle. sw, swimbladder; sm, sonic muscle; g, gonad.

in vascularization and deepening to a dark red during the spawning season.

DISCUSSION

This study describes the suite of acoustic characteristics that enable sound production by male striped weakfish (*Cynoscion guatucupa*) of varying sizes and how this sound is related to spawning and disturbance behaviors. As in most sciaenid species, male striped weakfish possess sonic muscles, but they are absent from females (Smith 1905, Tower 1908, Chao 1978, Hill et al. 1987, Connaughton et al. 2000).

In the striped weakfish, as in other weakfish (e.g., *C. regalis*), drumming behavior (advertisement calls) was correlated with spawning in the field (Connaughton and Taylor 1994) and in captivity (Connaughton and Taylor 1996). Herein, we confirmed that the striped weakfish advertisement call recorded in the field was similar to voluntary calls recorded by fish in tanks during the spawning season.

The striped weakfish produces a disturbance call when handled. Each individual male fish captured for the study was exposed to stimuli that evoked disturbance calls. Disturbance calls varied with a fish's size, in that the pulse duration increased with an increasing size of the fish. Larger fish with longer muscles and presumably longer fibers take longer to complete a twitch (Connaughton et al. 2000). There were significant differences between numbers of pulses in advertisement calls and disturbance calls emitted by the same individuals of striped weakfish, as found among *C. regalis*, *M. undulatus*, and *M. furnieri* (Connaughton et al. 2002b, Tellechea et al.

Table 3. Relationship for dominant frequency to L_T (total length = cm), and dominant frequency to pulse duration. Linear regressions, sample sizes (N), and correlations coefficient (r) for fish less than (Model 1) and greater than (Model 2) according to the break points (BP) calculated by the model (See material and methods)

Sound parameters	Model 1			Model 2		
	$L_T < \text{BP } L_T$	N_1	r_1	$L_T > \text{BP } L_T$	N_2	r_2
Dominant frequency (Df)	$Df = 803 - 17.1 L_T$	10	-0.82*	$Df = 575 - 3.78 L_T$	35	-0.83*
BP	17.1 cm					
Relationship Df - Pd	$Df = 719 - 3.29 Pd$	18	-0.68*	$Df = 569 - 1.20 Pd$	27	-0.56*
BP	7.17 ms					

* $p < 0.05$.

2010). The pulses produced during advertisement calls have longer inter-pulse intervals, suggesting that disturbances cause a more-rapid pacing of pattern generators in the central nervous system than courtship vocalizations (Tellechea et al. 2010).

Ontogenetic changes in sound-emitting sciaenids were correlated with the development of sonic muscles, the swimbladder, and gonads (Hill et al. 1987). The development of sonic muscles, together with a fish's size and water temperature, determines characteristics of the sound parameters (Connaughton et al. 1997). Sonic muscles of the weakfish *C. regalis* undergo a yearly hypertrophy-atrophy cycle whereby muscles increase in thickness and mass during the spawning season (Connaughton et al. 1994 1997). Sound production by male weakfish (*C. regalis*) is also seasonal and correlated with late-spring and early-summer spawning activities in natural conditions (Connaughton and Taylor 1995) and with courtship behavior observed prior to spawning in captivity (Connaughton and Taylor 1996). The size and color of the sonic muscles change seasonally, changing to a dark red during the spawning season in *C. regalis* (Merriner 1976). As in the weakfish (*C. regalis*), the coloration of the sonic muscles of the male striped weakfish was darker in the spawning season. This darkening occurs simultaneously with dramatic seasonal variations in the sonic muscle size, when the sonic muscle triples in mass during the spring spawning season and decreases to its pre-spawning mass by the end of the summer in response to changing androgen titers (Connaughton and Taylor 1994). Our observations of the reproductive status, including male and female gonad conditions (females with hydrated oocytes and males producing milt when handled and stripped), suggest that spawning activities for this species coincide with peak drumming activity.

The sound frequency appears to be determined by the speed at which the sonic muscle vibrates the swimbladder rather than by the resonant frequency of the bladder (Connaughton et al. 2002a). Connaughton et al. (2000) argued that larger sonic muscles in weakfish require more time to complete a twitch (Hill 1950, Wainwright and Barton 1995), such that slower movement of the bladder decreases the dominant pulse frequency among larger fish, as found in *M. furnieri* (Tellechea et al. 2010). Male striped weakfish begin producing sounds as juveniles of 14-20 cm TL, similar to the weakfish *C. regalis* (Connaughton et al. 2000) and the whitemouth croaker *M. furnieri*

(Tellechea et al. 2010). The inverse relationship between the dominant frequency and pulse duration in this study also supports the conclusion by Connaughton et al. (2000 2002a) that slower contractions produce a lower dominant frequency.

As striped weakfish (*C. regalis*) spawn at night (personal observations in captivity and in the field) when visibility is low, the acoustic parameters of drumming sounds could provide a valuable cue for female attraction and mate choice (Connaughton et al. 2000). Although untested, it is unlikely that weakfish perceive differences in pulse durations of < 1 ms (Fay and Megala Simmons 1999). Variations in amplitude and frequency with size, which are likely to be observed, may indicate that acoustic pulses by weakfish are an honest signal (Sargent et al. 1998) that permit females to discriminate males on the basis of their size (Connaughton et al. 2000). In the Atlantic cod *Gadus morhu* (of the Gadidae), sound production may also be an indicator of the size of the signaler and may also reveal information about an individual's quality (Rowe and Hutchings 2004). The BP found at 17 cm in the relationship between dominant frequency (of disturbance calls) and TL corresponds to individuals that are 1-2 yr old (Vieira and Haimovici 1993), i.e., sexually immature fish (Vieira and Haimovici 1997). Striped weakfish show a size-age spatial distribution in the study area, whereby juveniles (< 2 yr old) inhabit brackish, warmer waters in the shallowest portion of the Uruguayan coast, while adults are most abundant in waters with high bottom salinities and depth and low temperature (Jaureguizar et al. 2006 2009). If disturbance calls are used by males for communication, the BP in the relationship between the dominant frequency and size could be an indicator of differential spatial distributions of juveniles and adults, but more studies are necessary to confirm this hypothesis.

Sounds produced by sciaenids have been associated with the mating season since the early 20th century (Smith 1905), and are now routinely used to monitor spawning populations in the field (Mok and Gilmore 1983, Saucier and Baltz 1993, Connaughton and Taylor 1995, Rountree et al. 2006). Variations in call quality with fish size in the striped weakfish suggest that acoustic parameters are a valuable non-invasive tool for fisheries biologists to gather size and age data on males in spawning populations.

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REFERENCES

- Cassia MC. 1986. Reproducción y fecundidad de la pescadilla de red (*Cynoscion striatus*). Publ. Comis. Técnica Mixta Frente Mar. 1: 191-203.
- Chao LN. 1978. A basis for classifying western Atlantic Sciaenidae (Teleostei: Perciformes). U.S. Dep. Commer., National Oceanic and Atmospheric Administration Technical Report. NMFS Circ. 415, 64 p.
- Chao LN. 1986. A synopsis on zoogeography of the Sciaenidae. In T. Uyeno, R. Arai, T. Taniuchi, K. Masuura, eds. Indo-Pacific fish biology: proceedings of the Second International Conference of Indo-Pacific Fishes. Tokyo: Ichthyological Society of Japan, pp. 570-589.
- Connaughton MA, ML Fine, MH Taylor. 1997. The effects of seasonal hypertrophy and atrophy on fiber morphology, metabolic substrate concentration and sound characteristics of the weakfish sonic muscle. J. Exp. Biol. 200: 2449-2457.
- Connaughton MA, ML Fine, MH Taylor. 2002a. Weakfish sonic muscle: influence of size, temperature and season. J. Exp. Biol. 205: 2183-2188.
- Connaughton MA, ML Lunn, ML Fine, MH Taylor. 2002b. Characterization of sounds and their use in two sciaenid species: weakfish and Atlantic croaker. In Conference proceedings: listening to fish. Passive acoustic applications in marine fisheries, 8-10 Apr. 2002, An International Workshop on the Applications of Passive Acoustics in Fisheries, Massachusetts Institute of Technology, Cambridge, MD. MIT Sea Grant Special Report.
- Connaughton MA, MH Taylor. 1994. Seasonal cycles in the sonic muscles of the weakfish, *Cynoscion regalis*. Fish. Bull. 92: 697-703.
- Connaughton MA, MH Taylor. 1995. Seasonal and daily cycles in sound production associated with spawning in weakfish, *Cynoscion regalis*. Environ. Biol. Fish. 42: 233-240.
- Connaughton MA, MH Taylor. 1996. Drumming, courtship and spawning behavior in captive weakfish, *Cynoscion regalis*. Copeia 1996: 195-199.
- Connaughton MA, MH Taylor, ML Fine. 2000. Effects of fish size and temperature on weakfish disturbance calls: implications for the mechanism of sound generation. J. Exp. Biol. 203: 1503-1512.
- Cousseau MB, RG Perrotta. 2004. Peces marinos de Argentina: biología, distribución, pesca. Mar del Plata, Argentina: Instituto Nacional de Investigación y Desarrollo Pesquero (INIDEP), 167 pp.
- Fay RR, A Megala Simmons. 1999. The sense of hearing in fishes and amphibians. In RR Fay and AN Popper, eds. Comparative hearing: fish and amphibians. New York: Springer-Verlag, pp. 269-318.
- Fine ML, HE Winn, B Olla. 1977. Communication in fishes. In T Sebeok, ed. How animals communicate. Bloomington, IN: Indiana Univ. Press, pp. 472-518.
- Fish JF, WC Cummings. 1972. A 50-Db increase in sustained ambient noise from fish (*Cynoscion xanthurus*). J. Acoust. Soc. Am. 52: 1266-1270.
- Fish MP, WH Mowbray. 1970. Sound of the western North Atlantic fishes. Baltimore, MD: Johns Hopkins Press.
- Gannon DP. 2008. Passive acoustic techniques in fisheries science: a review and prospectus. Trans. Am. Fish. Soc. 137: 683-656.
- Guest WC, JL Lasswell. 1978. A note on courtship behavior and sound production of red drum. Copeia 1978: 337-338.
- Hammer Ø, DAT Harper, PD Ryan. 2001. PAST: Paleontological Statistical software package for education and data analysis. Paleontol. Electron. 4: 9.
- Hill AV. 1950. The dimensions of animals and their muscular dynamics. Sci. Progr. 38: 209-230.
- Hill GL, ML Fine, JA Musick. 1987. Ontogeny of the sexually dimorphic sonic muscle in three sciaenid species. Copeia 1987: 708-713.
- Jaureguizar AJ, R Guerrero. 2009. Striped weakfish (*Cynoscion guatucupa*) population structure in waters adjacent to Rio de la Plata, environmental influence on its inter-annual variability. Estuar. Coast. Shelf Sci. 85: 89-96.
- Jaureguizar AJ, C Ruarte, R Guerrero. 2006. Distribution of age-classes of striped weakfish (*Cynoscion guatucupa*) along an estuarine-marine gradient: correlations with the environmental parameters. Estuar. Coast. Shelf Sci. 67: 82-92.
- Locascio JV, DA Mann. 2008. Diel periodicity of fish sound production in Charlotte Harbor, Florida. Trans. Am. Fish. Soc. 137: 606-615. doi:10.1577/T06-069.1.
- Lowerre-Barbieri ISK, LR Barbieri, JR Flanders. 2008. Use of passive acoustics to determine red drum spawning in Georgia waters. Trans. Am. Fish. Soc. 137: 562-575.
- Luczkovich JJ, MW Sprague, SE Johnson, RC Paullinger. 1999. Delimiting spawning areas of weakfish, *Cynoscion regalis* (Family Sciaenidae) in Palmico Sound, North Carolina using passive hydroacoustic surveys. Bioacoustics. 10: 143-160.
- Luczkovich JJ, DA Mann, RA Rountree. 2008. Passive Acoustics as a tool in fisheries: an introduction to the American Fisheries Society Symposium. Trans. Am. Fish. Soc. 137: 533-541.
- Mazzoni D. 2006. AUDACITY 1.2.6. Available at <http://audacity.sourceforge.net/> Accessed 16 Dec. 2009.
- Menezes NA, PA Buckup, JL Figueiredo, ML Moura. 2003. Catalogo de Peixes Marinhos do Brasil. Sao Paulo, Brazil: Museu de Zoologia da Univ. de Sao Paulo.
- Merriner JV. 1976. Aspects of the reproductive biology of the weakfish *Cynoscion regalis* (Sciaenidae) in North Carolina. Fish. Bull. 74: 18-26.
- Militelli MI, GJ Macchi. 2006. Spawning and fecundity of striped weakfish, *Cynoscion guatucupa*, in the Rio de la Plata estuary and adjacent marine waters, Argentina-Uruguay. Fish. Res. 77: 110-114.
- Mok HK, RG Gilmore. 1983. Analysis of sound production in estuarine aggregations of *Pogonias cromis*, *Bairdiella chrysoura*, and *Cynoscion nebulosus* (Sciaenidae). Bull. Inst. Zool., Academia Sinica. 22: 157-186.

- Myrberg AA. 1981. Sound communication and interception in fishes. In WN Tavolga, AN Popper, RR Fay, eds. Hearing and sound communication in fishes. New York: Springer-Verlag, pp. 395-428.
- Neter J, W Wasserman, MH Kutner. 1990. Applied linear statistical models, 3rd ed Irwin, Homewood, Illinois, USA.
- Norbis W, L Paesch, O Galli. 2006. Los recursos pesqueros de la costa de Uruguay: ambiente, biología y gestión. In R Menafrá, L Rodríguez-Gallego, F Scarabino, D Conde, eds. Bases para la conservación y manejo de la costa uruguaya. Montevideo: Vida Silvestre Uruguay, pp. 197-211.
- Oosterbaan RJ. 1994. Frequency and regression analysis of hydrologic data, Part II: Regression analysis, Chapter 6. In HP Ritzema, ed. Drainage principles and applications, 2nd revised edition. Wageningen, the Netherlands: ILRI Publication 16.
- Rountree RA, RG Gilmore, CA Goudey, AD Hawkins, J Luczkovich, DA Mann. 2006. Listening to fish: applications of passive acoustics to fisheries science. Fisheries. **31**: 433-446.
- Rowe S, JA Hutchings. 2004. The function of sound production by Atlantic cod as inferred from patterns of variation in drumming muscle mass. Can. J. Zool. **82**: 1391-1398.
- Ruarte C, C Lasta, C Carozza. 2004. Pescadilla de Red (*Cynoscion guatucupa*). In RP Sanchez, SI Bezzi, eds. El Mar Argentino y sus Recursos Pesqueros, 4: Los peces marinos de interés pesquero caracterización, biología y evaluación del estado de explotación. Mar del Plata, Argentina: Instituto Nacional de Investigación y Desarrollo Pesquero, pp. 271-281.
- Sargent RC, VN Rush, BD Wisenden, HY Yan. 1998. Courtship and mate choice in fishes: integrating behavioral and sensory ecology. Am. Zool. **38**: 82-96.
- Saucier MH, DM Baltz. 1993. Spawning site selection by spotted seatrout, *Cynoscion nebulosus*, and black drum, *Pogonias cromis*, in Louisiana. Environ. Biol. Fish. **36**: 257-272.
- Smith HM. 1905. The drumming of the drum-fishes (Sciaenidae). Science **22**: 376-378.
- Sokal RR, FJ Rohlf. 1995. Biometry: the principles and practice of statistics in biological research. New York: WH Freeman, 850 pp.
- Tavolga WN. 1964. Sonic characteristics and mechanisms in marine fishes. In WN Tavolga, ed. Marine bio-acoustics. New York: Pergamon Press, pp. 195-211.
- Tellechea SJ, C Martínez, ML Fine, W Norbis. 2010. Sound production in whitemouth croaker (*Micropogonias furnieri*-Sciaenidae) and relationship between fish size and disturbance call parameters. Environ. Biol. Fish. **89**: 163-172.
- Tellechea JS, W Norbis, D Olsson, ML Fine. 2011. Calls of the black drum (*Pogonias cromis*: Sciaenidae): geographical differences in sound production between northern and southern hemisphere populations. J. Exp. Zool. **1**: 48-55.
- Tower RW. 1908. The production of sound in the drumfishes, the sea-robin and the toadfish. Ann. NY Acad. Sci. **18**: 149-180.
- Vieira PC, M Haimovici. 1993. Idade e crescimento da pescada - olhuda *Cynoscion guatucupa*, sin. *C. striatus* (Pisces, Sciaenidae) no sul do Brasil. Atlântica **15**: 73-91.
- Vieira PC, M Haimovici. 1997. Reprodução da pescada-olhuda *Cynoscion guatucupa*, sin. *C. striatus* (Sciaenidae, Teleostei) no sul do Brasil. Atlântica **19**: 133-144.
- Villwock L, M Haimovici. 2007. Changes in the population structure, growth and mortality of striped weakfish *Cynoscion guatucupa* (Sciaenidae, Teleostei) of southern Brazil between 1976 and 2002. Hydrobiologia **589**: 69-78.
- Vizziano D. 2002. Reproductive cycle of the whitemouth croaker, *Micropogonias furnieri* in the frontal zone of the Río de la Plata. In D Vizziano, P Puig, C Mesones, G Nagy, eds. The Río de la Plata. Research to manage the environment, fish resources and the fishery in the saline front. Montevideo: ECOPLATA, UNESCO, pp. 103-111.
- Wainwright PC, RC Barton. 1995. Scaling in the feeding mechanism of the largemouth bass (*Micropterus salmoides*): motor pattern. J. Exp. Biol. **198**: 1161-1171.
- Walters S, S Lowerre-Barbieri, J Bickfoed, D Mann. 2009. Using a passive acoustic survey to identify spotted seatrout spawning sites and associated habitat in Tampa Bay, Florida. Trans. Am. Fish. Soc. **138**: 88-98.
- Winn HE. 1964. The biological significance of fish sounds. In WN Tavolga, ed. Marine bio-acoustics, Vol. 1. New York: Pergamon Press, pp. 213-231.