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Comparing Observed and Theoretical Acoustic Range of the *Sciaena umbra* Calls in a Marine Protected Area

Marta Picciulin, Carola Chicco, Antonio Codarin, Carlo Franzosini, Chiara Soriani, Saul Ciriaco, Maurizio Spoto, and Tomaso Gaggero

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M. Picciulin (✉) · C. Franzosini · C. Soriani · S. Ciriaco · M. Spoto
WWF Miramare Marine Protected Area, Trieste, Italy
e-mail: marta.picciulin@gmail.com; carlo.franzosini@shoreline.it; chiaras@ampmiramare.it; saul.ciriaco@shoreline.it; direzione@ampmiramare.it

C. Chicco
Department of Environment, Land and Infrastructure Engineering, Politecnico di Torino, Torino, Italy
e-mail: carola.chicco@polito.it

A. Codarin
ARPA FVG – Regional Environmental Protection Agency of Friuli-Venezia Giulia, Palmanova, Udine, Italy
e-mail: antonio.codarin@arpa.fvg.it

T. Gaggero
Department of Telecommunications, Electrical and Electronics Engineering and Naval Architecture, University of Genoa, Genova, Italy
e-mail: tomaso.gaggero@unige.it

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Abstract

This study investigates the acoustic propagation of reproductive calls produced by the brown meagre (*Sciaena umbra*) within the Miramare Marine Protected Area (Gulf of Trieste, Italy). Sound pressure levels recorded along three radial transects extending from the center of vocal activity were compared with predictions from transmission loss modeling. The presence of chorusing was assessed through manual inspection of audio recordings and spectrograms. Although the shallow coastal environment imposes strong constraints on sound transmission, choruses were detectable at distances of up to 400 m under low anthropogenic sound conditions. This detection range, together with the spatial distribution of calling activity, suggests the presence of multiple aggregations and supports the hypothesis of lek-like reproductive behavior. Because chorusing is a reliable proxy for spawning in this Vulnerable species, these findings underscore the ecological importance of the Miramare MPA in facilitating successful reproduction and sustaining long-term population viability.

Keywords

Brown meagre · Reproductive behavior · Fish

Introduction

Acoustic communication is a widespread phenomenon among fish species, serving diverse ecological and behavioral functions, particularly in contexts such as territorial defense and reproductive interactions (Amorim 2006). However, the aquatic environment imposes significant constraints on sound propagation, acting as an acoustic filter that shapes both the structure and the efficacy of communication signals. In shallow coastal habitats, many teleost fishes produce low-frequency sounds that are subject to strong attenuation due to environmental factors such as substrate composition, water depth, and surface interference (Bass and Clarke 2003). These factors collectively limit the effective communication range. Yet, empirical estimations of transmission distances remain scarce and are largely confined to a few species studied under shallow-water conditions (e.g., Ramos et al. 2012). Advancing the understanding of acoustic communication in fishes requires in situ studies that quantify transmission loss in naturally noise-limited environments. Integrating such empirical data with acoustic propagation modeling will further refine the understanding of the ecological relevance of fish sounds and inform conservation strategies in increasingly noisy coastal ecosystems (Lindseth and Lobel 2018). This is particularly relevant for marine protected areas (MPAs) that harbor vulnerable, vocal species such as the brown meagre (*Sciaena umbra*).

In *Sciaena umbra,* sound production is restricted to males, which emit calls composed of 5–6 pulses with dominant frequencies ranging from 240 to 330 Hz (Parmentier et al. 2018). These calls occur in both irregular or regular rhythmic patterns and may merge into sustained choruses (Picciulin et al. 2012). Passive

acoustic monitoring (PAM) has proven to be an effective method for tracking *S. umbra* distribution due to the high temporal and spatial consistency of their vocalizations during the reproductive period (Parmentier et al. 2018). Although courtship calling occurs both within and outside MPAs, chorusing is rare (recorded at only 11 out of 271 monitored sites by Di Iorio et al. 2020) and predominantly takes place within fully protected or long-established no-take zones. This pattern is particularly of interest, as *S. umbra* choruses are recognized as reliable natural indicators of spawning activity (Picciulin et al. 2020). The species is very sensitive to management measures, with even small MPAs providing measurable conservation benefits. Consistent with acoustic evidence, numerical abundance, individual size, and biomass all increase with the degree of protection, whereas outside most protected areas, the brown meagre remains rare (Harmelin-Vivien et al. 2015; Di Iorio et al. 2020). Moreover, *S. umbra* exhibits strong site-fidelity, with home range typically less than 1.0 km^2 (Marques et al. 2024).

Chorusing by *Sciaena umbra* is a defining feature of the soundscape of the World Wildlife Fund Miramare Marine Protected Area, a United Nations Educational, Scientific and Cultural Organization (UNESCO) Man and Biosphere Reserve located in the Gulf of Trieste, Northern Adriatic Sea (Italy). Within this reserve, brown meagres are commonly observed in small groups from the sea surface to the base of the artificial rocky reef, at depths of 6–8 m, seeking refuge in crevices when disturbed. The objectives of this study were to (i) quantify the in situ transmission loss of the *S. umbra* choruses in this very shallow coastal environment, based on their measured source levels, and (ii) assess the effective spatial distribution of the sounds within the Marine Protected Area.

Materials and Methods

Within the Miramare Reserve (Trieste, Italy), *Sciaena umbra* choruses were recorded in close proximity to the coastline near artificial rocky reefs at a depth of 9 m (monitoring point number 0; Fig. 1). Transmission loss was calculated for the sound peak frequencies corresponding to the 200, 250, and 300 Hz one-third octave bands, hereafter TOB, along three transects radiating from this point (see below). Transmission losses were obtained using the RAM model (Collins 1993), a range-dependent parabolic equation code that accounts for local bathymetry, sediment type (sand), and sound speed derived from CTD measurements. Two assumptions regarding the distribution of the chorusing aggregation were based on local ad hoc visual observations: (i) individuals contributing significantly to the chorusing sound levels were concentrated within approximately 5 m of monitoring point 0 (see text below) and (ii) the aggregation was vertically distributed at about 4 m depth.

Acoustic Data Collection

Recordings were conducted on the nights of August 8, 13, and 21, 2024, coinciding with the seasonal peak of *S. umbra* calling activity, which typically occurs between

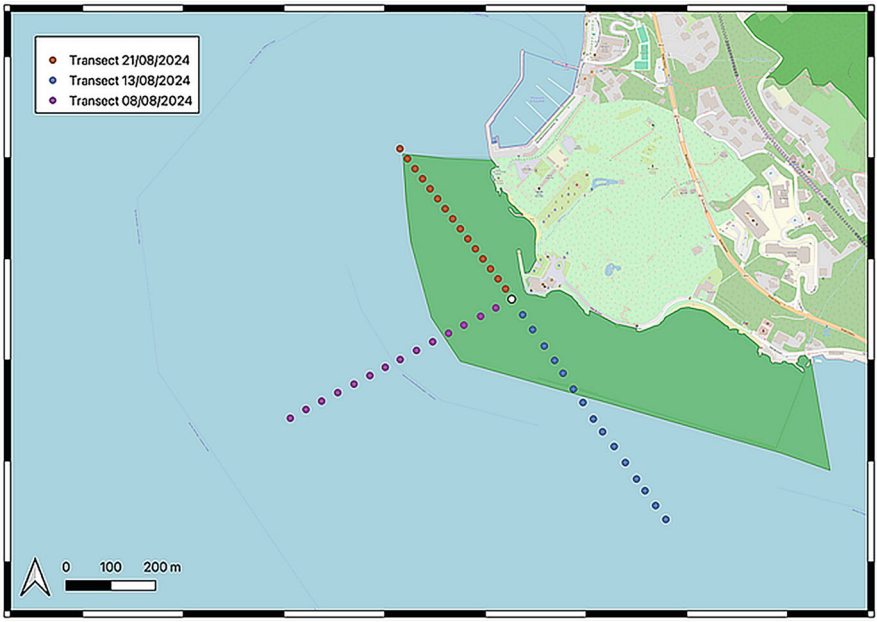

Fig. 1 Recording locations along three transects in the core and buffer zone of the Natural Marine Reserve of Miramare (Trieste, Italy)

20:00 and 24:00 hours during summer (Parmentier et al. 2018). Surveys were performed under comparable sea-state conditions (Douglas scale < 1) to minimize variation in shallow-water ambient noise caused by wind. During the study period, water temperature ranged from approximately 24 °C near the surface (0 to 7–8 m) to 21 °C at the bottom (Arpa FVG 2024).

Acoustic recordings were collected along three transects extending seaward from the nearshore point (Fig. 1) where a resident group of *S. umbra* had been visually confirmed by MPA staff (Ciriaco, pers. com.). Each transect consisted of 15 recording stations, spaced approximately 40 m apart. A GPS unit onboard the recording vessel logged position and time every second to ensure precise spatial referencing during post-processing. At each listening station, a 3-minute WAV file was recorded (16-bit resolution, 44.1 kHz sampling rate).

Recording Setup

Recordings were made using an omnidirectional, preamplified ResonTC 4032 hydrophone (sensitivity −170 dB re 1 V/µPa, frequency range 1 Hz–170 kHz) connected to a ZoomH1 Handy recorder (sampling rate 48 kHz, 16-bit, battery-powered). The hydrophone was calibrated prior to deployment using a pistonphone (GRAS 42AA Pistonphone, Class 1) using a sound source operating at 250 Hz.

Recordings were obtained from an 8-meter long Trimaran Pontoon Boat equipped with two outboard Torqueedo electric engines. During sampling, the boat drifted with the engines turned off and power disconnected to minimize platform noise. The hydrophone was suspended at mid-water depth using a float and rope system to avoid contact with the hull and reduce mechanical vibrations or flow noise.

Acoustic Analysis

Sound pressure levels (hereafter "SPLs") were analyzed using VSLM (Virtual Sound Level Meter) software (MATLAB-based; Hanning window, 75% FFT overlap, fast averaging). The frequency spectrum was computed using Fast Fourier Transform over one-third octave bands from 50 to 16,000 Hz for each recording station (i.e., transect point).

In addition, files were analyzed with Raven Pro 64 (version 1.4) developed by the Bioacoustic Research Program at the Cornell Lab of Ornithology. Sound files down-sampled to 4 kHz and analyzed using a Hanning window (FFT size 256 points, 50% overlap). Each recording was evaluated both through audio and visual assessments, and assigned a chorus quality score from 0 to 3: a score 3 indicated a very good signal/noise ratio and a score 1 a poor condition (as examples see panel a and c, Fig. 2, respectively). Acoustic recordings with a score from 1 to 3 included a recognizable *S. umbra* chorus. A score of 0 indicated that it was not possible to identify the sound from the background noise. Files contaminated by boat noise, even if faint or distant, were excluded from both SPL and spectral analyses.

Results

The *Sciaena umbra* chorusing level, measured over a wideband frequency range (50 Hz–20 kHz), reached maximum values of 118–120 dB re 1 μPa at Point 0 (white dot in Fig. 1). At the dominant frequency bands, 200, 250, and 315 Hz one-third octave bands (TOBs), the maximum source levels were 104–107 dB re 1 μPa, whereas in absence of chorusing, background noise levels were 89–90 dB re 1 μPa within the same frequency range.

Figure 3 shows the modeled transmission loss (dB) for the three TOBs (200, 250, and 315 Hz) calculated along the measurement transects. As expected for shallow-water conditions, transmission loss was strongly influenced by seabed interactions, with propagation patterns showing a pronounced dependence on bathymetry. This dependency is particularly evident when comparing the August 8th transect, which extends offshore over a gradually deepening sea floor, to the other two transects that exhibit a series of convergent zones. It should be emphasized that these results are based on simulations of a single-frequency point source in a coherent acoustic environment.

Based on this analysis, significant attenuation of the chorusing signal is expected to occur between Point 0 and Point 1 along each transect. Figure 4 illustrates the

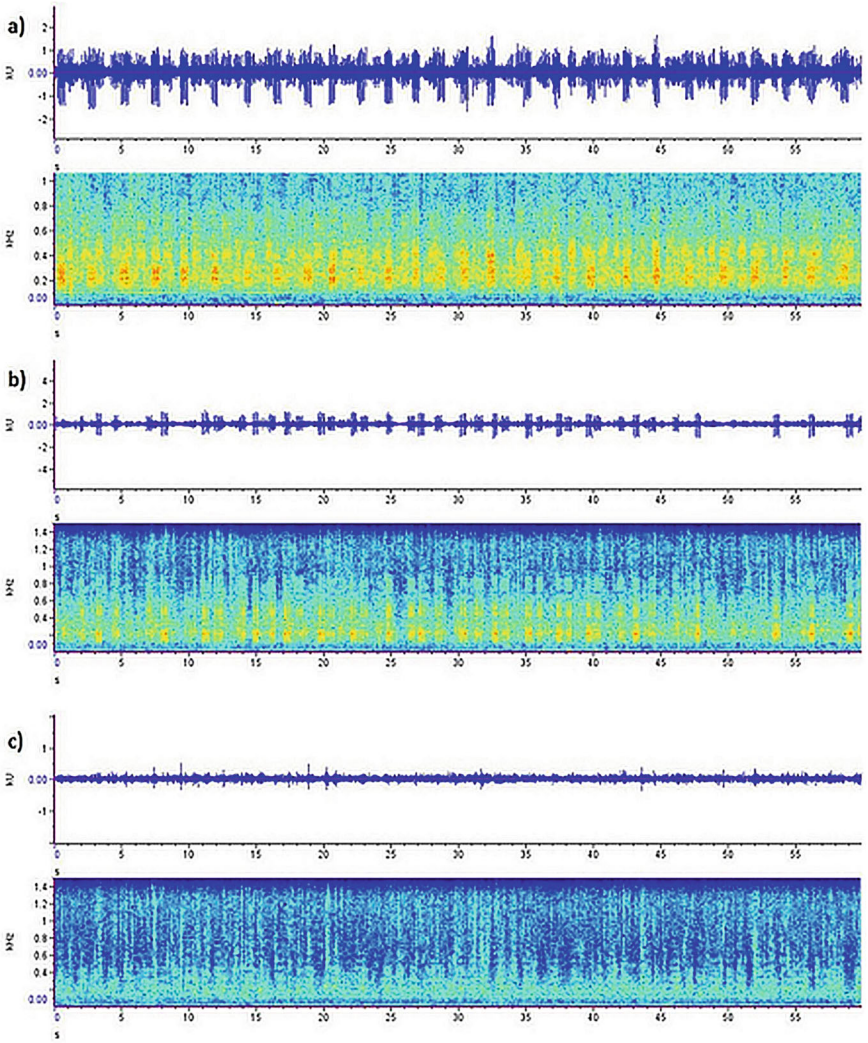

Fig. 2 Spectrogram of *Sciaena umbra* sounds as recorded in the Miramare MPA scored as 3 (**a**), 2 (**b**), and 1 (**c**), corresponding to a poor signal to noise ratio condition (Hanning window, FFT size 256)

measured received sound pressure levels recorded at the same three peak frequencies along the three transects. The results reveal a generally linear decrease in SPLs from Point 0 towards the distal ends of the transects, with a notable increase in sound levels around Point 7 on the August 13th transect.

Visual inspection of the sonogram confirmed the presence of *S. umbra* chorusing in the recorded files (Fig. 5). Chorusing sounds were detectable from the first monitoring point up to 400 m along transect 1, 360 m along transect 3, and about

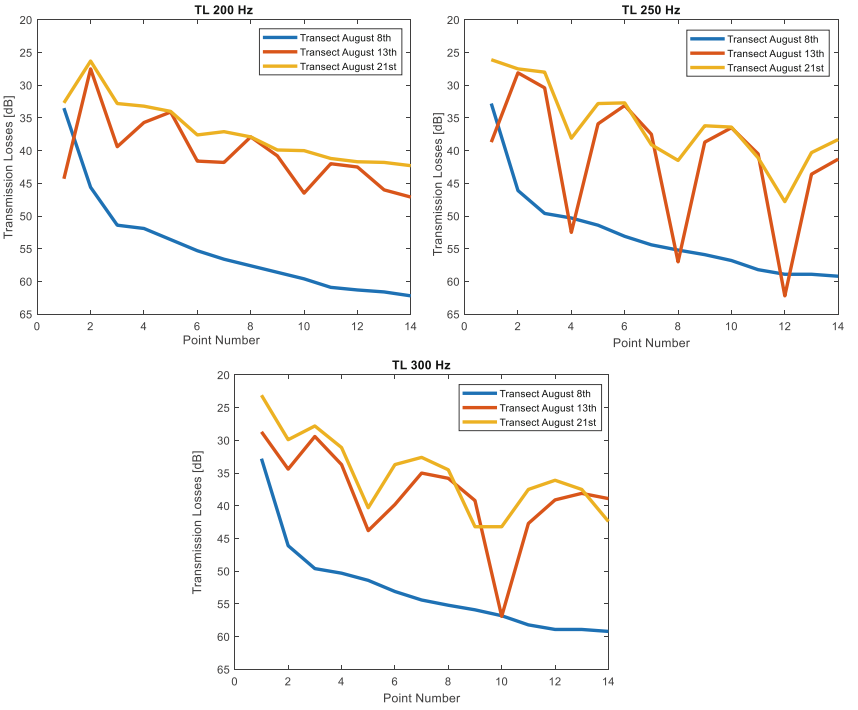

Fig. 3 Computed transmission losses (200, 250, and 315 Hz one-third octave bands) for each transect

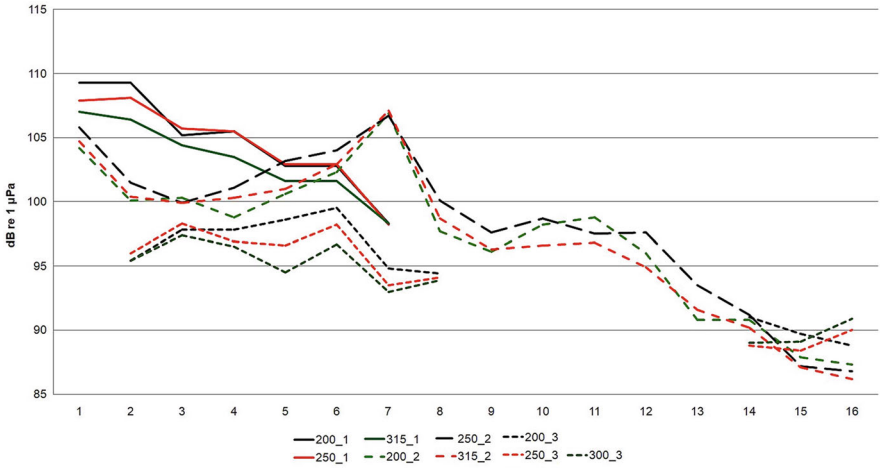

Fig. 4 Sound pressure levels in the 200, 250, and 315 Hz one-third octave bands as measured along the different recording points of the three transects run 8th August (transect 1), August 13th (transect 2), and August 18th (transect 3). Missing points in transects curves correspond to audio files contaminated by boat noise, which were excluded from analysis

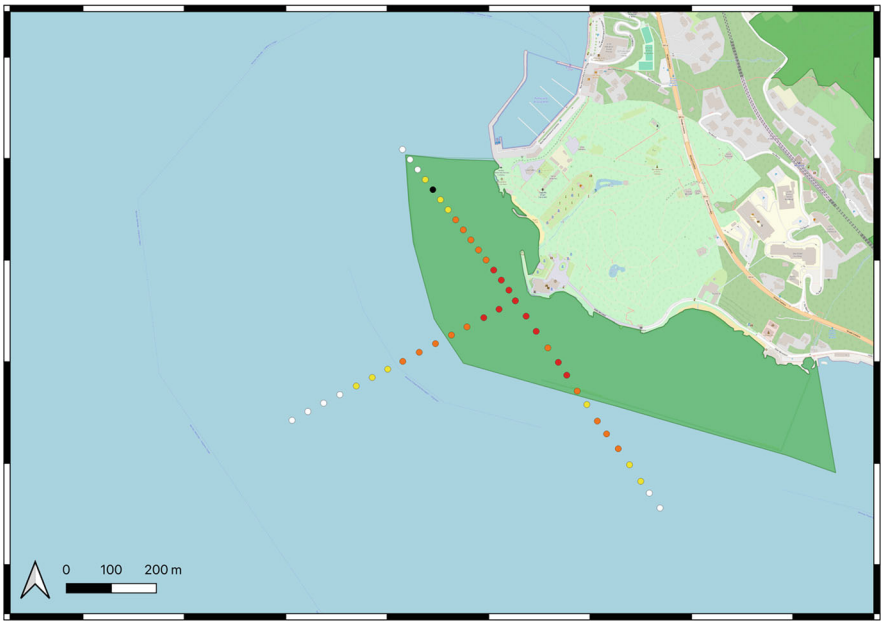

Fig. 5 Spatial distribution of the detection of the *Sciaena umbra* chorus along three transects inside and outside the core zone of the Miramare MPA. Red dots indicate a score of 3, orange dots a score of 2, and yellow dots a score of 1 for the signal to noise ratio of sounds. No sound detection is visualized by white dots

600 m along transect 2. The latter transect also exhibited a secondary bout of chorusing at monitoring stations 7–8, consistent with the SPL patterns shown in Fig. 4. This indicates that recognizable chorusing activity extended up to roughly 320 m from the nearest peak of sonic activity along transect 2.

Discussion

The sound pressure level (SPL) of *S. umbra* chorusing recorded at Point 0, located within the core zone of the Miramare Marine Protected Area (MPA), was consistent with previous field measurements conducted in marine environments (wideband SPL: 124 dB re 1 µPa; $n = 121$, Codarin et al. 2009; 126 dB re 1 µPa; $n = 30$, Picciulin et al. 2022). At peak frequencies, chorusing intensity exceeded ambient noise levels by approximately 15–20 dB. However, transmission loss-modeling indicates that this acoustic advantage declines rapidly with distance: SPL values fall below background noise levels as early as Point 1, corresponding to a modeled attenuation of 30–40 dB over the first 40 m, depending on frequency, and local environmental parameters such as bathymetry, substrate composition, and sound-speed profiles during the recording period.

These suggest that individuals located at Point 1 would be unable, or only marginally able, to detect conspecific vocalizations originating from Point 0. This interpretation aligns with known auditory thresholds of *S. umbra* under ambient noise conditions in the Miramare Reserve, which are 94 dB re 1 µPa at 200 Hz and 84 dB re 1 µPa at 300 Hz (Codarin et al. 2009). Overall, the present findings confirm that courtship-related acoustic communication in such shallow coastal waters is constrained to relatively short spatial ranges.

Nonetheless, field measurements demonstrate that, in the absence of anthropogenic sound, *S. umbra* choruses were detectable within and beyond the core area of the reserve. SPL values remained above auditory thresholds up to at least 300 m from Point 0, suggesting a broader distribution of vocalizing individuals across the core zone and possibly extending into the buffer zone. This pattern implies the existence of a multisource chorusing configuration, potentially reflecting additional aggregation centers near Points 2 and 3 (surveyed on August 8th) and Points 7 and 8 (surveyed on August 13th). Such a spatial arrangement may correspond to lekking-like reproductive behavior.

Lekking is a mating strategy in which males congregate in discrete areas, known as leks, to perform competitive acoustic or visual displays and attract females. Although studies on lekking behavior in fish remain limited, several Sciaenid species exhibit characteristics consistent with this strategy (Ramcharitar et al. 2006). Males typically produce loud courtship sounds to attract conspecifics and synchronize spawning, show site fidelity to small areas, and form dense spawning aggregations where acoustic competition enhances mating opportunities. Indeed, chorus intensity has been positively correlated with fish abundance and biomass (Rowell et al. 2017). It has been therefore hypothesized that during the summer vocalization period, *S. umbra* males may extend their spatial distribution to include nearby muddy substrates distant from the artificial rocky reef. This would be consistent with the species' known nocturnal foraging behavior, as it occasionally exploits sandy bottoms despite generally preferring rocky habitats (Chater et al. 2012).

Understanding the reproductive behavior of *S. umbra* is crucial for the effective management of Marine Protected Areas (MPAs), given its conservation status and ecological significance. *S. umbra* is currently listed as a Vulnerable species by the International Union for Conservation of Nature (IUCN 2019), and detailed knowledge of its spawning habitat distribution is essential to inform targeted conservation strategies. Based on the present findings, the entire core zone of the Miramare Natural Marine Reserve likely functions as reproductive hotspot for the brown meagre. Furthermore, in the absence of anthropogenic sound, acoustic emissions generated within this area may promote the aggregation of individuals from adjacent buffer areas, enhancing reproductive success and population. These results underscore the importance of preserving natural acoustic environments within MPAs to sustain reproductive behaviors and to support the long-term conservation of *S. umbra* populations.

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Competing Interest Declaration The author(s) has no competing interests to declare that are relevant to the content of this manuscript.

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