The end of silent predators: First cases of active sound production in batoids from the Mediterranean Sea and its potential implications

Álvaro Almagro*[1] and Claudio Barría[2, 3].

*Corresponding autor

aalmrod@upv.edu.es

[1]Polytechnic University of Valencia, Valencia, Spain.

[2]Catsharks, Association for the study and conservation of elasmobranchs and its ecosystems, Institut de Ciències del Mar - CSIC, Barcelona, Spain.

[3]Unitat de Zoologia, Universitat Autònoma de Barcelona, Barcelona, Spain.

Abstract

The production of sound in terrestrial animals has been extensively studied, yet documentation of sound production in fish remains comparatively limited. Furthermore, certain groups such as elasmobranchs have traditionally been regarded as silent predators. This study presents two cases of active sound production in batoids, marking the first documented records in the Mediterranean Sea. Between November and December of 2023, multiple encounters with batoids were observed in the important shark and ray area of Marina Alta, Spain. Four distinct species were documented, with active sound production, in the form of clicks, recorded in two species: the rough skate, *Raja radula*, and the marbled electric ray, *Torpedo marmorata*. These clicks were produced while opening and closing their mouths, accompanied by the movement of their pectoral fins, both cases presumably associated with an agonistic display of defense against the divers, perceived as a threat. The clicks were produced when the threat was close, and as it moved away from the divers, the frequency of the clicks decreased until they ceased.

Keywords Active sound production · Communication · Batoidea · Agonistic display · Mediterranean Sea · Elasmobranch

Introduction

Sound production by animals has been extensively studied, including in prehistoric fossils (Everett 2021). These sounds can be associated with reproductive processes, such as those emitted by male north Atlantic right whales, *Eubalaena glacialis*, to attract females (Parks et al. 2005), or for defense purposes, such as clicking produced by the caterpillar's pincers (Bura et al. 2012). Despite the broad scope of this field, sound production in marine fishes is not as well-documented compared to terrestrial animals.

Sound production in fishes is vital to an array of behaviours, including territorial defense, reproduction, and competitive feeding (Looby et al. 2022). Fishes display a variety of mechanisms for producing sounds, including muscular vibration of the swim bladder (Tower 1908; Fine and Parmentier 2014), expulsion of gas from the swim bladder (Wilson et al. 2004), muscular vibration of the peritoneum (Takemura et al. 1978), and stridulation by rubbing hard parts of the body such as incisor teeth, pharyngeal teeth or fin spines (Burkenroad 1931; Fish and Mowbray 1970; Tavolga 1971).

Approximately 990 species of fishes produce sounds (Looby et al. 2022). Of the 27 species belonging to the class Elasmobranchii, 13 of them produced sound passively (Looby et al. 2022). For a long time, elasmobranchs have been considered as 'silent predators' since their role as sound producers was not well-known. Many of the sounds they produce are linked to feeding actions, such as shell cracking (Ajemian et al. 2021). Although Bass and Rice (2010) described that some stingrays produce defensive sounds by grinding their teeth as a warning or defense mechanism, they did not provide references, and this statement still remains to be proven.

To date, from the 665 species of batoids (Ebert and Dando 2020), only three species of active sound-producing batoids have been documented, all belonging to the Myliobatiformes order. One case occurred in captivity, where a cownose ray (*Rhinoptera bonasus,* family Myliobatidae) produced short, sharp clicks under stressand forceful prodding (Fish and Mowbray 1970). In the wild, only two species that actively produce sounds have been described: the mangrove whipray (*Urogymnus granulatus*) and the cowtail stingray (*Pastinachus ater*) both from the family Dasyatidae (Fetterplace et al. 2022). Their study describes three videos in which these species generate short clicks associated with the spiracle and the cranial area, when the observer approached to the rays. These clicks had an average duration of 0.033 seconds, with a peak frequency of 1,500 Hz and the mean bandwidth across all clicks was 22,983 Hz approximately. Two more examples of 'active' sound production have been documented, one of 'crunching' while chewing and another of 'murmuring' after feeding in *Dasyatis pastinaca*. Additionally other type of sound described as “rumbles” was observed when a picked dogfish, *Squalus acanthias,* grabbed food in captivity (Shishkova 1958). Both sounds were associated with feeding processes and the active generation of these sounds is not fully described, thus, these cases can be considered dubious.

Elasmobranchs, unlike bony fish, do not have accessory auditory organs, and the labyrinths are located in the inner ear. Each labyrinth includes three membranous semicircular canals and four sensory maculae in each (Myrberg 2001; Maisey 2001). Elasmobranchs are more sensitive to low-frequency sounds between 100 Hz and 1500 Hz, with the greatest sensitivity between 400 and 600 Hz, but only a few species have been studied (Myrberg 2001; Casper 2006). Although elasmobranchs can hear, hearing capacity is not necessarily linked to the ability to produce acoustic sounds (Mélotte et al. 2018). The emission and reception of sounds in elasmobranchs are part of communication mechanisms, both intra- and interspecific, especially in the case of rays, and is probably bidirectional, as occurs in other species (Ladich and Popper 2004; Gardiner et al. 2012).

Although there are some studies, the mechanism and purpose behind ray sound production remain largely unknown to date. Among documented cases occurring in natural environments, active sound production has only been consistently observed within the family Dasyatidae (Myliobatiformes). This study aims to document sound production within the orders Rajiformes and Torpediniformes, and confirm that the production of sounds and communication can be transversal phenomenon in batoids.

Material and methods

During November and December of 2023, recreational divers were conducted between 0 and 13 meters depth in Marina Alta ISRA and surrounding areas (Fig. 1). This zone is identified as Important Shark and Ray Areas (ISRA) which are marine areas recognized by the International Union for Conservation of Nature (IUCN) as critical for the conservation of various species of sharks and rays; and they are distinguished by their significance for the reproduction, feeding, migration, or other vital aspects of the life cycle of these animals (Jabado et al. 2023). In 6 of the dives batoids were observed, specifically 4 different species (Table 1). In Table 2, encounters with the species that produced sound are described in greater detail.

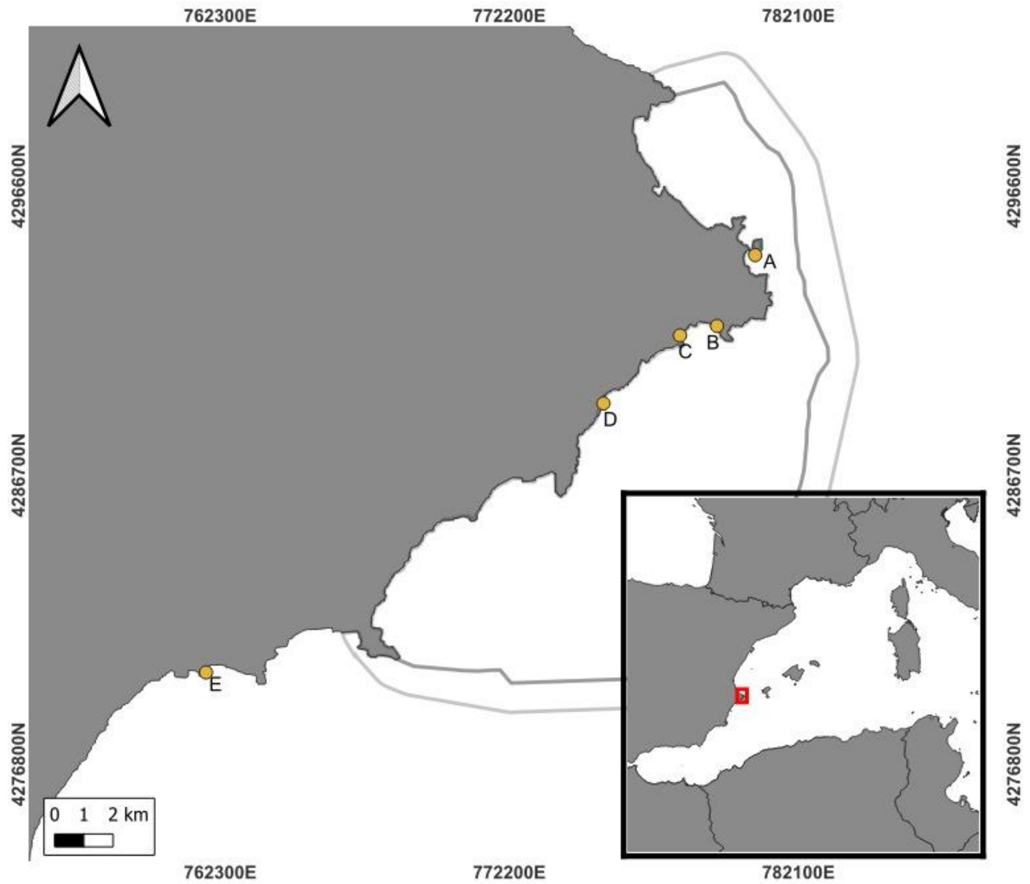

Fig. 1 Observation location (A) Cala Portixol, (B) Cala en Calo, (C) Cala Granadella, (D) Cala Moraig, (E) Mascarat. The gray line marks the boundary of ISRA Marina Alta

Table 1. Species observed at ISRA Marina Alta during November and December of 2023. F: Female, M: Male, Indet: Indeterminate, TL: Total length, DW: Disc width

Species	No. of specimens	Length range in cm	Sex rate
Gymnura altavela	16	60-140 DW	9F;7M
Raja radula	4	48-58 TL	2F;2M
Torpedo marmorata	3	45-55 TL	1F;2Indet
Dasyatis pastinaca	2	38-60 DW	1F;1M

The camera used during the dives was a Sony Alpha 7 IV with an IKELITE 200DL housing and an 8-inch dome port. The post-processing of the videos was done using the Audacity version 3.4.2.

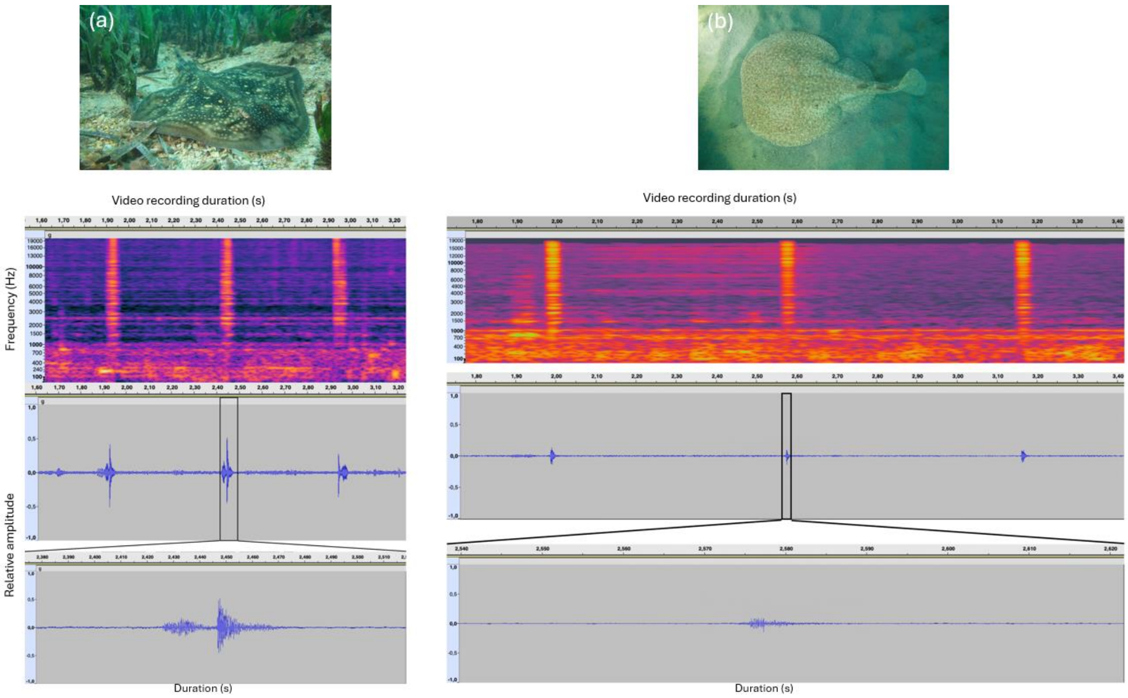

Fig. 2 Records of sound production by stingrays. (a) Adult male specimen of rough skate, *R. radula*, emitting sound, along with its sound profile. (b) Adult female specimen of marbled electric ray, *T. marmorata*, emitting sound, along with its sound profile

Table 2. Description of observation from the species that produced sound. F: Female, M: Male, Indet: Indeterminate, TL: Total length

Date	Species	Size (TL cm)	Sex	Location (N, W)
12/11/2023	*R. radula*	49	F	38.753367;0.228506
15/12/2023	*T. marmorata*	50	Indet	38.727508; 0.198835
16/12/2023	*R. radula**	53	M	38.731297; 0.212904
22/12/2023	*R. radula*	56	M	38.628633; 0.006550
22/12/2023	*R. radula*	58	F	38.629170; 0.007908
22/12/2023	*T. marmorata**	55	F	38.628836; 0.008229
29/12/2023	*T. marmorata*	45	Indet	38.708229; 0.167059

* Individuals that emitted sound in the form of clicks.

Results

In the dives conducted, 25 individuals belonging to 4 species were observed: 16 *G. altavela*, 4 *R. radula*, 3 *T. marmorata*, and 2 *D. pastinaca* (Table 1). Out of the 4 observed species, 2 produced sound: rough skate and marbled electric ray, representing 50% of the observed species (Table 2), and there are cases of both, males and females producing sound (Table 2).

Regarding the rough skate, of the 4 specimens observed, only 1 produced sound, representing 25% of sightings of this species. The individual that produced sound was sighted at Cala en Calo, point B of Fig 1, on December 16th, a 53 cm male. When first found, it remained motionless for 5 minutes on dead leaves of *Posidonia oceanica*, then began swimming slowly above the seabed. It swam for 7 minutes and stopped every 7 or 8 meters, then began to swim about 1.5 meters above the seabed at a higher speed. Just at that moment, one of the divers positioned himself between the ray and the seabed and started taking photographs. After approximately 15 seconds, the ray began to produce sounds in the form of clicks (Online Resource Video 1). At the beginning of the video, the diver recording was about 40 cm from the specimen, and towards the end, he was about 2 meters. Seventeen broadband clicks were recorded, ranging from 0.025 to 0.082 s in duration (mean ± SE = 0.04 ± 0.01) (Fig. 2, Table 3). The mean peak frequency was 3146 Hz (Table 3). The mean minimum frequency was 144 Hz. Mean bandwidth (± SE) across all clicks was 20.026 kHz ± 5.17 kHz (Table 3). At the beginning, the time between clicks was 0.438 second, increasing by 0.024 seconds between each one until the last one, where there is a waiting time of 0.81 seconds between them. Also, in the spectrogram of Fig. 1a, a faint sound is noticeable before the click, lasting about 0.02 seconds. The fourteenth click could not be analysed due to external noise distorting it.

Concerning marbled electric ray specimens, three individuals were observed, of which one produced sound, representing 33% of the encounters (Table 2). The individual that produced sound was sighted at Mascarat, point E of Fig. 1, on December 22 nd, a 55 cm female. The individual was initially buried, but after a couple of minutes of taking photos, it assumed a defensive posture, previously described by Belbenoit (1986) and began to produce clicks. Twenty-eight broadband clicks were recorded, ranging from 0.004 to 0.013 s in duration (mean ± SE = 0.009 ± 0.0029) (Fig. 2, Table 4). The mean peak frequency was 8387 Hz (Table 4). The mean minimum frequency was 505 Hz. Mean bandwidth (± SE) across all clicks was 16.130 kHz ± 4.71 kHz (Table 4). At the beginning, the time between clicks was 0.538 second, until the last one, where there is a waiting time of 0.78 seconds between them. Out of the twenty-eight clicks, clicks 10 and 11, 15 and 16, 19 and 20, 21 and 22, 27 and 28 were double clicks. Clicks 23 and 24 could not be analysed because they were distorted by external noise.

Discussion

The present study demonstrates, for the first time, sound production in Batoids of the orders Rajiformes and Torpediniformes, and documents, for the first time, sound production in elasmobranchs in the Mediterranean Sea. Although the study has been conducted over a short period of time, for the first time, the batoid community of an area is studied, and quantitative data on sound-producing species are obtained. Furthermore, this study sheds light on the broader context of sound production in batoids, building upon previous research findings and exploring novel insights into the mechanisms behind sound generation in elasmobranchs.

A large number of fish generate low-frequency pulses produced at different rates by mechanism related to the swim bladder (Amorim 2006). For example, in the North Atlantic, in stressful situations, the cod, *Gadus morhua*, can produce knocks and grunts (Brawn 1961). In the Grand Bank, courtship sounds have been recorded in haddock, *Melanogrammus aeglefinus*, where only the males produce them to attract females (Templeman and Hodder 1958). Another case would be the cichlids of Lake Malawi, which produce sound to defend their offspring (Myrberg et al. 1965). It is likely that the sounds emitted by the batoids in our study also serve to alert about a threatening situation. Elasmobranchs, lacking a swim bladder, have developed other methods. Bass and Rice (2010) proposed mechanism of sound production using grinding plates. Fetterplace et al. (2022) describes the sound production due to contractions of the spiracles and associated gill openings simultaneously with click sounds. These would be achieved through the rapid expulsion of water or another internal mechanism, indicating that sounds can be produced through rapid contractions in the cranial and gill region. Although the exact mechanism of sound production remains unclear. In the case of the rough skate, having a ventral view of the sound production reveals that the clicks occur in the oral cavity, synchronized with the movement of the pectoral fins. Therefore, the process of cranial cavity contraction described by Fetterplace et al. (2022) would serve to generate a larger contact surface between the upper and lower jaw. Also, in the spectrogram, a sound of lower amplitude preceding the click is observed. This may be produced passively by rapidly filling the oral cavity with water, similar to how people inhale (Werner et al. 2023). In the marbled electric ray video, the coordinated movement of the pectoral fins with the clicks is more noticeable. In this case, some clicks are double. This has been observed in other fish species such as *Priontus carolinus*, which in distressing situations can produce sounds with different durations but the same frequency (Fish et al. 1953; Connaughton 2004). In the case of the marbled electric ray, the double clicks could be due to its defensive posture when producing them. Unlike other species that produce sounds while swimming, this one does statically. By producing them in this posture and contracting both pectoral fins significantly, it could give it the ability to produce these double clicks. The bandwidth of the clicks produced by both individuals coincides with the hearing range of elasmobranchs, 40-1500 Hz (Chapuis and Collin 2022). Although the order Torpediniformes has been studied in captivity for many years (Hughes and Johnston 1978; Smith et al. 2004), the clicks they are capable of producing have never been described or recorded. This could suggest that they only produce these clicks in the wild, such as cod, *Gadus morhua*, which produces a wider repertoire of sounds in the wild (Midling et al. 2002). Out of approximately 660 batoid species worldwide, around 270 belong to the order Rajiformes, making it the most numerous. Within this order, there are 3 endemics in the Mediterranean Sea, one of which is the rough skate (Ebert and Dando 2020). Consequently, it is highly probable that other species of this order have also developed the ability to generate clicks but never have been studied.

The sound production is associated with a reaction to a stimulus, the threatening presence of humans, Fetterplace et al. (2022) also suggests that it is an antagonistic response. This behaviour could be an indicator of stress (Skomal and Bernal 2010; Cooke et al. 2014; Sopinka et al. 2016), and among the reactions, there is a disturbance in their behaviour (Anderson et al. 2011). In the video of the rough skate, it starts producing sounds when a diver is close to its ventral area, decreasing the frequency of clicks as the diver moves away and stopping them when the diver is at a certain distance. Also, the marbled electric ray starts producing clicks when it feels threatened, accompanied by a defensive posture. In addition to the stress involved in emitting the clicks, it is also accompanied by a high energy cost to produce them and the potential hormonal reactions that induce (Ladich and Popper 2004; Skomal and Bernal 2010). As observed in numerous studies, divers have a significant impact, especially on sessile or slow-moving species (Hawkins et al. 1999; Barker et al. 2011; Blumstein et al. 2017). Therefore, it is important to create a code of conduct for diving with rays, with a particular emphasis on the distance between the diver and the animal (Giglio et al. 2019; Murray et al. 2020). This is especially crucial for the the rough skate, as it is an endangered species (Mancusi et al. 2016). Additionally, being an endemic species of the Mediterranean Sea, it faces a higher risk of extinction (Manes et al. 2021). For that reason, conservation actions such as the protection of their habitats are of vital importance (Jefferson et al. 2021; Hannah and Midgley 2023). It is highly probable that anthropogenic noise is disrupting communication among sound-producing species, so integrating batoids as particularly sensitive animals in environmental impact studies is crucial.

The present study describes the active sound production of two batoid species out of the 35 found in the Mediterranean Sea (Ebert and Dando 2020), which represents nearly 6% of the species capable of doing so. In the area where the sightings took place, these records account for 50% of the observed species. We describe the production of active sounds in response to a potential threat in two phylogenetically different groups, Torpediniformes and Rajiformes, in addition to those previously described by Fatterplace et al. (2022) in Myliobatiformes. Therefore, we propose that the production of communication sounds may be a common characteristic in batoids. Investigating and disseminating these studies on communication in elasmobranchs can be crucial for changing the negative perception held towards these species in public opinion (Giovos et al. 2021; Papageorgiou et al. 2022). By uncovering the acoustic potential of elasmobranchs, specifically batoids, this study pioneers a new avenue of inquiry into their sensory ecology, advocating for a broader recognition of their communicative capacities.

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Data availability Videographic data can be found at this link […..]

Declarations

Conflict of interests Authors declare that they have no competing interests.

Ethics approval All encounters with batoids described in the paper have been sporadic, respectful, and without contact with the animal.

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