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Use of passive acoustic monitoring to fill knowledge gaps of fish global conservation status

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Abstract

1. Knowledge of the ecology, spatial distribution and conservation status of fish populations is achieved by fishery-dependent techniques, and by more recently developed non-invasive fishery-independent techniques. Passive acoustic monitoring (PAM) is a fishery-independent method that provides remote sensing of soniferous species, populations, communities and ecosystems by recording soundscapes and their components.
2. A case study is presented to demonstrate how PAM can contribute to a dynamic understanding of fish distribution, ecological preferences and conservation status. This case study refers to the cusk-eel *Ophidion rochei* (Ophidiiformes), a nocturnal, behaviourally cryptic, soniferous fish species, described as uncommon and rare in the scientific literature, and listed as Data Deficient in the IUCN Red List.
3. A systematized literature review was carried out using *Ophidion*+*rochei* as the search term, and by grouping records into two main categories: (i) traditional techniques (including all fishery-dependent techniques and underwater visual census); and (ii) PAM.
4. This review highlights how PAM has provided new sightings of *O. rochei* at a rate three times higher than all other monitoring techniques combined. In contrast with the knowledge achieved to date by fishery-dependent techniques, the reported acoustic mass phenomena indicate that this species can be very abundant. *Ophidion rochei* was found to inhabit a wide range of depths and ecosystems, at least throughout the Mediterranean basin.
5. This paper supports the urgency and the importance of relying on the integration of different fishery-independent techniques for multidisciplinary monitoring, in line with the Goal 14 requirements of the UN Decade of Ocean Science for Sustainable Development.

KEYWORDS

bioacoustics, cusk-eel, ecoacoustics, Ophidiidae, remote sensing, species distribution

1 | INTRODUCTION

Human activities are pushing biodiversity into a new extinction crisis, and it is therefore essential to improve knowledge of species distribution and conservation status (Newson et al., 2016; Conde et al., 2019; Sugai & Llusia, 2019). Knowledge of fish populations' ecology and spatial distribution can be achieved by traditional fishery-dependent techniques, as well as by more recently introduced fishery-independent techniques, for example, underwater visual census (UVC), passive acoustic monitoring (PAM) and environmental DNA (eDNA) (Murphy & Jenkins, 2010; Lacoursière-Roussel et al., 2016; Picciulin et al., 2019).

Passive acoustic monitoring provides remote sensing of soniferous species, populations, communities and ecosystems by recording soundscapes and their components (Rountree et al., 2006; Mooney et al., 2020; Ross et al., 2023). In the past few years, there has been growing interest in the use of environmental sounds to investigate ecological and community complexity (Farina & James, 2016; Desiderà et al., 2019; Di Iorio et al., 2021; Bolgan et al., 2022; Ross et al., 2023). Sounds emitted by animals for communication purposes can be used as proxies that inform on the diversity of species, their distribution and the phenology of biological events. Such sounds can also be used to assess habitat quality and the health of soniferous species stocks (Rountree et al., 2006; Lindseth & Lobel, 2018). At sea, the use of PAM can enhance the resolution of soniferous fish population monitoring and therefore provide essential information for conservation programmes (Picciulin et al., 2019).

A case study is presented to show how PAM can contribute to rapid change in the level of knowledge on fish distribution, ecological preferences and conservation status. This case study refers to the cusk-eel *Ophidion rochei* (Ophidiiformes), a nocturnal and behaviourally cryptic fish species. This species is described as both uncommon (i.e. present in few locations) and rare (i.e. present with low abundances) (Pallaoro & Jardas, 1996; Kovacic, 1998; Nielsen et al., 1999; Maximov & Zaharia, 2010), possibly explaining its 'Data Deficient' status in the IUCN Red List (IUCN, 2022).

Traditionally, this species has been surveyed using invasive techniques such as trapping, fishing and analysis of fishery discards (e.g. Pallaoro & Jardas, 1996; Kovacic, 1998; Tsagarakis et al., 2008; Maximov & Zaharia, 2010). *Ophidion rochei* is difficult to detect by UVC and can only be detected at night (Menut et al., 2018) owing to its nocturnal preferences. This sand-dwelling fish, however, can be easily detected through PAM. *Ophidion rochei* produce conspicuous courtship calls characterized by their long duration (typically 3.5–4.5 s) and unique temporal pattern. Each call can be divided into two parts, the first of which consists of a train of pulses that increases in amplitude and decreases in rate, and the second of which shows a characteristic alternation pattern of pulse period duration (Parmentier et al., 2010; Kéver et al., 2014; Kéver, Boyle & Parmentier, 2015; Kéver et al., 2016). This unique temporal pattern within the sound (Figure 1a,b) is due to complex morphological adaptations leading to a specific sonic mechanism (Parmentier et al., 2010). Interestingly, this specific sonic mechanism is markedly different from that of the co-generic *Ophidion barbatum* (Parmentier et al., 2006; Parmentier et al., 2010). This difference contrasts with these species being at risk of misclassification owing to their similar external morphology and practically identical appearance (Facciolà, 1933; Casadevall et al., 1996). Unfortunately, *O. barbatum* sounds have not been recorded yet; however, the close relationship between sonic morphology and sound characteristics strongly suggests that Ophidiidae sounds are species specific. This would allow for discrimination between closely related species, as demonstrated in other fish taxa (e.g. Serrasalmidae, Pomacentridae, Sciaenidae; Monczak et al., 2017; Monczak et al., 2019; Raick et al., 2020; Picciulin et al., 2021; Parmentier & Lecchini, 2022). In particular, the temporal succession of pulses within *O. rochei*'s sounds constitutes a species-specific, easily measurable and reliable acoustic tag of this species' presence at sea (Figure 1).

Published and unpublished data on *O. rochei*'s presence and distribution were analysed to: (i) evaluate the relevance of PAM for improving knowledge of fish populations at sea; and (ii) provide the most up-to-date and comprehensive description of this species' distribution and ecological preferences.

2 | MATERIAL AND METHODS

To assess the known distribution of *O. rochei*, Fishbase (Froese & Pauly, 2021) was consulted on 22 October 2021, using '*Ophidion +rochei*' as the search term. Results listed under countries (10 records, https://www.fishbase.se/country/CountryList.php?ID=25961&GenusName=Ophidion&SpeciesName=rochei) were used to create an initial occurrence map. To supplement this dataset, a systematized review was carried out by screening three research databases (Scopus, Web of Science and Google Scholar). On 22 October 2021, the Google Scholar, Scopus and Web of Sciences (WoS) databases were surveyed using '*Ophidion + rochei*' as the search term. A total of 846 papers were rendered from Google Scholar, 19 from WoS and 16 from Scopus. All Scopus and WoS references were duplicates of the Google Scholar database. Each of the 846 papers was inspected manually. Only manuscripts providing detections of *O. rochei* (or its larvae/eggs) were retained. The exclusion criteria included mismatches (e.g. papers mentioning *Auxis rochei*, *Ophidian amino L-oxidasi*, etc.) and papers for which an English translation could not be found. Four additional references were included, mentioned in the reference lists of the rendered papers that were inspected. Eighty-one references were finally retained and 769 were excluded. Except from the first description of this species (Müller, 1845), all references rendered by this systematized review referred to the last 62 years (from 1960 to date). Although two cases of morphological description of *O. rochei* were published earlier (Emery, 1880; Facciolà, 1933), these were not included in the final list because the location of fish collection could not be retrieved.

The final number of retained records was 94 (10 from Fishbase, 81 from the literature review and three studies that were published

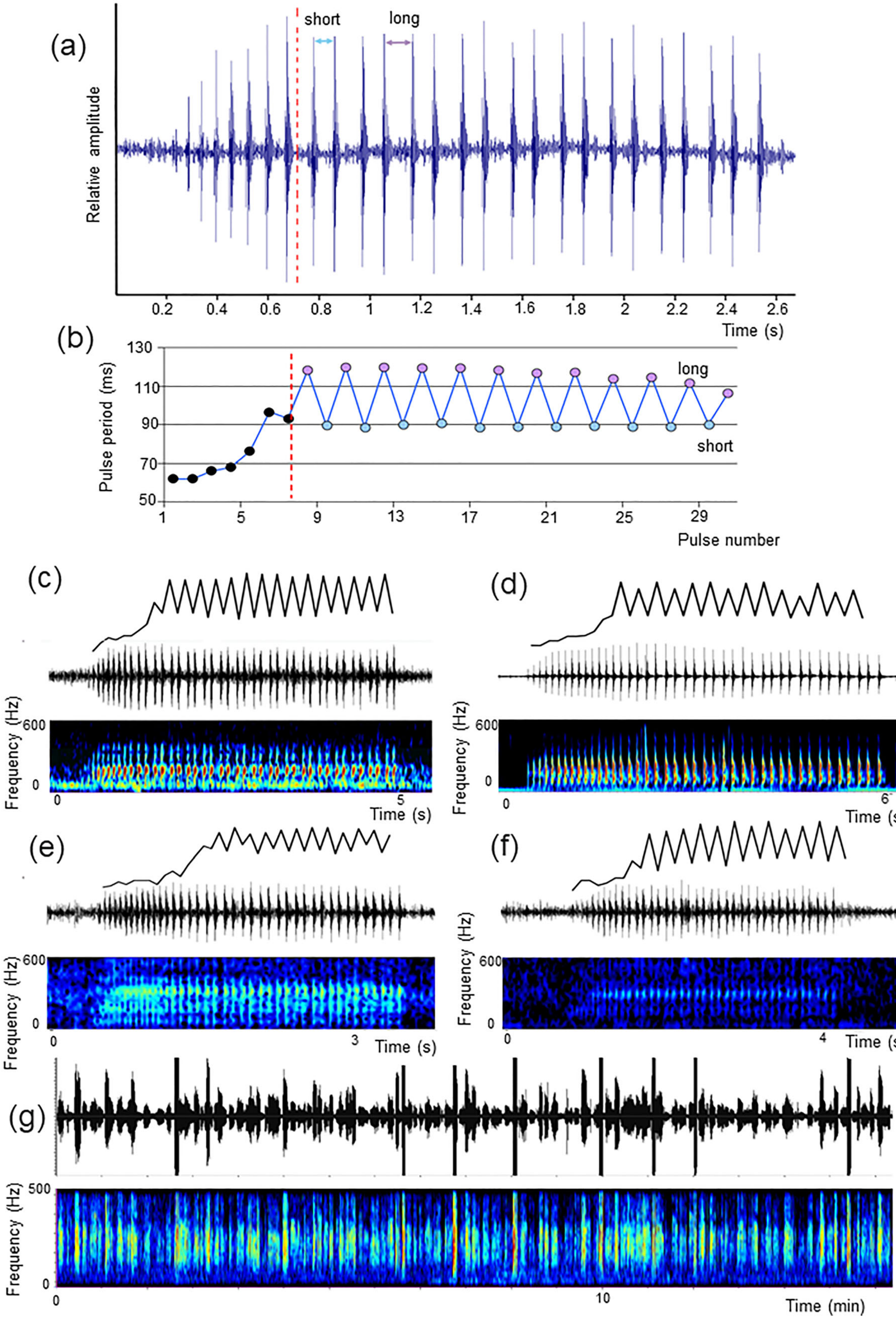

FIGURE 1 Legend on next page.

FIGURE 1 Oscillogram of an *Ophidion rochei* call (a). Graph of the periods of successive pulses within a given call. Right of the red dotted line, the call shows alternation between short and long pulse periods (b). Sounds recorded in different environments, with different hydrophones and in different moments, that is: (c) Picciulin et al. (2019); (d) Parmentier et al. (2010); (e) Bolgan et al. (2022); and (f) Bolgan et al. (2022). Despite obvious differences in signal-to-noise ratio, duration, stereotypicity, etc., all sounds can be clearly assigned to *O. rochei* thanks to pulse period succession and its alternation. (g) A 15 min recording, showing a chorus of *O. rochei* sounds (i.e. each block visible in both waveform and spectrogram is one *O. rochei* sound); this type of acoustic emission can only be sustained by many individuals.

and included during writing). These were manually inspected to compile a matrix (see Table S1) composed of the following variables (whenever available): (i) methods (two categories, i.e. 'traditional' and 'acoustic'); (ii) country and location of sightings; (iii) year of sightings; (iv) depth; (v) geographical coordinates; and (vi) habitat.

'Traditional' methods include all those studies in which *O. rochei* specimens (or its eggs or body parts, e.g. swimbladders, otoliths) were located or collected using techniques such as trapping, experimental fishing, fisheries catches, fisheries discards, fish collections by scuba divers and UVC.

'Acoustic' methods include studies in which *O. rochei* sounds were recorded at sea by means of PAM. This includes acoustic detections from scientific publications, as well as recordings collected by the authors (unpublished acoustic data, see details below).

Although species-specific eDNA also represents a powerful 'non-traditional' tool to detect cryptobenthic and rare species (Eble et al., 2020; Boulanger et al., 2021; Bianchi et al., 2022), this tool was not included here because no studies reporting the presence of *O. rochei* using eDNA techniques were found.

An initial map was generated using the 10 points extracted from Fishbase and each new sighting (i.e. identification of this species in a geographical location), arising from either the literature review or the unpublished acoustic data, was added to this map. Each sighting was univocally identified with a numerical code corresponding to the reference matrix (see Table S1 and Figure 2). When multiple records (i.e. published references) were found for the same geographical location, only one point was represented on the map, unless they referred to different methods (i.e. 'traditional' and 'acoustic').

Finally, the unpublished acoustic sightings carried out by the authors were added ($N = 5$) to both the matrix and the map. *Ophidion rochei* acoustic sightings reported in this study and referring to unpublished acoustic data (see Table S1) refer to five locations: Venice, Ancona, Cala Gonone, Cinque Terre (Italy) and Lara beach (Cyprus). Unpublished data were not available for 'traditional' methods and have therefore not been included.

In Venice and Ancona (Italy), acoustic files were collected during the project SOUNDSCAPE, funded by the EU Interreg Italy–Croatia CBC Programme 2014–2020 (project ID 10043643). SOUNDSCAPE included a shared network of nine monitoring stations in the North Adriatic Sea dedicated to continuous recording (i.e. 24 × 1 h files) of the underwater soundscape for 15 months (February 2020 to June 2021). At each site, a stationary acoustic recorder (SonoVault SN1106, Develogic, Hamburg, Germany; sampling rate 48 kHz, 16-bit resolution), equipped with a D60 omnidirectional hydrophone (sensitivity −193 dB re 1 V/μPa; flat frequency response 2–20 kHz; Neptune Sonar, Kelk, UK), was anchored to the bottom with a rig design consisting of an anchor, the logger secured by a polypropylene rope and extra flotations. The logger was positioned at ca. 3 m from the sea bed at depths of 17 and 15 m in Venice and Ancona, respectively.

At Lara beach (Cyprus), acoustic files were collected for a total of 11 days (3–13 August 2021). At this site two stationary acoustic recorders (SNAP, Loggerhead Instruments, Sarasota, FL, USA; sampling rate 44 kHz, 16-bit resolution), equipped with a wideband HTI–96 min omnidirectional hydrophone (sensitivity −170 dB re 1 V/μPa; flat frequency response 2–30 kHz; High Tech Inc., Long Beach, MS, USA), were positioned on the bottom (by snorkelling) at a depth of 10–12 m.

At Cala Gonone (Italy), acoustic files were collected almost year-round as part of the SEACOSUTIC programme (2015–2019) co-funded by the Water Agency Rhône Méditerranée Corse and the Chorus Institute. A stationary acoustic recorder (Song-Meter SM3M Wildlife Acoustics, Maynard, MA, USA; sampling rate 96 kHz, 16-bit resolution), equipped with a wideband HTI–92–WB omnidirectional hydrophone (sensitivity −164.5 dB re 1 V/μPa; flat frequency response 2–50 kHz; High Inc., Long Beach, MS, USA) was anchored to the sea bed at a depth of 15 m.

In the Cinque Terre National Park (Italy), acoustic files were collected during the summers of 2020 and 2021 as part of the Marine Protected Area monitoring programme of the Cinque Terre National Park. Two stationary acoustic recorders (SYLENCE LP440, RTSYS, Caudan, France; sampling rate 156 kHz, 24-bit resolution), equipped with a wideband GT1516 omnidirectional hydrophone (sensitivity −169 dB re 1 V/μPa; flat frequency response 2–70 kHz; Colmar, La Spezia, Italy) were anchored on the sea bed, at depths of 15 and 23 m, respectively.

Since most fish vocalize and hear in the low (below 2 kHz) frequency band, audio recordings were downsampled to 4 kHz. In all the above-mentioned datasets, *O. rochei* sounds were detected by aural and visual assessment of spectrograms (Hanning window, FFT = 512, 50% overlap) in Raven 1.5 for Windows (Bioacoustic Research Program, Cornell Laboratory of Ornithology, Ithaca, NY, USA) using the specific temporal succession of pulses (Figure 1a,b) as a reliable acoustic tag of its presence.

3 | RESULTS

Eighty-two references were found for traditional monitoring techniques combined over a time span of 63 years, while 12 published references

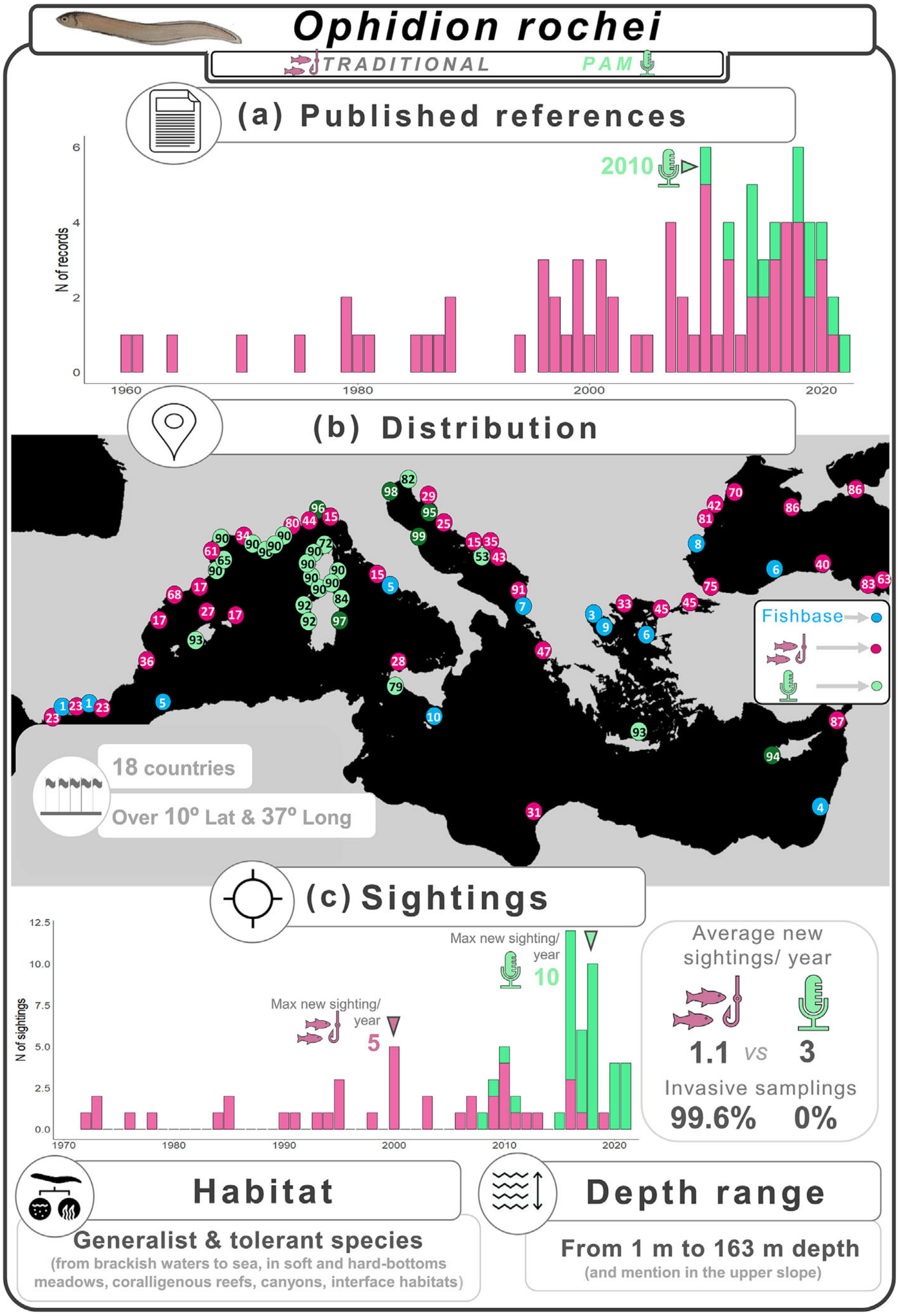

FIGURE 2 Iconography summarizing the main findings (pink = 'traditional' and green = 'acoustics'). (a) Published records: number of manuscripts rendered by the systematized review, stacked histogram; arrow indicates first 'acoustics' publication. (b) Distribution: sightings of *Ophidion rochei*. When multiple records were found for the same geographical location, only one point was represented on the map, unless they referred to different methods ('traditional', 'acoustics' and Fishbase = light blue). The two shades of green of the 'acoustics' data points refer to published (light green) and unpublished (dark green) data. (c) Sightings: new sightings (i.e. first identification (in a specific location) of *O. rochei*, stacked histogram). Arrows indicate the maximum number of sightings per year for both 'traditional' and 'acoustics'. Average new sightings per year, minimum and maximum depth range and habitat types.

referred to PAM over a time span of 13 years (Table S1; Figure 2a). The first description of this species' sound was published in 2010 (Parmentier et al., 2010). Since PAM identification of *O. rochei* relies on this sound characterization, this method of detection has been available for only approximately the last decade. In this short period of time, PAM has provided new sightings (i.e. first identification of this species in a geographical location) at a rate three times higher than that for all other monitoring techniques combined ('traditional' = 1.1 new sightings per year; 'acoustic' = 3 new sightings per year; Figure 2c).

The maximum number of new sightings per year was 10 for PAM and five for traditional monitoring techniques (Figure 2c). Of these, 100% of PAM sightings were non-invasive, while 99.6% of traditional sightings were invasive (i.e. only one UVC study; Figure 2c). One study in particular recorded *O. rochei* sounds in 21 new locations (Di Iorio et al., 2021; Table S1) and acoustic mass phenomena (i.e. a chorus of many individuals emitting sounds in the same location and at the same time; McCauley & Cato, 2016) were generally recorded (e.g. Figure 1g; Di Iorio et al., 2021; Bolgan et al., 2022).

Considering all monitoring techniques combined, it appears that *O. rochei* is distributed throughout the entire Mediterranean basin, the Black Sea and Azov Sea. This species has been detected over 10° latitude and 38° longitude, from 18 countries (Figure 2b). Furthermore, one study mentions its presence outside the

Mediterranean Sea, along the continental slope off Morocco in the East Atlantic (Haedrich & Merrett, 1988).

Ophidion rochei inhabits a great variety of habitats. It has been found in depths ranging from 1 to 193 m (Haedrich & Merrett, 1988; Dulcic, 2001; Bolgan et al., 2020; Figure 2c), and can colonize habitats characterized by different levels of human pressure, salinity and substrates. *Ophidion rochei* is found in highly eutrophicated coastal areas (Letourneur et al., 2001; Di Iorio et al., 2021), river estuaries (Dulcic, 2001; Dulčić et al., 2007), semi-enclosed coastal areas with strong freshwater inputs (Letourneur et al., 2001) and managed (e.g. Marine Protected Areas; Picciulin et al., 2019) and unmanaged areas characterized by soft bottoms (Keskin, 2007; Farré et al., 2015) and hard substrates (Desiderà et al., 2019; La Manna et al., 2021). *Ophidion rochei* has also been found in meadows of *Posidonia oceanica* (Keskin, 2007; Ceraulo et al., 2018; Bolgan et al., 2022), *Cystoseira barbata* and *Ulva rigida* (Dulcic, 2001) and *Cymodocea nodosa* and *Zostera marina* (Keskin, 2007), and in coralligenous reefs (Di Iorio et al., 2021).

4 | DISCUSSION

This study presents the case of *O. rochei*, an endemic Mediterranean fish species classified as Data Deficient in the IUCN Red List and defined as uncommon and rare (Pallaoro & Jardas, 1996; Kovacic, 1998; Maximov & Zaharia, 2010). This species was used to demonstrate how the application of remote sensing techniques, such as PAM, can provide novel information on fish distribution, ecological preferences and relative acoustic abundances which is relevant for management and conservation.

In particular, this study suggests that 'traditional methods' are less efficient than 'acoustic methods' (i.e. PAM) for detecting the presence of *O. rochei* at sea; in fact, in a relatively short period of time (i.e. 13 years), PAM has provided new sightings of this species at a three times higher rate than all other monitoring techniques combined ('traditional methods'). The country distribution map retrieved from Fishbase for *O. rochei* (10 data points) could be supplemented with 89 additional sightings (Figure 2; Table S1). The results indicate that *O. rochei* is more widely distributed than currently reported (i.e. 18 countries in this study vs. 10 countries reported in Fishbase), and that it inhabits a diverse array of environments (e.g. Parmentier et al., 2010; Kéver et al., 2016; Bolgan et al., 2020; Di Iorio et al., 2021; La Manna et al., 2021; Bolgan et al., 2022). Furthermore, acoustic studies show that *O. rochei* sounds are among the most abundant fish sound types recorded in Mediterranean coastal areas, often generating acoustic mass phenomena (Di Iorio et al., 2021; La Manna et al., 2021; Bolgan et al., 2022; Figure 1g). This, in its turn, suggests high abundances of this species in these areas.

Ophidion rochei have been recorded as an either uncommon or rare species (e.g. Pallaoro & Jardas, 1996; Kovacic, 1998; Nielsen et al., 1999); however, the results presented here suggest that it may be a relatively widely distributed, potentially abundant and generalist species. Many factors may explain the discrepancy between these results, ranging from species-specific characteristics, such as external morphology and behaviour, to the monitoring technique used to survey this species.

Ophidion rochei is a sand-dwelling species, meaning that it spends day-time hours buried within the sediment. Furthermore, its external morphology is practically identical to that of the congeneric *O. barbatum*, and these species are often confused if identification is based solely on external morphology (Casadevall et al., 1996). Spatial monitoring of fish presence and distribution is dependent on observational methods capable of providing accurate data (Edgar & Barrett, 1997; Murphy & Jenkins, 2010). The behavioural and phenotypical crypsis of *O. rochei*, in contrast to its conspicuous sound production and species-specific acoustic tag (Figure 1a,b), can explain why this species' distribution and relative abundance have been underestimated using 'traditional' monitoring techniques (Picciulin et al., 2019).

In this study, 'traditional' techniques included fishery-dependent techniques, as well as fishery-independent techniques such as UVC. Common fishery-dependent techniques include trapping and trawling (Murphy & Jenkins, 2010), which provide data on population size and age composition with a relatively reduced sampling effort (Murphy & Jenkins, 2010). Trawling, in particular, is effective for bottom-living species, such as *O. rochei*, and has been used for detecting this species (e.g. Casadevall et al., 1996; Murphy & Jenkins, 2010). However, these fishery-dependent techniques present two main disadvantages. Firstly, they might be unsuitable for phenotypically cryptic species, such as those belonging to the *Ophidion* genus, if identification is carried out solely by external morphological examination (Casadevall et al., 1996). Secondly, and importantly, these techniques are destructive since they can induce severe or fatal damage (Urra et al., 2017). To achieve a sustainable use of marine fisheries resources, the use of these techniques should therefore be limited, and in many Marine Protected Areas their use is not allowed.

Remote sensing techniques have been used for decades to help manage fish populations at a sustainable level (Klemas, 2013). These techniques are non-destructive and include UVC, split-beam echosounders, acoustic cameras, eDNA and PAM (i.e. the 'acoustic' method in this paper). UVC provides data that are useful for biodiversity monitoring in shallow marine habitats; these data range from species distribution to fish abundances and size information (Murphy & Jenkins, 2010). The most suitable UVC technique for surveying cryptic species such as *O. rochei* is the rapid visual technique; however, rapid visual technique surveys are affected by observer experience and training, and might underestimate animal presence (Murphy & Jenkins, 2010). The only report within the 'traditional' method category used in this case study highlighted that UVC can be effective for *O. rochei* only if carried out at night, and its presence is likely to be underestimated (Menut et al., 2018).

Split-beam echosounders permit the, possibly immediate, measurement of the biomass of aggregations of fishes using post-production software onboard a vessel (Murphy & Jenkins, 2010). However, echosounders provide low taxonomic resolution, and their use would not be appropriate for cryptic species such as *O. rochei*.

The same shortcoming of low taxonomic resolution applies to acoustic cameras (Murphy & Jenkins, 2010), which can be used to monitor fish movements and behaviours. Finally, species-specific eDNA represents a powerful tool for detecting cryptobenthic and rare species (Eble et al., 2020; Boulanger et al., 2021; Bianchi et al., 2022). However, to the best of our knowledge, eDNA reports of *O. rochei* are still lacking.

The increasing use of spatial management in marine systems requires that managers and researchers choose the most appropriate observational methods to meet monitoring objectives and to obtain accurate and precise population data on target fish species (Murphy & Jenkins, 2010). This study suggests that PAM is the most appropriate fishery-independent, remote sensing method for monitoring the presence of cryptic, soniferous fish species such as *O. rochei*. The adage 'You can hardly see it, but you can easily hear it' applies well in this context.

It has to be underlined that, in this study, unpublished data were available and have therefore been included only for the 'acoustic' method (i.e. PAM). Although this might have skewed the results, the conclusion regarding PAM's suitability for surveying this species in contrast with 'traditional' methods can still be drawn. A notable example supporting this statement is represented by the case of an Italian Marine Protected Area (Miramare, Trieste, Italy). Rigorous monthly surveys of the local fauna have been carried out in this area for two decades using UVC (e.g. Guidetti et al., 2005; Guidetti et al., 2008; Poloniato et al., 2010); however, *O. rochei* was undetected until the use of PAM (Picciulin et al., 2019). Considering that 'acoustic' methods have only been applied for about a decade (i.e. since the sounds of *O. rochei* were first described; Parmentier et al., 2010), this might explain why the distribution and abundances of this species have been underestimated throughout the Mediterranean basin.

In particular, PAM can provide information on the presence, distribution and relative abundance over different spatial and temporal scales. This can be achieved with a reduced sampling effort at sea (e.g. deployment of autonomous stationary, long-term acoustic recorders; e.g. Bolgan et al., 2022), and taking the high species specificity of *O. rochei*'s conspicuous acoustic tag (Figure 1a,b) into account, with relatively limited analytical effort and observer training. Furthermore, this study shows how PAM has been used to detect the presence of *O. rochei* despite a high variability in PAM configurations (Parmentier et al., 2010; Kéver et al., 2016; Ceraulo et al., 2018; Gervaise et al., 2018; Desiderà et al., 2019; Di Iorio et al., 2021; La Manna et al., 2021; Bolgan et al., 2022). This implies that, as soon as recordings are collected during summer night-time hours, PAM of *O. rochei* is relatively independent of mooring and recording configurations, and these parameters can therefore be adapted to the specific needs of scientists and managers.

Finally, the effectiveness of PAM of *O. rochei* can be further improved by developing automatic recognition methods targeting this species' sounds; rule-based detectors and automated feature extractions are already employed for monitoring soniferous fishes belonging to different families (e.g. Monczak et al., 2019; Caiger et al., 2020; Mooney et al., 2020).

When applied to the monitoring of a single, target fish species such as *O. rochei*, the limitations of PAM include the impossibility of determining the size of individuals and the exact population size. At the current state of knowledge, only relative acoustic abundances (i.e. number of sounds per unit of time) can be compared between sites or within the same site over time (e.g. Di Iorio et al., 2021; La Manna et al., 2021; Bolgan et al., 2022). Furthermore, the efficacy of PAM for the detection and recognition of soniferous fish species might be limited to some periods of the year (i.e. most vocal species produce sounds only or mostly during their reproductive period; Amorim, Vasconcelos & Fonseca, 2015). It has to be stressed, however, that most fish families include soniferous species (Parmentier et al., 2021; Rice et al., 2022); this implies that PAM can potentially target more than one fish species simultaneously and provide presence and relative acoustic abundance information over a wide taxonomic range within the ray-finned fish group.

Seven out of 10 IUCN threatened (i.e. from Vulnerable to Critically Endangered) bony fish species inhabiting the Mediterranean Sea are soniferous and could therefore be monitored remotely using PAM (besides gobies; Picciulin et al., 2021). In this basin, PAM has already been applied to monitor *Epinephelus marginatus* (Endangered; Bertucci et al., 2015; IUCN, 2022), *Mycteroperca rubra* (Least Concearn; Desiderà et al., 2022; IUCN, 2022), *Sciaena umbra* (Near Threatened; Picciulin et al., 2013; Parmentier et al., 2017; Bolgan et al., 2022; IUCN, 2022), *Umbrina cirrosa* (Vulnerable; Picciulin et al., 2021; IUCN, 2022) and *Scorpaena* sp. (Least Concern; Di Iorio et al., 2018; Bolgan et al., 2019; Bolgan et al., 2022; IUCN, 2022). Increasing the number of fish species that could be monitored using PAM depends on the possibility of assigning a sound type recorded in the wild to its emitting species (Rountree et al., 2006; Mouy et al., 2018). This emphasizes the importance of shared sound databases (Looby et al., 2022; Parsons et al., 2022) and the relevance of dedicated studies in captivity and in the field for identifying the emitting species (Gannon & Gannon, 2010; Rountree et al., 2011; Mouy et al., 2018).

Importantly, the deployment of autonomous dataloggers for monitoring a specific fish species (e.g. *O. rochei*) will inevitably provide biological and ecological data for the whole soundscape characterizing an area (e.g. Mooney et al., 2020; Ross et al., 2023). The PAM data are scalable, since they can provide simultaneous information from the species to the ecosystem level (Mooney et al., 2020; Ross et al., 2023). By providing long-term, non-invasive and scalable data over multiple spatial scales, PAM can significantly contribute to the monitoring of populations, biodiversity and ecosystems in both protected and unprotected areas (Mooney et al., 2020; Ross et al., 2023).

In conclusion, this study suggests PAM as the most appropriate fishery-independent, remote sensing method for monitoring the presence of cryptic, soniferous and Data Deficient fish species such as *O. rochei*. Data Deficient species are those for which 'there is inadequate information to make a direct, or indirect, assessment of its risk of extinction based on distribution and/or population status'; the designation of a species as Data Deficient may effectively place those species 'out of sight, out of mind' for some policy-makers

(Parsons, 2016). The distribution map presented in this study (Figure 2b) could and should therefore be used for improving knowledge of this species distribution in both Fishbase and the IUCN Red List of endangered species.

Although this study was focused on a specific species, its conclusions can probably be applied to other fish species and contexts. For example, PAM has allowed the detection of an invasive fish species (i.e. *Cynoscion regalis*) in European waters, whose presence was only recently reported based on anglers' records (Amorim et al., 2023). Increasing the knowledge of fish communicative sounds on the one hand, and including PAM in the monitoring tool-kit of ecologists, scientists and managers on the other, will ultimately contribute to better information on a wider taxonomic spectrum. In this sense, this study supports the importance of relying on a combination of fishery-independent techniques for improving the resolution of marine biodiversity assessments, which are a priority for marine spatial planning and the sustainable development of ocean use (Claudet et al., 2020). This is in line with Goal 14 of the United Nations Decade of Ocean Science for Sustainable Development (2021–2030), which requires innovations in marine technology and the integration of multidisciplinary monitoring systems in order to increase scientific knowledge, and to develop research capacity to conserve and protect biodiversity (Ryabinin et al., 2019; Claudet et al., 2020).

AUTHOR CONTRIBUTIONS

Marta Bolgan, Lucia Di Iorio, Eric Parmentier and Marta Picciulin conceived and designed the study; all authors collected the acoustic data; Marta Bolgan carried out the literature review and wrote the first draft of the manuscript; all authors contributed substantially to revisions.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data that supports the findings of this study are available in the supplementary material of this article.

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SUPPORTING INFORMATION

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