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Artificial Structures as Shark Egg-Laying Substrate in a Previously Fished Mediterranean Demersal No-Take MPA

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ABSTRACT

The location of shark egg nursery areas in the Mediterranean Sea is not well known. Moreover, decades of trawling have depleted flat muddy bottoms of both organic (sessile colonial organisms) and inorganic (rocks) three-dimensional structures in the western Mediterranean Sea. Here, we present observations of 263 egg cases of small-spotted catshark (*Scyliorhinus canicula*) that were found attached to artificial mooring structures located within a demersal no-take MPA at 300- to 400-m depth. The area is located within a previously identified suitable habitat for small-spotted catshark egg nurseries, and where conservation measures, such as a no-take MPAs, have been implemented to recover the heavily-impacted ecosystem. However, the slow growth of habitat-forming sessile organisms combined with previous extraction of rocks and other objects from the seabed is hampering the recovery of these areas and the reproduction of oviparous sharks such as the small-spotted catshark. Our findings reveal that three-dimensional artificial structures with ropes and other attachments placed within suitable egg nursery habitat are effectively used by small-spotted catsharks to complete their reproductive cycle. Passive conservation tools such as no-take MPA may be coupled with active restoration activities such as the deployment of artificial structures in order to improve the conservation and recovery of oviparous elasmobranchs and other marine fauna.

1 | Introduction

Demersal oviparous sharks are known to use habitat-forming benthic organisms to attach their egg cases, such as cold-water octocorals (Etnoyer and Warrenchuk 2007; Henry et al. 2013; Cau et al. 2017) and tubeworms (Treude et al. 2011). The benthic organisms used by oviparous sharks constitute vulnerable marine ecosystems (VMEs) that, when used repeatedly, can be classified as egg nurseries. Egg nurseries are considered essential fish habitats that should be prioritised for their conservation (Heithaus 2007; Flammang et al. 2011). They are essential for oviparous elasmobranchs, as eggs once deposited go through long incubation periods that can last between several months to several years, depending on the species (Hoff 2008).

However, in the western Mediterranean Sea, similarly to many other marine ecosystems worldwide, bottom trawl fisheries have long impacted the seabed by removing habitat-forming marine organisms and damaging VMEs. Future recovery of these areas is a long-lasting process due to the slow growth of these benthic organisms (Althaus et al. 2009). Consequently, demersal oviparous elasmobranchs are affected by both the direct removal of egg cases and their associated egg-laying structures. The scale of bottom trawling impacts at the ecosystem level has

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already been described in the northwestern Mediterranean for shark species such as the small-spotted catshark (*Scyliorhinus canicula*). Here, overfishing is causing small-spotted catsharks to reach maturity at much smaller sizes (L_{50}) (Ramírez-Amaro et al. 2020). Furthermore, the destruction of their egg-laying habitats appears to have caused a shift in their egg-laying behaviour: from laying eggs in sessile organisms (natural substrate) to laying them on marine litter such as ghost nets and single-use plastic (artificial and potentially nonviable substrates) (Figuerola et al. 2024).

In order to revert some of the effects that fishing activities have had in the ecosystem, active and passive restoration efforts of lost and damaged habitats are ongoing in the northwestern Mediterranean Sea (e.g., the implementation of a demersal no-take marine protected area network (Ministerio de Agricultura, Pesca y Alimentación 2020); the reintroduction of bycaught habitat-forming colonial organisms (Grinyó et al. 2021)). Monitoring projects are also ongoing to assess the effectiveness and success of these efforts. In this context, we report findings from two oceanographic monitoring expeditions conducted in 2023 and 2024 within one no-take deep-sea MPA. Specifically, we document the presence of small-spotted catshark egg cases attached to various moorings of an acoustic telemetry array deployed in the area, which was already identified as having suitable egg nursery habitat for the species (López et al. 2025).

2 | Material and Methods

The study area is located in a deep-sea demersal no-take MPA (hereafter no-take MPA) over the continental slope of the northwestern Mediterranean Sea, off the coast of Barcelona, Spain (Figure 1). The no-take MPA encompasses a total surface area

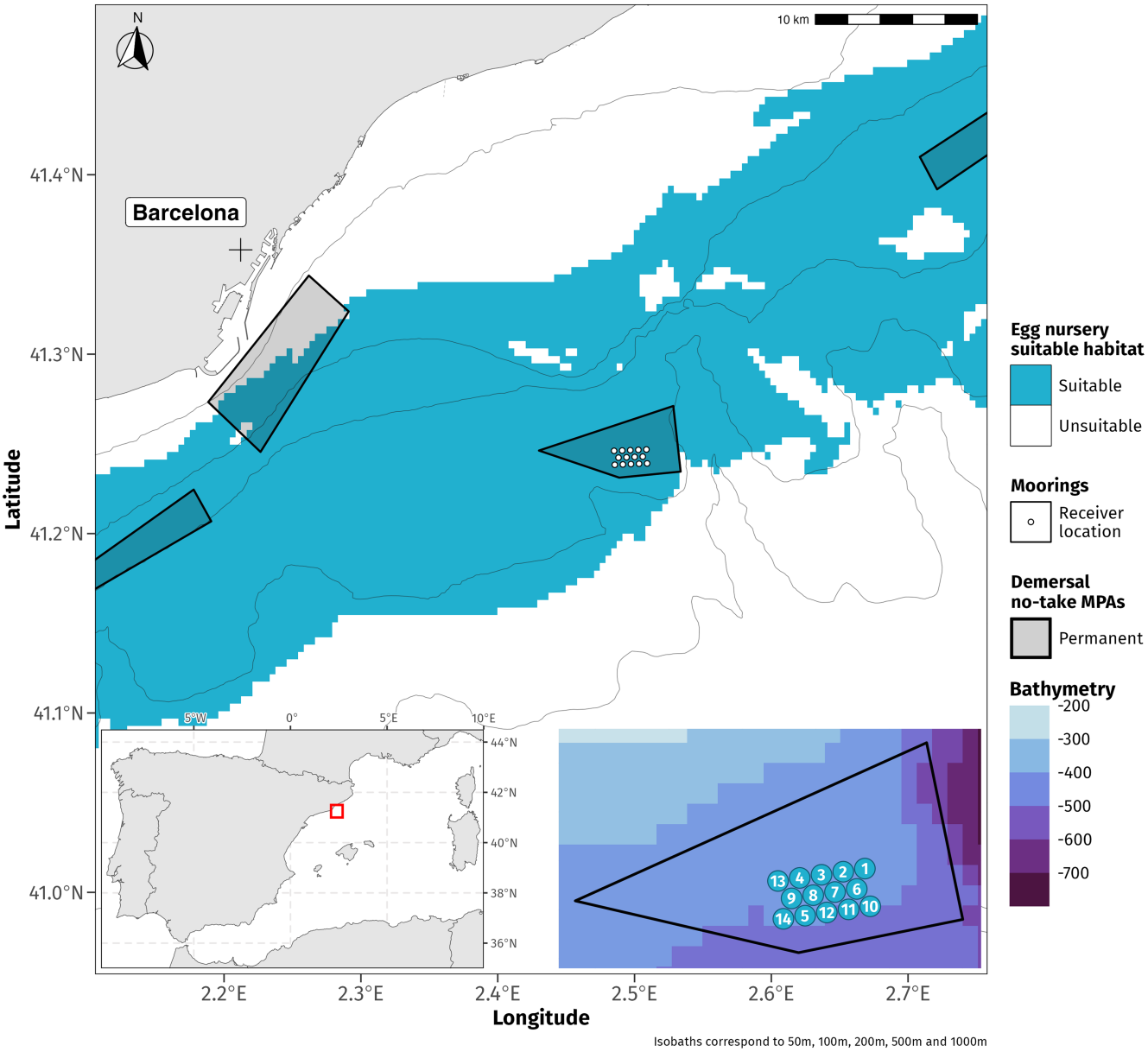


FIGURE 1 | Location of the acoustic telemetry array within a demersal no-take MPA in the western Mediterranean Sea, where small-spotted catshark egg cases were found attached to moorings during the 2023 and 2024 recovery operations. The light blue area shows modelled suitable egg nursery habitat for the species (López et al. 2025). The close up of the no-take MPA shows the receiver IDs and the depth distribution of the area.

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of 22 km^2, with a mean depth of 380 m (range 314–570 m) and is characterised by fine muddy substrates (Supplementary Figure S1). This no-take MPA is part of a network established in 2020 by the Spanish Government in the Mediterranean continental margin of the Iberian Peninsula (Ministerio de Agricultura, Pesca y Alimentación 2020).

In the context of an acoustic tracking experiment, an array of 14 receivers was deployed from June 2023 to December 2024 within the no-take MPA boundaries. The receivers covered an area of 4.5 km^2 and were positioned in a three-row rectangular formation. Each acoustic receiver was attached to a mooring (Figure 2C) and suspended 20 m above the seafloor. The moorings had a negative buoyancy to avoid drifting and consisted of a metallic H-shaped dead weight, a 20 m line (where the acoustic receiver was attached) and two floating buoys to keep the line and the acoustic receiver suspended in the water column. Moorings were first retrieved and redeployed in December 2023, with a second retrieval in December 2024. The maneuver was carried out with the assistance of a remotely operated vehicle (Tomahawk ROV 'Liropus 2000') equipped with GPS systems, which allowed for a precise positioning of the moorings within the no-take MPA. The collection of egg cases was essentially opportunistic, as use of the moorings by elasmobranchs was unexpected. Egg cases could only be collected after the research vessel operatives had finished the recovery operation of each mooring. Because of the depth at which the egg cases were laid and the time spent at surface before collection, releasing the egg cases back in a way that ensured their development was deemed unfeasible. After each retrieval, the whole mooring was inspected and all biological material was collected, with egg cases being preserved on-board at −20°C. Egg cases were identified as small-spotted catshark (*S. canicula*) due to their characteristic morphology and the known presence of adults within the area. In the vicinity of the study area, the only other species with similar eggs (not including species of the genus *Galeus*, as their egg cases do not present tendrils) is the nursehound (*Scyliorhinus stellaris*). Aside from their different depth distribution, small-spotted catshark egg cases are both smaller and paler in colour (Mancusi et al. 2021), which allowed for a straightforward morphological identification to the species level.

3 | Results and Discussion

We found 263 egg cases of small-spotted catshark (*S. canicula*) attached to the 14 moorings recovered (80 egg cases in 2023 and 183 in 2024; Figure 3). During the 2024 recovery operation, a single mooring (ID4) was found to have 101 egg cases attached (Figures 2E and 3). Regarding mooring ID8, 12 egg cases were collected on board, and at least 12 other egg cases were observed in the video recorded during the operation but were left behind as the operators had to cut the rope to recover the receiver. Spatially, egg case distribution within the array

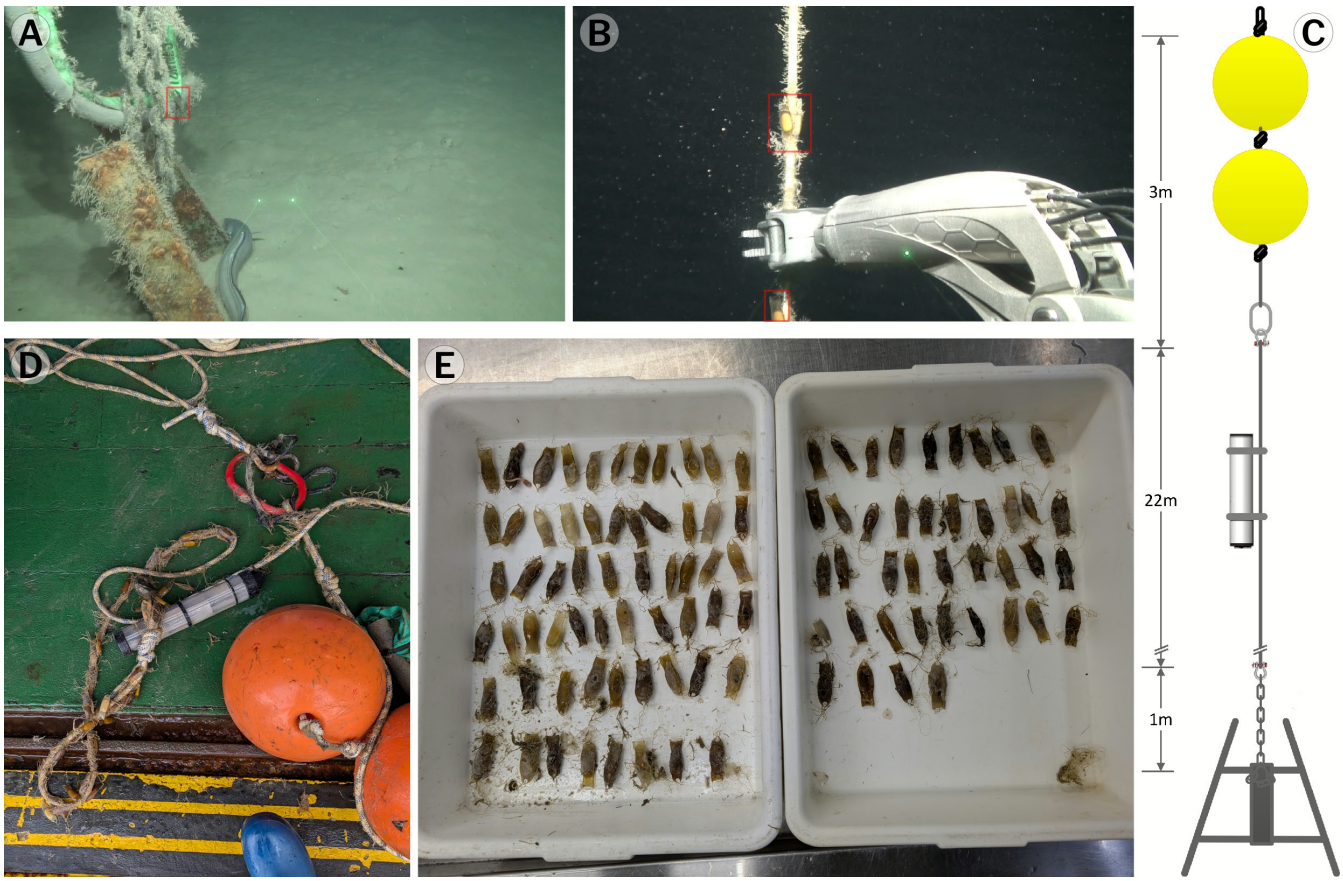


FIGURE 2 | Recovery operation of the deployed moorings. Small-spotted catshark egg cases attached to different parts of the artificial structure (A, B, D); (C) schematics of the mooring; and (E) the 101 egg cases found attached to mooring ID4 from 2024. Panel C figure was made by the Oceanographic Engineering Service (ICM-CSIC).

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FIGURE 3 | Abundance of egg cases found and collected from each mooring (HIDRO 1–14) during the recovery operations of the years 2023 and 2024. Moorings n°05 and n°09 were not recovered.

was more densely located in the shallower receivers. Collected egg cases were present with and without embryos (Figure 2E) at varying developmental stages. Incubation times for small-spotted catshark eggs vary with temperature, but it is generally considered to last up to 6 months (Ballard et al. 1993; Ellis and Shackley 1997). This suggests that several broods were developing simultaneously at the time of collection and that at least some of the egg cases were laid shortly after initial deployment of the moorings (from June to December 2023). Egg cases were also attached at different parts of the mooring structure and up to a height of 21–22 m from the seafloor (Figure 2A,B,D).

The seabed of the study area (within the no-take MPA) and its surroundings are entirely composed of either mud or muddy bottoms (Figure 2A, Supplementary Figure S1). Rocks and other inorganic materials in the seabed provide structural complexity and allow for a much more diverse community of habitat-forming sessile organisms in areas where, because of

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the soft muddy bottoms, it would not be possible otherwise (Bo et al. 2012). However, muddy seabed in the area is highly homogeneous because of the smoothing effect of decades of bottom trawling, as a result of the nets ploughing over it (Puig et al. 2012), with the lack of heterogeneity being mostly related to the removal of both organic and inorganic structures. Because of this, small-spotted catsharks appear to have limited substrate availability to lay eggs and establish egg nurseries within the area. This is important when considering that the species has a relatively wide suitable egg nursery habitat of approximately 10,500 km^2 in the Balearic Sea basin (northwestern Mediterranean Sea), of which only around 382 km^2 is currently under strict protection within no-take MPAs (López et al. 2025). Even if suitable environmental conditions exist in the Balearic Sea, the loss of natural egg-laying structures potentially disrupts small-spotted catshark and other oviparous shark species from successfully closing their reproductive cycle. Our observations of egg cases here agree with previous modelling results in the area and confirm that the no-take MPA is providing protection for this essential fish habitat. Furthermore, our findings show that once the suitable habitat is supplied with the necessary substrate to attach egg cases, in this case artificial moorings, small-spotted catsharks appear to make quick use of these structures and establish lasting egg-nursery locations.

After the implementation of conservation measures and the ceasing of bottom-trawl fishing, habitat-forming sessile organisms need decades to recover (Althaus et al. 2009). However, the recovery rates of oviparous elasmobranchs, even if also slow, could be faster when facilitated by having suitable substrates where egg cases could be deposited within no-take MPAs. Designed for bentho-demersal sharks such as small-spotted catshark and others with similar reproductive behaviours (e.g., the nursehound *Scyliorhinus stellaris*, a vulnerable scyliorhinid (Finucci et al. 2021)), these structures could be placed throughout existing no-take MPA networks temporarily and removed in due time when the benthic ecosystem recovers from bottom trawling impacts. Thus, offering valuable transitional tools towards improving elasmobranch conservation in these degraded areas now closed to fisheries, in line with current international nature restoration targets.

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Ethics Statement

The surveys and sampling that led to this work were conducted under both national (Spanish Government) and regional (Catalan Government) permits.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the current study are disclosed in the manuscript itself. They are also available on request.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Seabed type within and around the study area and no-take MPA boundaries. Seabed data was obtained from the European Marine Observation and Data Network (EMODnet). **Figure S2:** Small-spotted catshark eggs (marked in red boxes) and squid eggs (marked in yellow) attached to the rope of the mooring structures at different heights from the seabed.

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