



Integrating local ecological knowledge and scientific surveys: a pathway to understanding benthic mesophotic ecosystems

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Abstract

Marine ecosystems face increasing anthropogenic pressures, highlighting the need for effective conservation strategies such as Marine Protected Areas (MPAs). Knowledge gaps are particularly evident in mesophotic ecosystems (MEs), which provide vital ecological functions but are difficult to study due to logistical and technological challenges. This study explores the role of Local Ecological Knowledge (LEK) as a complementary tool to Remote Operated Vehicle (ROV) surveys for characterising MEs in Northern Portugal. We conducted 59 interviews with fishers to gather information on species distribution, depth ranges, habitat associations, and conservation views. Simultaneously, 187 ROV dives recorded species presence and habitat features. Fishers reported a high diversity of species, including several Vulnerable Marine Ecosystem (VME) indicators, some absent from ROV observations, thus expanding biodiversity records for the region. Comparisons revealed both overlaps and discrepancies, emphasising the complementarity of LEK and ROV methods. Fishers broadly recognised the ecological importance of corals and sponges and showed support for conservation measures, although opinions varied among different fishing groups. Our findings demonstrate that combining LEK with scientific surveys improves biodiversity assessments, helps identify key conservation areas, and fosters collaborative efforts to protect mesophotic ecosystems amidst increasing human impacts.

Keywords Biodiversity Conservation · Local Ecological Knowledge · Mesophotic Ecosystems · Northern Portugal · Remote Operated Vehicles · Vulnerable Marine Ecosystems

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Introduction

Marine ecosystems currently face unprecedented threats from increased exploitation and a growing range of human pressures, including habitat destruction (Halpern et al. 2015), overfishing (Sumaila and Tai 2020), pollution (Paul et al. 2024), and climate change (IPCC 2022). These combined factors have significantly impacted marine biodiversity and ecosystem functions (Halpern et al. 2015; IPCC 2022). In response, global conservation efforts have intensified, with establishing marine protected areas (MPAs) becoming a key strategy to mitigate these impacts and ensure the long-term sustainability of marine communities (Gill et al. 2024; Hollitzer et al. 2023; Zucconi et al. 2024). MPAs aim to safeguard essential habitats and vulnerable species, thereby boosting ecosystem productivity by alleviating pressures on marine environments (Hopf et al. 2024; Relano and Pauly 2023). Nonetheless, effective designation of these protected zones depends on robust ecological data for their design and implementation, along with stakeholder involvement (Giakoumi et al. 2024; Rubidge et al. 2024). Despite efforts to expand MPA coverage, a considerable knowledge gap persists regarding many marine communities, especially those in deeper or less accessible zones, such as mesophotic ecosystems (MEs) (Soares et al. 2020).

Mesophotic ecosystems, which range from roughly 30 to 150 m and are situated at the boundary between shallow and deeper benthic habitats (the “upper Twilight Zone”; Hinderstein et al. 2010), support a diverse array of both unique and shared species. They may act as refuges for taxa affected in shallower waters, potentially offering partial protection from climate change and fishing pressures (Beran et al. 2025; McWhorter et al. 2024). Moreover, they include ecosystems classified as Vulnerable Marine Ecosystems (VMEs) (UNGA 2006), which are essential for habitat formation and overall ecosystem productivity (Kahng et al. 2014). These ecosystems are particularly vulnerable to human impacts (Palummo et al. 2023), often consisting of cold-water coral reefs, sponge grounds, and sea pen fields that provide physical structures, serving as refuge, nursery, feeding, and settlement zones for various marine species (Baillon et al. 2012; Bell 2008; Folkers and Rombouts 2020). Additionally, they make significant contributions to the blue carbon budget as carbon sinks (Coppari 2019) and support secondary production by supplying biomass for human consumption (CoralFISH 2013).

Despite their significance, mesophotic ecosystems remain poorly studied worldwide, mainly because of the logistical and technological challenges of reaching these depths (Pyle and Copus 2019; Radice et al. 2024). The scant data on species composition, habitat structure, ecological functions, and vulnerability within MEs limits the ability to make well-informed decisions regarding the designation and spatial planning of MPAs in these zones (Pyke and Copus 2019; Rocha et al. 2018). This restriction is especially concerning as human activities, such as fishing, frequently target mesophotic zones, directly endangering their biodiversity.

Local ecological knowledge (LEK) is a valuable yet often underused resource for studying marine ecosystems (Petriki et al. 2024; Reid et al. 2020). LEK comprises the accumulated body of knowledge, practices, and beliefs that local communities develop through long-term interaction with their environment (Berkes et al. 2000). In fisheries, fishers have historically been key observers of the marine environment, often noticing changes in species’ presence, behaviour, and habitat use long before these are formally documented by scientific research (da Silva et al. 2023; Johannes et al. 2000). For vocal marine taxa such

as cetaceans, passive acoustic surveys are commonly employed to detect species presence (Giakoumi et al. 2024). While these methods are effective for identifying vocal species, they provide limited information about concurrent environmental changes or non-acoustic aspects of ecosystem dynamics, such as the characteristics and composition of benthic habitats, including vulnerable marine species (Duporge et al. 2024). Consequently, LEK plays a critical role in addressing knowledge gaps that other survey methods cannot.

In areas where fishing has been a central activity for generations, fishers' observations and experiences can offer valuable insights into species distribution, abundance, and environmental changes that might otherwise be overlooked by more sporadic scientific surveys. Previous studies have demonstrated that LEK has been effectively utilised to identify critical habitats, monitor changes in species distribution, and guide sustainable management practices (Côté et al. 2023; Gomes et al. 2025; Hind 2015; Shephard et al. 2021).

In mesophotic ecosystems, where direct observation is limited, LEK can serve as an essential supplement to scientific surveys, helping identify species or ecological patterns that might otherwise remain unnoticed. In this study, we aim to evaluate the value of LEK as a complementary tool for studying mesophotic ecosystems in a coastal area of Northern Portugal through interviews with local fishers about the presence of mesophotic species, including VME indicators. Furthermore, we seek to understand fishers' perception of the importance of mesophotic species to their activities and how their activities impact them. By combining these perspectives, we will provide a more comprehensive picture of the biodiversity in these ecologically vital yet challenging ecosystems to study.

Materials and methods

Study site and fishery descriptions

The data analysed in this study relate to an area of approximately 1,600 square kilometres, exploited by the fishing communities of Viana do Castelo (41° 41' 16" N, 8° 50' 13" W) and Castelo do Neiva (41° 37' 47" N, 8° 49' 12" W) (Fig. 1).

The fishing fleet operating in this area is divided into (i) the local fleet (fishing vessels with lengths overall (LOA) below 9 m) and (ii) the coastal fleet (fishing vessels with LOA between 9 and 35 m).

The fishing gear types considered in this study were (a) gillnets and similar nets - combined trammel and gillnets, + set (anchored) gillnets+trammel nets; (b) hook and lines - hand and pole lines (hand-operated)+ set longlines+troll lines; (c) pots and traps. In addition to professional fishing, recreational boat fishing is also a significant activity in Viana do Castelo. This activity is restricted to line and hook fishing, and they use the same areas as professional anglers.

Fisheries operating in the study area mainly target finfish, as well as cephalopods and some crustaceans. Sessile and low-mobility benthic invertebrates, including sponges, octocorals, scleractinian corals, black corals, sea pens, and related echinoderms, are not directly targeted and are only encountered incidentally through gear interactions or bycatch.

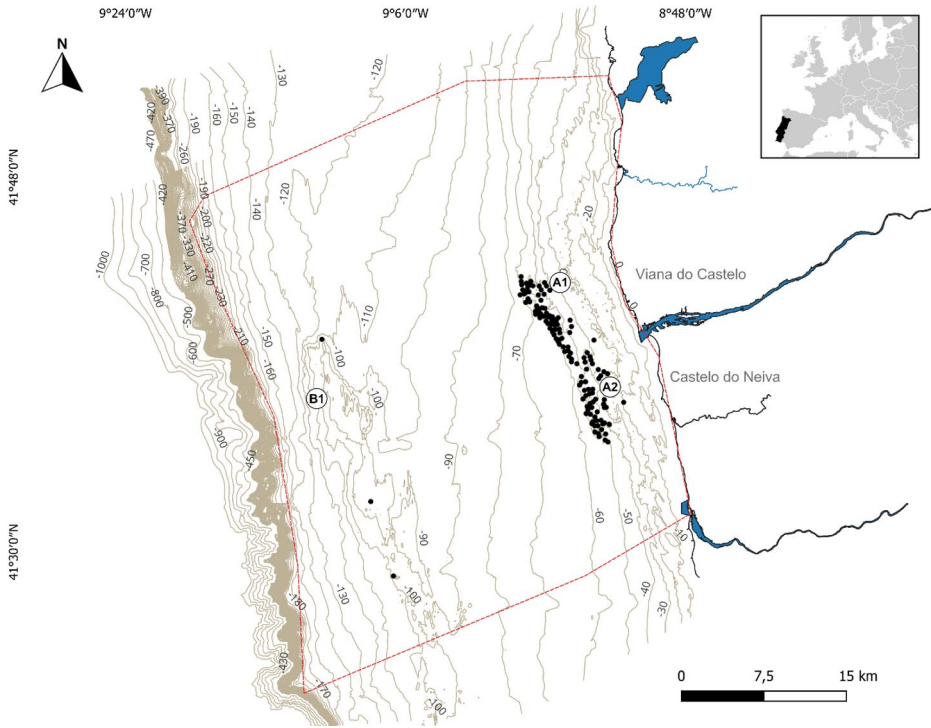


Fig. 1 Delimitation of the study area. Bathymetric contours were derived from EMODnet cartography (EMODnet 2022) using the contour tool in QGIS. Dots indicate the locations of ROV survey transects. Known fishing grounds are identified as: A1) Sumalhas, A2) Parcel and Moiteira, and B1) Beiral de Viana

Data collection – ROV dives

Between May 2022 and September 2023, circalittoral and upper mesophotic habitats off the northern coast of Portugal were surveyed using two remotely operated vehicles (ROVs; Chasing M2 and Chasing M2 Pro Max; <https://www.chasing.com/en>). Both platforms were equipped with depth and temperature sensors, dual external LED lighting, and an integrated 4 K video camera with a 150° field of view. To increase seabed coverage, an additional wide-angle GoPro camera was mounted on the ROVs.

A total of 145 ROV dives were carried out across depths ranging from approximately 30 to 93 m. Dive locations were selected to sample the main rocky habitats within the near-shore circalittoral–upper mesophotic zone, including areas used by local fisheries, and were spaced at least 200 m apart to minimise spatial overlap. Each dive involved a continuous video transect along the seabed for at least 10 min. The ROV was kept at a height of about 0.5–1 m above the seabed and followed a horizontal path of roughly 100–120 m, resulting in an estimated surveyed area of approximately 225 m² per dive.

Video footage was subsequently analysed, and all identifiable benthic taxa were documented. For each dive, species presence was recorded, and the number of individuals or colonies was counted where possible.

Data collection – Interviews

Between March 2023 and September 2024, we interviewed 59 fishers involved in coastal, local, and recreational boat fishing within the study area. A pilot survey was carried out to validate the questionnaires. The fishers interviewed were approached as they arrived at the dock, near their storage facilities, or at well-known socialisation events and locations.

The interviews began after we obtained oral consent from the participants, who were informed about the study's purpose, their role, and the anonymity of the data collected. In addition to general demographic details and fishing activity (fleet, fishing gear used), participants were asked to identify target bycatch species from a visual chart. They also rated the overall abundance (from a six-option scale: “Super Abundant”, “Abundant”, “Common”, “Frequent”, “Occasional”, and “Rare”) and indicated the average bathymetric distribution of each species.

Fishing areas were mapped using spatial information provided by fishers during the interviews. Participants were asked to identify their main fishing grounds on printed nautical charts covering the study region, indicating areas where fishing activity is most frequently conducted and where interactions with benthic organisms are commonly observed.

The selection of target species was based on (i) species previously recorded in the area through remote-operated video (ROV), (ii) species physically retrieved by fishers with whom we had contact in previous projects, (iii) literature reports of species found along the Portuguese coast, and (iv) species listed as indicators of vulnerable habitats (FAO 2009, 2016). In the final part of the interview, we gathered fishers' perceptions on (i) the importance of the selected species to their activity (such as habitat, feeding grounds, or shelter) and (ii) potential conservation measures to ensure the long-term viability of these species, along with the impacts of their fishing gear.

Fishers' perceptions were evaluated using eight structured statements addressing views on the ecological importance of benthic communities, perceived impacts of fishing activities, and attitudes towards conservation and management measures. Participants were asked to rank each statement on a five-point Likert scale (“Strongly agree”, “Agree”, “Do not know”, “Disagree”, “Strongly disagree”). These responses were used to characterise and compare perceptions across different fishing categories.

Data analysis

A Kruskal–Wallis test was conducted to (i) determine if the number of species recognised by fishers varied significantly across fishing categories (Coastal, Local, Recreational) and (ii) assess how the fishing category influenced fishers' ecological and conservation perceptions. For the analysis, response categories were combined to emphasise directional agreement rather than response intensity. Specifically, “Strongly agree” and “Agree” were merged into a single “Agree” category, and “Strongly disagree” and “Disagree” into a single “Disagree” category, while “Do not know” remained as a separate category. This merging reduced redundancy between adjacent ordinal categories expressing the same direction and decreased variability caused by sparse responses across multiple levels (DiStefano et al. 2020). Kruskal–Wallis tests were performed on both the original five-category responses and the combined three-category responses to assess overall differences among fishing categories. When significant effects were found in the three-category analysis, post hoc pairwise

comparisons were carried out using Dunn's test (Dunn 1961), with p-values adjusted via the Bonferroni correction to control the overall error rate (Bonferroni 1936). All statistical analyses were carried out in R (R Core Team 2023).

Based on their responses, the main fishing zones and areas with the highest fishing effort were mapped using QGIS (QGIS 2023). The extent of overlap among the polygons was measured, with greater overlap indicating more frequent or intensive fishing activity regions. Areas with higher overlaps were shown by darker colours, while those with fewer overlaps, corresponding to lower fishing effort, appeared in lighter shades.

Results

Sample characterisation

A total of 59 fishers were interviewed, encompassing three types of fishing: coastal ($n=25$, corresponding to 42,4%), local ($n=22$, accounting for 37,3%), and recreational ($n=12$, representing 20,3%). Local fishers mainly operate within a strip of 6 nautical miles (NM) from the coast (maximum depth around 50–80 m); coastal fishers work between 4 and 5 NM to the edge of the continental plateau (maximum depth approximately 200 m, although some may venture into deeper waters). Recreational fishers operate in any location without restrictions, apart from those related to the vessel used.

The ages of local fishers ranged from 30 to 77, with a mean age of 55 ± 14 years; coastal fishers ranged from 34 to 72, with a mean age of 53 ± 10 years; and recreational fishers ranged from 35 to 62, with a mean age of 46 ± 10 years. The average years of professional activity were 38 ± 12 years for coastal fishers and 41 ± 14 years for local fishers, while recreational fishers reported an average of 23 ± 15 years. Most respondents remain actively involved in fishing, although 8% of coastal fishers and 23% of local fishers are now retired.

Spatial distribution of high-intensity fishing areas

The coastline of Viana do Castelo shows significant differences in seabed types, which can be divided into three distinct zones (Fig. 2):

Zone A extends 8 km from the coast, with depths ranging from 0 to 100 m. This area features substantial rocky formations, including underwater peaks, canyons, and large boulder clusters. Within this zone, three areas of intense fishing effort are highlighted in darker shades, corresponding to submarine mountain peaks (A1 and A2 from Fig. 2) known for their rich diversity and abundance of fish species. While occasionally exploited by coastal fishers, local fishers primarily utilise this zone (Fig. 2).

Zone B extends for 13 km, with depths ranging from 90 to 110 m, and features unconsolidated substrates such as sand, gravel, and mud. This zone experiences the lowest fishing activity due to the lack of rigid substrates that typically attract fishers, as rocky areas tend to produce higher fish catches. Nonetheless, it is visited by coastal fishers targeting sand-dwelling species and recreational anglers (Fig. 2).

Zone C extends 16 km, with depths ranging from 110 to 300 m and features a mix of rocky substrata and extensive sandy areas. This zone also experiences high fishing activity

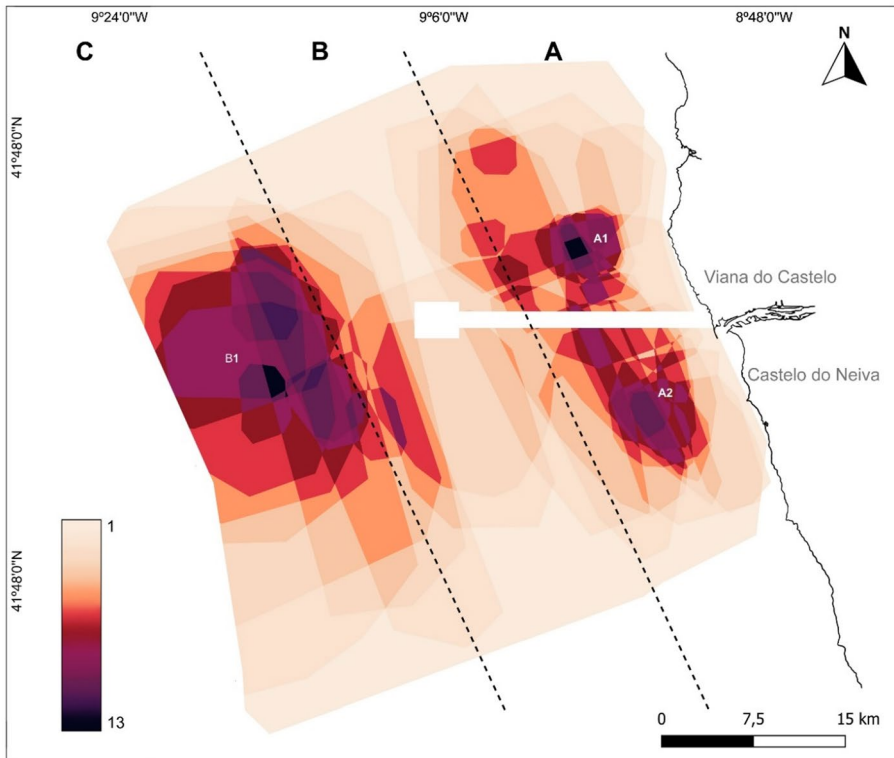


Fig. 2 Map of reported fishing areas, where darker colours indicate higher fishing intensity based on the number of overlapping fishing-area polygons. The white area marks a fishing restriction zone for the underwater cable of the offshore wind farm. The area is divided into zones (A, B, and C) according to significant changes in bottom substrate types. Known fishing grounds include: A1) Sumalhas, A2) Parcel and Moiteira, and B1) Beiral de Viana

and is the preferred area for coastal fishers, mainly on the rocky outcrop (B1 in Fig. 2), as fishers report higher catches there (Fig. 2).

Local Ecological Knowledge of target species

The respondents recognised all 25 species depicted in the visual chart at least once (Table 1).

Local fishers identified four sponge species, including the endemic *T. uigorri* (Table 1). Coastal fishers recognised six out of the seven sponge species, with *Geodia* sp. and *Polymastia* sp. being exclusive to this group. Among recreational fishers, only *H. oculata* was recognised.

In total, local fishers recognised 14 cnidarian species, with the gorgonians *E. verrucosa* and *L. sarmentosa* being the most commonly caught, the latter recognised by nearly all (95%) of the interviewed fishers. Coastal fishers successfully identified all 16 cnidarian species, including two exclusive captures: *V. flagellum* and *D. pertusum*. Soft corals such as *M. oculata*, *E. dabneyi*, and the scleractinian *D. cornigera* were more frequently caught by

Table 1 List of target species and the percentage of fishers reporting their catch, organised by fishing category (Local, Coastal, and Recreational) and taxonomic group: Porifera (POR), Cnidaria (CNI), and Echinodermata (ECHI)

Taxa	Common name	Species	Fishing category %		
			Local	Coastal	Recreational
POR	-	<i>Tedania urgorri</i>	14	0	0
	-	<i>Polymastia sp.</i>	0	4	0
	Cup sponge	<i>Phakellia ventilabrum</i>	18	88	0
	Mermaid's glove	<i>Haliclona oculata</i>	50	32	17
	Massive deep-sea sponge	<i>Geodia sp.</i>	0	16	0
	Prawn cracker sponge	<i>Axinella infundibuliformis</i>	9	36	0
	Mushroom sponge	<i>Artemisia transiens</i>	27	20	0
	CNI	Whip coral	<i>Viminella flagellum</i>	0	4
Sea pen		<i>Pennatula sp.</i>	5	20	0
-		<i>Paramuricea sp.</i>	27	36	8
Zigzag coral		<i>Madrepora oculata</i>	27	64	4
Orange gorgonian		<i>Leptogorgia sarmentosa</i>	95	84	92
Pink sea fan		<i>Eunicella verrucosa</i>	68	56	42
Gazelle sea fan		<i>Eunicella gazella</i>	45	48	92
Lace coral		<i>Errina dabneyi</i>	5	52	0
White stony coral		<i>Desmophyllum pertusum</i>	0	24	0
Orange tree coral		<i>Dendrophyllia ramea</i>	27	16	0
Yellow stony coral		<i>Dendrophyllia cornigera</i>	45	72	0
Black coral		<i>Antipatharia sp.</i>	9	20	0
Red Dead's man finger		<i>Alcyonium palmatum</i>	9	8	4
Red sea fingers		<i>Alcyonium glomeratum</i>	5	24	0
Dead's man finger		<i>Alcyonium digitatum</i>	14	20	0
Hairy sea fan	<i>Acanthogorgia hirsuta</i>	9	28	17	
ECHI	Purple heart urchin	<i>Spatangus purpureus</i>	55	48	0
	Basket star	<i>Astrospartus mediterraneus</i>	14	64	0

coastal fishers compared to other groups. Recreational fishers identified seven of the 16 cnidarian species, with *L. sarmentosa* and *Eunicella gazella* recognised by 92% of respondents.

Among echinoderms, *Spatangus purpureus* was caught by both professional groups, while *Astrospartus mediterraneus* was reported more often by coastal fishers. Recreational fishers did not report recognising any species from this group.

Alongside collecting data on the presence of these species, we also obtained information from fishers about the depth ranges where they were caught to identify potential limitations related to depth (Fig. 3).

Among the observed species, three sponges, *T. urgorri*, *H. oculata*, and *Polymastia sp.*, were found exclusively at depths shallower than 100 m. In contrast, gorgonians such as *E. gazella*, *E. verrucosa*, *L. sarmentosa*, and *Paramuricea sp.* were primarily distributed above 100 m, though occasionally observed in deeper zones. Deeper occurrences (> 100 m) were exclusively associated with *E. dabneyi*, *V. flagellum*, *D. pertusum*, *M. oculata*, *Pennatula sp.*, and *Geodia sp.* (Fig. 3).

All species included in this study, including several recognised as indicators of Vulnerable Marine Ecosystems (VME), were consistently reported within the typical depth ranges

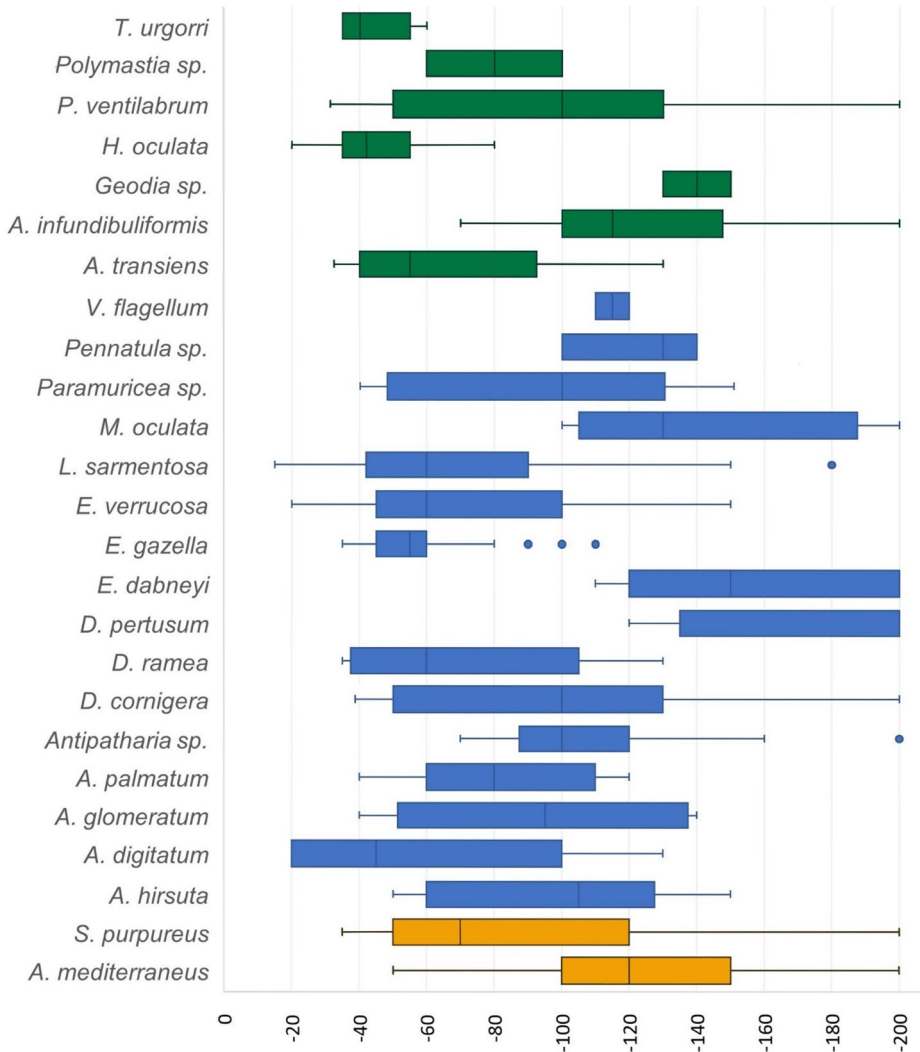


Fig. 3 Fishers reported the depth distribution of target species based on bycatch records ($n=25$). The green colour represents Porifera, blue represents Cnidaria, and yellow represents Echinodermata

of mesophotic ecosystems. However, reports of abundance varied significantly among species and fishing categories.

Local fishers identified 10 VME indicator species. The gorgonian *M. oculata*, an indicator of cold-water coral reefs (CWC) and non-reefal colonial scleractinian aggregations (SA), was reported as rarely caught by 82% of fishers. By contrast, 17% reported it as frequently caught. All respondents identified *D. ramea*, an indicator of SA, as a rare catch; however, 50% of local fishers classified *D. cornigera* as occasional. The coral *E. dabneyi*, associated with stylasterid coral-dominated ecosystems (S), and *Pennatula sp.*, an indicator of sea pen fields (SP), were consistently reported as rare catches by all fishers who identified them. Among species indicators of hard-bottom coral gardens (HBCG) dominated by

gorgonians, *L. sarmentosa*, *E. verrucosa*, and *E. gazella* were the most frequently caught. *E. verrucosa* was reported as highly abundant by 27% of local fishers and as abundant by 60%. Similarly, *L. sarmentosa* was considered highly abundant by 24% and abundant by 19% of local fishers. In contrast, 50% of respondents classified *E. gazella* as a common species.

Coastal fishers identified the highest number of VME indicators ($n=14$), including exclusive catches of *D. pertusum* and *M. oculata* (Figs. 2 and 4). These species serve as indicators of CWC, coral gardens on rocky outcrops (CS), and SA, which also include *D. cornigera* and *D. ramea*. About half of the respondents occasionally caught *D. pertusum*, while 48% reported *M. oculata* as a more common catch. Furthermore, 50% of coastal fishers considered *D. ramea* as occasional, in contrast to local fishers, who described it as rarely caught.

The gorgonians *A. hirsuta*, *Paramuricea* sp., and the coral *V. flagellum*—indicators of HBCG (*Habitat-Building Coral Gardens dominated by gorgonians*)—were more likely to be caught in Zone C, according to coastal fishers. Over 70% of coastal fishers reported *A. hirsuta* as a frequent catch, whereas 50% of local fishers considered it rare. Similarly, 67% of coastal fishers reported *Paramuricea* sp. as a frequent catch, with only 10% of local fishers describing it as rare. In contrast, more than 70% of local fishers considered *Paramuricea* sp. to be rare. Although *V. flagellum* is exclusive to Zone C, it was rarely captured according to the respondents. The capture rates of other gorgonians, such as *L. sarmentosa* and *E. verrucosa*, were similar between coastal and local fishers, while *E. gazella* was caught more often by 42% of coastal fishers.

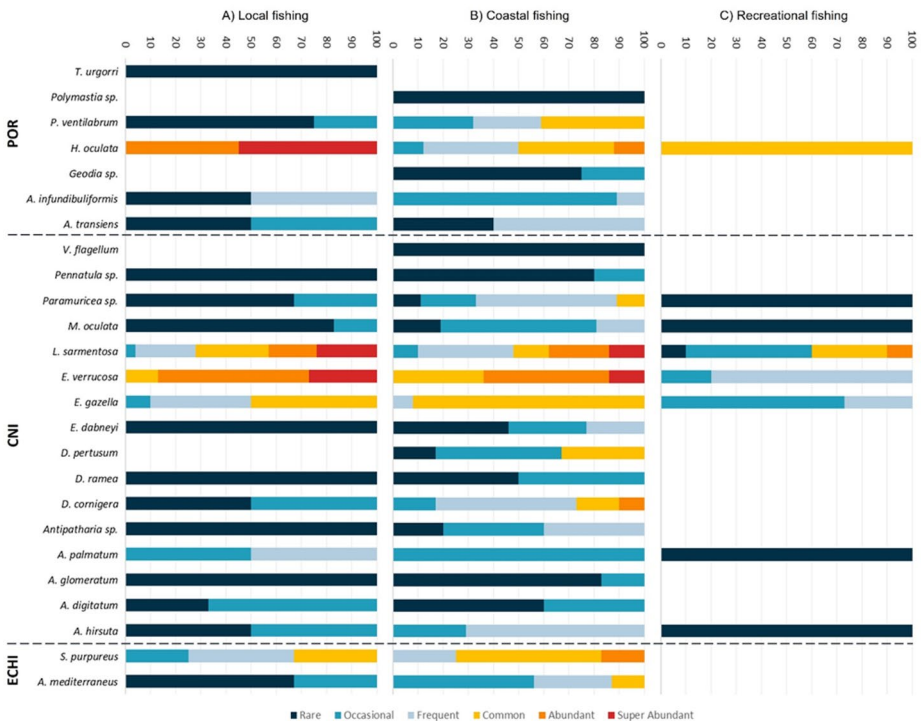


Fig. 4 Recognised species’ abundance reported by (A) Local fishing, (B) Coastal fishing, (C) Recreational fishing (%). Taxonomic groups are categorised as POR (Porifera), CNI (Cnidaria), and ECHI (Echinodermata)

E. dabneyi, an indicator of ST, showed a similar trend, being more frequently captured in zone C. Over 50% of coastal fishers described it as an occasional or frequent catch. In contrast, in zone A, it was rarely captured (Fig. 2). For the sea pen *Pennatula* sp., an indicator of SP, 20% of fishers reported it as an occasional capture. However, it became more common when targeting sand-dwelling species in zone B (Fig. 2).

Among sponges, species like *Geodia* sp., *Polymastia* sp., *P. ventilabrum*, and *A. infundibuliformis*, indicators of deep-sea aggregations (DSA), were also more frequently caught in zone C (Fig. 2). *P. ventilabrum* was reported as a common catch by over 40% of coastal fishers, in contrast with local fishers, who usually described it as rare. Similarly, *A. infundibuliformis* was regarded as an occasional catch by over 90% of coastal fishers, while half of the local fishers described it as rare.

Recreational fishers identified only four VME indicator species: *Paramuricea* sp., *E. verrucosa*, *E. gazella*, and *A. hirsuta*, which signal the presence of HBCG, along with *M. oculata*, an indicator of CWC and SA. Of these, only *E. verrucosa* and *E. gazella* were reported frequently or occasionally, while the remaining species were classified as rare (Fig. 4).

Comparison between fishing practices

The fishing category showed notable differences in the number of recognised species across various groups. Coastal fishing recorded the highest number of recognised species, ranging from 4 to 16 species (mean 11 ± 3 , $n=25$), followed by local fishing, with 2 to 11 species (mean 8 ± 3 , $n=22$), and recreational fishing, which identified the fewest species, ranging from 2 to 7 species (mean 4 ± 2 , $n=12$) (Fig. 5). The Mann-Whitney U test indicated significant differences between the groups ($U=25.4438$, $df=2$, $p=2.985e-06$), and the Dunn test confirmed significant differences among all groups (Table 2).

Comparison between LEK and ROV data

ROV surveys, carried out in the survey area, identified 18 of the 25 target species, including nine VME indicators. Table 3 offers a detailed comparison between species observed through ROV and those reported by fishers. Additionally, the table lists mollusc and echinoderm species, which, though not classified as VME indicators, are linked to these habitats and represent the first documented records for this study site (Table 3).

Although both methods identified overlapping species, ROV surveys provided detailed information on species distributions and their habitat context, which cannot be obtained solely from bycatch observations. They also enabled comparisons between fishers' reports and video observations, highlighting both areas of agreement and discrepancies where patterns differed. In the ROV surveys, the gorgonian *Paramuricea* sp. was found in large groups in zone C and, to a lesser extent, among clusters of *L. sarmentosa*, *E. gazella*, and *E. verrucosa* in zone A. The recordings also showed extensive *E. verrucosa* gardens along the coast, making it one of the most common species on rocky substrates, consistent with fishers' reports of frequently catching this species. Similarly, large groups of *A. transiens* were observed in more coastal areas, matching fishers' accounts of both frequent and occasional catches.

Additionally, large aggregations of the scleractinian coral *D. cornigera* were observed in zone C. However, due to the limited number of video recordings, the extent and abundance

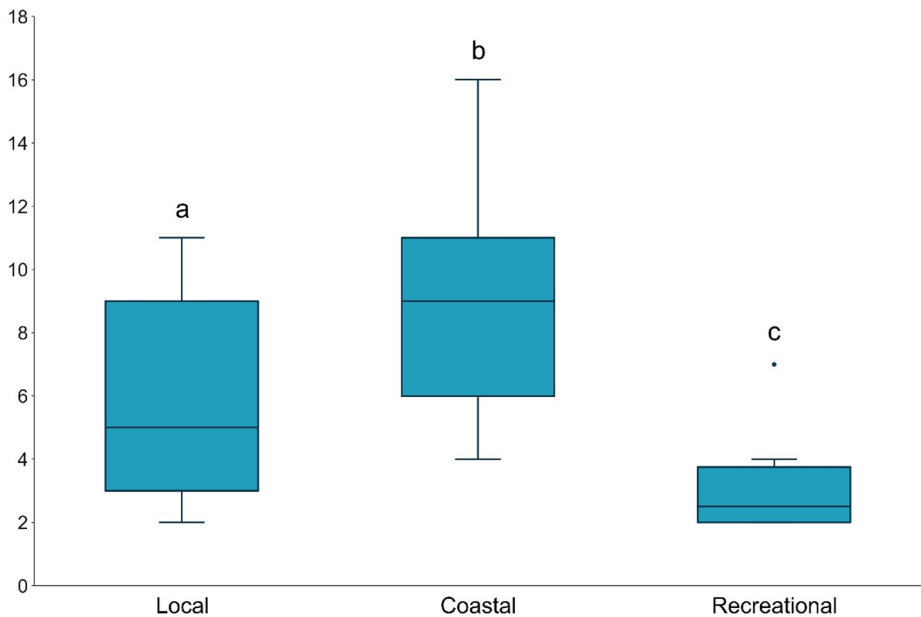


Fig. 5 Comparison of the number of species recognised by fishers according to fishing category (local, coastal, and recreational). Different letters indicate statistically significant differences

Table 2 Results of the Kruskal-Wallis and Dunn tests evaluating whether the number of species recognised by fishers varies significantly across fishing categories (Coastal vs. Local vs. Recreational)

Group	N	Median	Rank Sum	Dunn test
Coastal	25	9	1039.5	Significantly different from 'Local' $p=0.004$
Local	22	5	584.5	Significantly different from 'Recreational' $p=0.028$
Recreational	12	2.5	146	Significantly different from 'Coastal' $p=0.000$
Test statistic (H)			25.4438	
Degrees of freedom (df)			2	
p-value			2.985e-06	

of these aggregations remain uncertain (Table 3). Fishers reported encountering this species in zone A, but no specimens were observed along the surveyed area. A similar pattern was observed with *D. ramea*, where fishers reported its presence multiple times in both zones A and C. However, only one specimen was detected in zone A across all video surveys.

Incorporating Local Ecological Knowledge (LEK) expanded the list of VME indicator species for the study site by identifying seven cnidarians and two sponges occurring beyond the operational range of the video surveys, consistent with the broader spatial and depth coverage of LEK compared to ROV observations. LEK proved valuable in identifying previously undocumented areas that may include (i) cold-water coral reefs, such as *D. pertusum* and *M. oculata*, (ii) coral gardens formed by *E. dabneyi*, *V. flagellum*, and *A.*

Table 3 Species recorded by the ROV and LEK survey methods across zones (A, B, C from Fig. 5). Species without a physical specimen to confirm identification at the species level are marked with an asterisk (*). Additional species identified but not included in the visual guide are marked with an (*¹)

Species	Method	Zone	Species	Method	Zone
<i>Artemisina transiens</i>	Both	A, C	<i>Madrepora oculata</i> *	LEK	C
<i>Axinella infundibuliformis</i> *	LEK	A, C	<i>Paramuricea sp.</i>	Both	A, C
<i>Geodia sp.</i>	LEK	C, D	<i>Alcyonium palmatum</i>	Both	A, C
<i>Haliclona oculata</i>	Both	A	<i>Alcyonium digitatum</i>	Both	A, C
<i>Phakellia ventilabrum</i>	Both	A, C, D	<i>Alcyonium glomeratum</i>	Both	A, C
<i>Polymastia sp.</i>	Both	A	<i>Viminella flagellum</i> *	LEK	C
<i>Tedania urgorri</i>	Both	A	<i>Acanthogorgia hirsuta</i>	LEK	A, C
<i>Antipatharia sp.</i>	Both	A, C	<i>Pennatula sp.</i>	LEK	B, C
<i>Corallium rubrum</i> * ¹	LEK	C	<i>Calappa granulata</i> * ¹	LEK	B
<i>Dendrophyllia cornigera</i>	Both	A, C	<i>Pagurus bernardi</i> * ¹	LEK	B
<i>Dendrophyllia ramea</i>	Both	A, C	<i>Spatangus purpureus</i>	Both	A, B, C
<i>Errina dabneyi</i> *	LEK	C	<i>Cidaris cidaris</i> * ¹	LEK	C
<i>Eunicella gazella</i>	Both	A, C	<i>Astropecten sp.</i> * ¹	LEK	C, D
<i>Eunicella verrucosa</i>	Both	A, C	<i>Astrospartus mediterraneus</i>	Both	A, B, C
<i>Leptogorgia sarmentosa</i>	Both	A, C	<i>Antedon bifida</i> * ¹	Both	A, B, C
<i>Desmophyllum pertusum</i> *	LEK	C, D			

hirsuta, (iii) sea pen fields, and (iv) deep-sea sponge aggregations containing *Geodia sp.* and *A. infundibuliformis*. While *P. ventilabrum* and *Polymastia sp.* were detected in zone A through video surveys, fishers' reports indicated a higher abundance of these species in zone C, particularly near the 200-metre bathymetric line.

Fishers' Perspectives on the Ecological Importance, Impacts, and Conservation of Marine Communities

Eight questions were asked to the fishers, covering topics from the ecological significance of the species to management and conservation measures. To determine whether the fishing category influenced the types of responses given, respondents were asked to select one of the five options—"Strongly agree", "Agree", "Neutral", "Disagree", or "Strongly Disagree"—for their answers (Fig. 6). To evaluate the robustness of observed patterns across response levels, analyses were conducted using both the original five-category scale and an aggregated three-category structure: "Agree", "Do not know", "Disagree". Results from both methods are shown for clarity. However, interpretation primarily concentrates on the three-category structure, which highlights the direction of agreement rather than response strength and reduces redundancy among adjacent ordinal categories.

To assess fishers' opinions on the ecological importance of the species presented, we asked if "Q1 - Are these organisms important to marine ecosystems?" and if "Q2 - Is there a connection between the presence of these communities and species biodiversity?" The responses showed no significant differences across the three groups (p-value=0.220 for both questions), with unanimous agreement on the importance of these species.

Considering the impacts faced by marine ecosystems, including those from fishing activities, we asked fishers: "Q3 - Do you believe that marine ecosystems recover on their own from human impacts without the need for conservation measures?" Although statistical tests

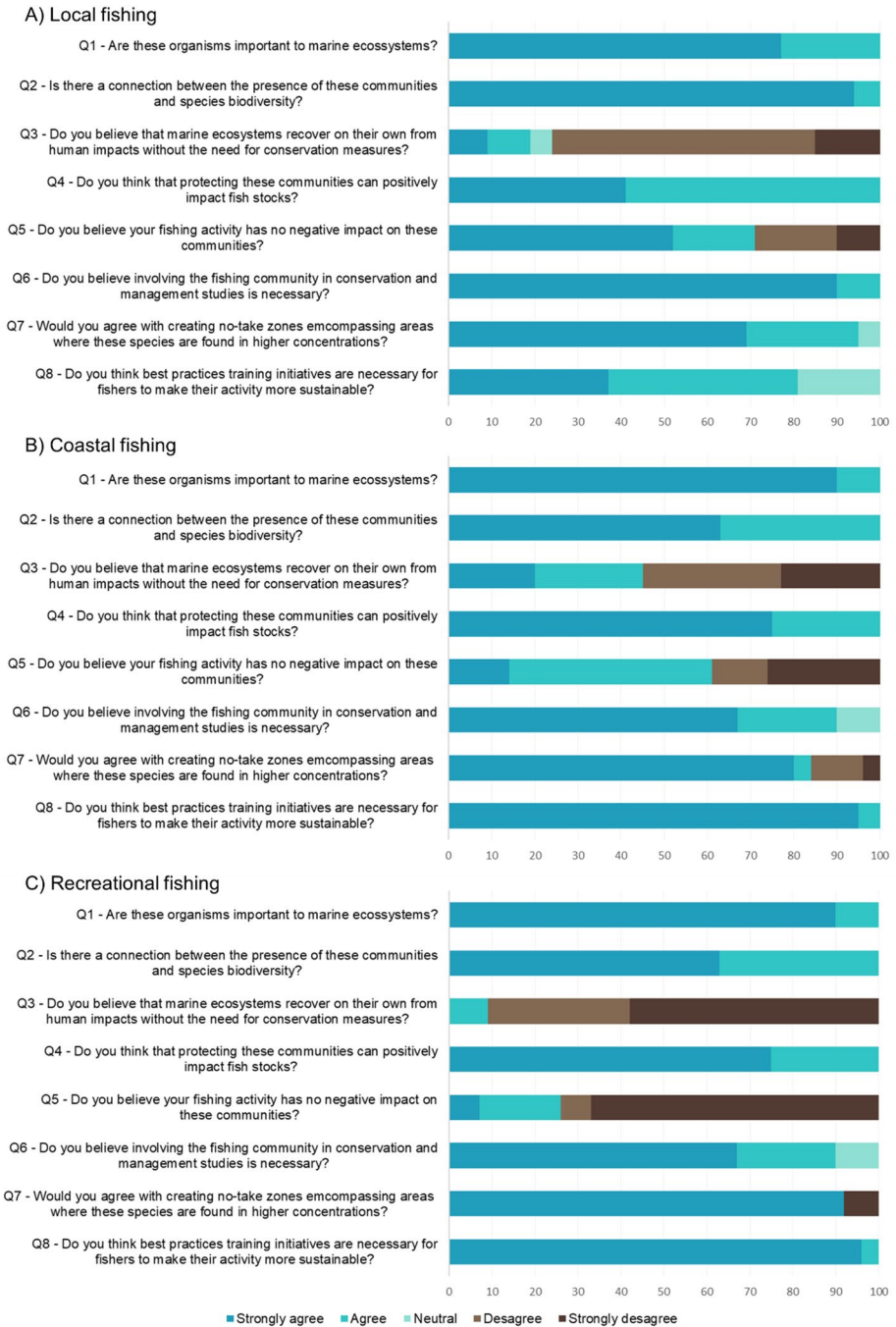


Fig. 6 Fisher’s perception of the sustainability of their activities based on fishing category: (A) Local fishing, (B) Coastal fishing, and (C) Recreational fishing

Table 4 Results of the Kruskal-Wallis test examining the impact of the fishing category (Coastal vs. Local versus Recreational) on the five response categories (“Strongly agree”, “Agree”, “Do not know”, “Disagree”, and “Strongly disagree”) and on three combined categories (“Agree”, “Do not know”, “Disagree”) within the questionnaire. Post hoc pairwise comparisons (Dunn’s test) are conducted based on the three-category structure

Questionnaire statements	<i>p</i> -value (5 categories)	<i>p</i> -value (3 categories)	Dunn’s test (3 categories)
Q1 – Are these organisms important to marine ecosystems	0.290	0.220	-
Q2 - Is there a connection between the presence of these communities and species biodiversity?	0.003	0.220	-
Q3 - Do you believe that marine ecosystems recover on their own from human impacts without the need for conservation measures?	0.005	0.05	Local=Recreational>Coastal
Q4 - Do you think protecting these communities can positively impact fish stocks?	0.002	0.220	-
Q5 - Do you believe your fishing activity has no negative impact on these communities?	0.025	0.03	Local=Coastal>Recreational
Q6 - Do you believe involving the fishing community in conservation and management studies is necessary?	0.493	0.220	-
Q7 - Would you agree with creating no-take zones encompassing areas where these species are found in higher concentrations?	0.0142	0.066	-
Q8 - Do you think best practices training initiatives are necessary for fishers to make their activity more sustainable?	0.007	0.022	Local=Coastal>Recreational

indicated a *p*-value of 0.05, Dunn’s test confirmed significant differences between coastal and local fishers (*p*-value: 0.043) and between coastal and recreational fishers (*p*-value: 0.012) (Table 4). Coastal fishers represented the largest proportion of respondents who agreed (45%) that current measures are sufficient for marine ecosystems to recover, stating that it is a matter of time. In contrast, local and recreational fishers expressed a greater need for additional conservation measures, with 75% and 91% advocating for further initiatives.

To assess their perceptions of the importance of these species to their fishing activities, we asked: “Q4 - Do you think that protecting these communities can positively impact fish stocks?” There were no significant differences between the fishing categories (*p*-value=0.220), as they generally agreed with the question and recognised their importance: “These animals (corals and sponges) help fish to aggregate” and “I catch more fish in areas with many (corals) on the rocks”.

In response to the question “Q5 - Do you believe that your fishing activity has no negative impact on these communities?” significant differences were observed between recreational fishers and both local and coastal fishers (Local=Coastal>Recreational; Table 4; *p*-value: 0.003 and 0.022, respectively). Only 30% of local fishers and 40% of coastal fishers disagreed with this statement, while 90% of recreational fishers disagreed.

Regarding management measures, we asked, “Q6 - Do you believe involving the fishing community in conservation and management studies is necessary?” and “Q7 - Would you agree with creating no-take zones encompassing areas where these species are found in higher concentrations?” Most respondents across fishing categories agreed with both questions, indicating general support for community involvement in conservation efforts. How-

ever, there was some reluctance regarding no-take zones, with 16% of coastal fishers and 8% of local fishers opposing their establishment, citing concerns over numerous existing regulations.

When discussing potential conservation initiatives, particularly “Q8 – Do you think best practices training initiatives are necessary for fishers to make their activity more sustainable?” significant differences were again observed between recreational fishers and both local and coastal fishers (Local=Coastal>Recreational; Table 4; p-value: 0.048 for both) (Table 4). Nearly 20% of local fishers responded that they did not know how to answer this question (Fig. 6).

Discussion

Impact of Fishers’ Practices on the Detection and Distribution Patterns of Vulnerable Marine Ecosystems

This study showed distinct patterns of fishing activity and species distribution were observed across the three zones, illustrating how ecological characteristics, depth, and fishing practices influence the capture and, consequently, the identification of Vulnerable Marine Ecosystem (VME) indicator species. Among professional fishers, coastal fishers recognised 96% of the species presented and VME indicators, whereas local fishers recognised 84%. This difference in species recognition is likely linked to their primary fishing zones. Coastal fishers operate in zones B and C, where a wider variety of habitat-forming species are present, whereas local fishers focus on zone A, which supports fewer of these taxa. As both groups use similar gear types, differences in species recognition reflect variation in exposure to habitat-specific species rather than differences in fishing practice or taxonomic knowledge.

Zone C, the outermost region extending from 100 to 300 m in depth, was identified as the most biodiverse area. It included both species shared with zone A and additional taxa confined to deeper habitats, such as low-light filter feeders, which increased the diversity encountered by coastal fishers. In this zone, the scleractinian corals *M. oculata* and *D. pertusum*, along with the sponges *Geodia* sp. and *A. infundibuliformis*, were recorded exclusively. *Geodia* sp. was rarely captured, suggesting a preference for deeper or more stable environments, while the other species were described as occasional or frequent bycatches. The observations suggest the presence of well-developed coral and sponge communities, reflecting structurally complex benthic habitats in zone C. These cold-water corals and sponge grounds are renowned framework builders, supporting high biodiversity, comparable in ecological importance to shallow tropical reefs (Rogers 1999). Acting as biodiversity hotspots, they provide essential habitats, including shelter, spawning grounds, and nurseries for various marine species, including commercially important fish, which tend to occur in higher densities within these environments (Costello 2005; Fosså et al. 2002; Husebø et al. 2002; Maldonado et al. 2017). They also play a critical role in biogeochemical cycles, releasing organic matter that enhances primary productivity in nutrient-poor environments (Wild et al. 2004). Despite their ecological importance, these ecosystems remain highly vulnerable to deep-sea fishing practices, particularly bottom trawling, which causes severe damage to their fragile structures and leads to prolonged recovery periods or mortality (Pham et al. 2019). Given the high biodiversity and ecological significance of zone

C, combined with its exposure to intensive fishing activities, this area holds considerable potential for targeted protection measures to ensure the sustainability of these communities and support the long-term productivity of the fisheries that rely on these ecosystems.

Although zone C exhibited higher overall richness, zone A supported the greatest abundances of *L. sarmentosa*, *E. verrucosa*, and *E. gazella*. Indeed, fisher-reported data indicated depth-related patterns, with these species being most frequently captured between 40 and 90 m. ROV observations further revealed extensive coral garden aggregations, some dominated by *E. verrucosa*, a species classified as vulnerable by the IUCN (World Conservation Monitoring Centre 1996). Conservation strategies should therefore prioritise not only areas of high species richness but also zones that support dense and spatially concentrated populations of habitat-forming species.

Recreational fishers recognised fewer species than professional fishers. The differences in species encountered are more likely due to gear types. Professional fishers use a variety of gear that interacts with different parts of the water column and seafloor, increasing their exposure to a wider range of benthic organisms (Fennell et al. 2021; Kaiser et al. 2003). In contrast, recreational fishers, who mainly rely on boat angling, engage in more selective fishing with limited habitat interaction and generally shorter fishing sessions, which decreases the likelihood of bycatch.

Integrating Local Ecological Knowledge and ROV Surveys for Comprehensive Marine Ecosystem Assessment and Conservation

The significance of conducting studies that incorporate diverse methodologies cannot be underestimated. By integrating Local Ecological Knowledge (LEK) and ROV surveys, researchers can gain complementary insights into marine ecosystems. One key advantage of LEK is its capacity to identify biologically important areas that might otherwise be missed due to the cost and logistical challenges of ROV surveys, as well as species with patchy or highly localised distributions that are hard to detect (Anadón et al. 2009; Petriki et al. 2024). For example, fishers reported the presence of *Dendrophyllia cornigera* near the coast, a species not documented by ROV surveys in the same vicinity. LEK also offers valuable information on areas of intense fishing activity, and when this is combined with biological data, such as biodiversity hotspots and the distribution, extent, and health status of key communities, it becomes possible to identify the most vulnerable areas to human impacts and prioritise them for conservation.

Furthermore, LEK provides a valuable long-term perspective for identifying trends, including species declines. We examined potential links between fishing experience and reported species occurrence, recognition, and perception-based metrics; however, no significant differences were found across experience levels for any of the variables analysed. Fishers did not report the appearance of new species within the study area but noted a general decline over time in the number of benthic species caught as bycatch, along with associated fish species. The only species consistently reported as having disappeared over time was *Corallium rubrum*, which multiple fishers stated was once present but no longer encountered due to trawling, noting: “*C. rubrum* disappeared after the trawls”. This highlights the cumulative effects of fishing and habitat degradation. This decline aligns with the destructive impact of bottom trawling on the seafloor, which damages key habitats for these sensitive species (Jarvis and Brennan 2024). Such impacts are especially concern-

ing as *C. rubrum* is classified as endangered (Otero et al. 2017). Independent evidence supports the presence and persistence of trawling in the area. ROV footage from zone C reveals clear trawl marks in areas where gorgonians and sponges occur, indicating physical disturbance of the seafloor. In addition, fishing activity data from the study area, available through Global Fishing Watch (<https://globalfishingwatch.org>), provide AIS/VMS records dating back to 2012 and consistently indicate trawling activity from 2012 to the present. Because vessels operating at this scale are required to use AIS, these records provide robust evidence of continued trawling, a finding further corroborated through communication with local fishers.

Although attempts to interview trawling vessel operators were unsuccessful, engaging them in future assessments will be vital to fully understand the impact of trawling on ecosystem diversity and species abundance.

Despite its broad scope, LEK has inherent limitations. Fishers' identifications may lack the taxonomic resolution of scientific surveys, especially for species that require close morphological inspection or genetic confirmation (Aswani et al. 2020). Some reports therefore remain uncertain without specimens or corroborating observations. Additionally, while LEK provides information on both current and past species occurrences, it is based on opportunistic observations rather than standardised surveys and therefore cannot offer quantitative assessments of population size, fine-scale abundance, or precise spatial extent (Early-Capistrán et al. 2020).

Although not the main focus of this study, when standardised, ROV surveys enable the estimation of at least the relative abundance of the species present, as well as perceptions of the spatial extent of the populations, the habitat background, and the relationships between co-occurring species. For example, in Zone A, ROV surveys uncovered extensive coral gardens and sponge aggregations across various habitats, depths, and environmental conditions, allowing for analyses of relationships between environmental factors and species richness and abundance, as demonstrated by the authors in the same study area in Neto et al. (2025).

The differences between LEK and ROV records are also influenced by organism morphology and their susceptibility to interaction with fishing gear. Branched and semi-rigid taxa, such as arborescent gorgonians, are more likely to become entangled and retrieved as bycatch, increasing their representation in fishers' reports (Montseny et al. 2021). In contrast, encrusting or low-relief organisms, including many sponge taxa, are less commonly captured by fishing gear but are readily detected in visual surveys.

Overall, this study demonstrates that integrating LEK and ROV surveys provides a robust and transferable approach for advancing knowledge of benthic mesophotic ecosystems. Rather than functioning as isolated sources of information, the two methods together strengthen ecological inference across spatial and temporal scales, improving confidence in the identification of sensitive habitats and areas exposed to anthropogenic pressure. Beyond the present case study, this integrated methodology offers a practical framework for mesophotic ecosystem assessment in data-limited regions, supporting marine spatial planning, Vulnerable Marine Ecosystem identification, and adaptive fisheries management. It is particularly applicable to fisheries authorities, environmental agencies, and marine protected area managers operating in offshore or logistically constrained environments, where comprehensive seabed mapping is not feasible.

Fishers' Views on the Ecological Significance, Impacts, and Conservation of Marine Communities

Local Ecological Knowledge offers vital insights into how fishing communities view the ecological role of benthic habitats and their own interactions with them (da Silva et al. 2025; Gomes et al. 2025; Idrus et al. 2025). However, the long-term success of conservation measures depends on active involvement from fishing communities, ensuring the measures are widely adopted while balancing marine conservation objectives with economic livelihoods (Bennett and Dearden 2014; Charles et al. 2016).

This study examined fishers' perceptions of the ecological significance of coral and sponge communities, both in maintaining marine ecosystems and supporting their fishing activities. It also assesses their understanding of the impacts caused by fishing, the importance of conservation measures, and their willingness to adopt sustainable practices.

Across all fishing categories, there was strong and consistent recognition of the ecological role of these organisms. Fishers unanimously agreed that habitat-forming species contribute to marine ecosystem functioning and support fish stocks (Q1, Q2, and Q4), reflecting a shared understanding of the link between benthic structure, biodiversity, and fisheries productivity. This broad consensus provides a solid basis for collaborative conservation initiatives, since fishers who recognise and appreciate the role of biodiversity are more likely to support measures to protect vulnerable ecosystems, which is essential for the long-term success of conservation initiatives (Chen and Huang 2025).

However, differences appeared in fishers' views about the negative effects of their activities on these communities (Q5). Recreational fishers consistently believed that all types of fishing gear, including their own, damage these ecosystems and held a more pessimistic outlook on the future of marine environments affected by fishing activities. This view likely reflects their lack of economic dependence on fishing and a greater environmental awareness (Shephard et al. 2023). In contrast, professional fishers, whose livelihoods rely directly on the sea, showed a more balanced perspective, weighing the need for conservation against economic priorities (Allison and Ellis 2001). Notably, most professional fishers did not see their own fishing practices as highly damaging, often distinguishing their activities from bottom trawling, which they consistently identified as the most destructive gear type.

Attitudes towards the implementation of additional conservation measures (Q3) also varied. In our interviews, coastal fishers, who generally operate in deeper waters and harvest larger quantities of fish, showed greater resistance to extra restrictions, often citing concerns that stricter rules could limit fishing opportunities and decrease income. Conversely, local fishers working closer to shore were generally more supportive of conservation measures, frequently recognising the perceived vulnerability of nearshore ecosystems and the importance of maintaining their long-term sustainability. These differences highlight how the scale and location of fishing practices influence fishers' attitudes toward conservation, with coastal fishers prioritising economic stability and local fishers emphasising environmental sustainability over immediate financial gains (Pita et al. 2013).

Despite these differences, there was a broad consensus among fishers regarding the importance of initiatives aimed at encouraging sustainable fishing practices. These included both sharing ecological knowledge and implementing training programmes focused on best practices to minimise environmental impacts. However, when asked about the establishment of no-take zones to protect critical patches of the studied species, some professional

fishers expressed reservations due to concerns over potential restrictions on their activities. Nonetheless, the general willingness to adopt sustainable practices and engage in conservation efforts suggests significant opportunities for collaboration between fishers and conservation stakeholders (Pita et al. 2010; Savari et al. 2024).

Taken together, these findings emphasise the complex relationship between economic reliance, environmental awareness, and willingness to participate in conservation efforts. Effective management of mesophotic habitats will require approaches that are geographically targeted, socially inclusive, and based on dialogue with fishing communities. Participatory planning design to build trust and compliance, transparent communication that present conservation measures as mutually beneficial to ecosystems and fishers' livelihoods, and training initiatives focused on minimising habitat impacts can help align conservation objectives with fisheries sustainability, increasing the chances of long-term compliance and ecological success (Sultana and Abeyasekera, 2008; Vis et al. 2024).

Conclusion

This study highlights the importance of integrating Local Ecological Knowledge (LEK) from fishers into the assessment and conservation of benthic mesophotic ecosystems in Northern Portugal. Despite ongoing efforts to document and safeguard marine biodiversity, significant gaps remain, especially in deeper and less accessible habitats. By combining insights from 59 interviews with local, coastal, and recreational fishers with data from Remote Operated Vehicle (ROV) surveys, we created a more comprehensive understanding of the biodiversity within these ecosystems.

Fishers demonstrated detailed knowledge of species' distribution, abundance, and ecological roles, highlighting the importance of combining LEK with conventional scientific methods. Comparisons between LEK and ROV outputs showed both similarities and differences: some species were consistently identified by both approaches, while others were reported only by fishers, probably due to patchy distributions or occurrences outside the spatial and depth coverage of the ROV surveys. When species were sufficiently common and widely spread within surveyed areas, ROV data provided more reliable local estimates of abundance. Rather than showing contradictions, these differences exemplify how the two approaches complement each other, with LEK filling vital gaps and broadening the scope of biodiversity assessments.

Similar complementarities between scientific surveys and LEK have been documented in other regions. In Southeastern Brazil, LEK mapping, validated against SCUBA and sidescan sonar surveys, proved reliable in filling large-scale habitat knowledge gaps (Teixeira et al. 2013). In the Ligurian Sea, deep ROV surveys did not detect wreckfish on seamount tops, whereas interview-based data documented its continued capture and perceived decline, underscoring the complementary role of LEK in conservation assessments (Desiderà et al. 2022).

The findings emphasise the need for collaborative conservation strategies, including the creation of Marine Protected Areas (MPAs) based on both empirical evidence and local knowledge. This integrated LEK–ROV approach offers a practical tool for fisheries authorities, conservation agencies, and marine spatial planning organisations to identify priority areas for protection, guide targeted monitoring, and support evidence-based management

decisions in data-scarce mesophotic regions, thereby increasing the resilience of vulnerable marine habitats under growing human pressures. The framework also offers a pathway for formally incorporating stakeholder-derived ecological knowledge into conservation planning in underexplored marine regions.

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Data availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare no competing interests.

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