ORIGINAL RESEARCH

Identifying vulnerable marine ecosystems from imagery in the Uruguayan continental shelf

Alvar Carranza[1, 2, *], Pablo Limóngi[1], Rodrigo Gurdek-Bas[3], Agustín Loureiro[4], Hernán Pérez Orsi[5], Aitor Azcárate[3], Sofia Santos[3] and Pablo Muniz[3]

[1]Centro Universitario Regional del Este (CURE), Universidad de la República, Av. Cachimba del Rey e/ Bvar. Artigas y Av. Aparicio Saravia, Maldonado, Uruguay. [2]Museo Nacional de Historia Natural, Montevideo, Uruguay. [3]Oceanografía y Ecología Marina (OEM), Instituto de Ecología y Ciencias Ambientales, Facultad de Ciencias, Universidad de la República, Iguá 4225 esquina Mataojo, Montevideo, Uruguay. [4]Che Wirapita, Iniciativa Mar Azul Uruguayo. [5]Fundación Greenpeace Argentina, Buenos Aires, Argentina.
ORCID *Alvar Carranza* https://orcid.org/0000-0003-3016-7955

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ABSTRACT. Scientific surveys employing remotely operated vehicles (ROVs) provide valuable imagery for identifying Vulnerable Marine Ecosystems (VMEs). However, there is presently no established framework for distinguishing VMEs from these images. While existing guidelines effectively address certain habitat types, such as scleractinian reefs, dense octocoral gardens, and chemosynthetic ecosystems, achieving consensus becomes more challenging for other habitats. Our investigation centered on two key localized rocky outcrops on the Uruguayan shelf, conducting ROV dives to explore these environments. This study aims to evaluate initial global consensus guidelines for VME identification from imagery and discuss the suitability of these criteria, and report the existence of Hard Bottom Soft Coral Gardens and Sponge associations in the inner Uruguayan shelf. Recognizing these habitats is of utmost importance for the Uruguayan government, which has expressed the intent to safeguard ecologically representative and well-connected systems crucial for marine biodiversity.

Key words: *Octocorallia*, soft coral garden, inner shelf, rocky outcrops.

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*Correspondence:
alvardoc@fcien.edu.uy

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Identificando ecosistemas marinos vulnerables a partir de imágenes en la plataforma continental uruguaya

RESUMEN. Las investigaciones científicas que utilizan vehículos operados de forma remota (ROVs) proporcionan imágenes valiosas para identificar Ecosistemas Marinos Vulnerables (EMV). Sin embargo, actualmente no existe un marco establecido para distinguir los EMV a partir de estas imágenes. Si bien las directrices existentes abordan de manera efectiva ciertos tipos de hábitats, como arrecifes escleractinios, densos jardines de octocorales y ecosistemas quimiosintéticos, lograr consenso se vuelve más desafiante para otros hábitats. Nuestra investigación se centró en dos afloramientos rocosos localizados en la plataforma uruguaya, realizando inmersiones con ROV para explorar estos entornos. Este estudio tiene como objetivo evaluar las directrices iniciales de consenso global para la identificación de EMV a partir de imágenes, discutir la idoneidad de estos criterios e informar sobre la existencia de Jardines de Corales Blandos en Fondos Duros y asociaciones de Esponjas en la plataforma interna uruguaya. Reconocer estos hábitats es de suma importancia para el gobierno uruguayo, que ha expresado la intención de proteger sistemas ecológicamente representativos y bien conectados, fundamentales para la biodiversidad marina.

Palabras clave: *Octocorallia*, jardín de corales blandos, plataforma interna, afloramientos rocosos.

INTRODUCTION

The concept of 'vulnerable marine ecosystems' (VMEs) has been specifically developed for fisheries management in areas beyond national jurisdictions (FAO 2009). However, it can also prove valuable for shallow water systems. Scientific guidance on the presence of VMEs, as mandated by United Nations resolutions, has typically relied on qualitative assessments. These assessments are rooted in expert judgment, focusing on the occurrence of indicator taxa like cold-water corals and sponges. It is worth noting that, in the case of Uruguayan waters, only one VME has been reported so far, specifically, deep-water coral reefs formed by the scleractinian *Desmophyllum pertusum* in the shelf break and slope. The detection of this VME relied on multi-beam acoustic surveys followed by physical sampling (Carranza et al. 2012).

The Uruguayan continental shelf is primarily characterized by a uniform soft sediment body, featuring limited and poorly known rocky substrata (Urien and Ewing 1974; Urien et al. 1980a, 1980b). The exploration of relevant sites in the continental shelf, however, has historically faced challenges due to adverse oceanographic conditions, high turbidity, limited visibility, strong currents, and other factors. The lack of visual documentation significantly hampers our understanding of these environments, which harbor a diverse yet poorly documented benthic fauna. To address this, it is essential to establish the technical capacity for investigating these areas. One potential solution involves utilizing remotely operated vehicles (ROVs) to overcome the challenges posed by difficult oceanographic conditions. ROVs provide a means to explore and capture imagery in these challenging underwater habitats, facilitating the documentation and study of the rich biodiversity found on hard bottoms (Macreadie et al. 2018).

In December 2023, we conducted exploratory ROV test dives aboard SY 'Witness' at two sites in the Uruguayan continental shelf, both at depths of less than 30 m. Upon discovering unreported biological communities during these exploratory ROV dives, we applied a qualitative analysis of the obtained footage. The goal was to assess whether the material could be sufficient to establish the presence of VMEs. To achieve this, we employed the protocol developed by Baco et al. (2023), specifically designed to determine if a faunal community, as depicted in a single frame or image, qualifies as a VME.

MATERIALS AND METHODS

Study area and sampling

The Uruguayan Exclusive Economic Zone (UEEZ) is situated in the southwestern Atlantic margin within the subtropical region, between 33° S and 38° S. This area plays a crucial role in global ocean circulation as it is located in a transitional region and is also part of the Patagonian Shelf Large Marine Ecosystem (Bisbal 1995; Hempel and Sherman 2003). Considering marine conservation planning on a global scale, this area is located within the Uruguay-Buenos Aires shelf ecoregion (Marine Ecoregions of the World, MEOW No 183; Spalding et al. 2007) in the warm-temperate southwestern Atlantic. The region is characterized by the presence of multiple frontal systems, including the Brazil Current/Malvinas Current Confluence Zone and the Río de la Plata Plume (Ortega and Martínez 2007). The continental shelf exhibits a gradual incline, and the shelf break is situated at a water depth ranging from 160 to 200 m. The inner continental shelf is characterized by a prolonged depression on the seafloor running in a SW-NE direction, representing the Río de la Plata paleovalley. To the south of this paleovalley, the inner shelf displays a complex of relict barrier islands and sandbanks constituting the primary morphosedimentary features formed in the region during the post-glacial transgression.

During December 2023, a small Remote Operated Vehicle (ROV) model SIBIU Pro, manufactured by Nido Robotics (www.nidorobotics.com), was tested at two rocky outcrop locations in the inner Uruguayan shelf (Bajo San Jorge and Restinga del Pez Limón) (Figure 1) onboard SY 'Witness'. The SIBIU Pro is a compact submersible (29 × 35 × 52 cm) weighing 16 kg (without ballast) capable of operating at depths of up to 300 m. Thanks to its 8 motors, it can withstand a maximum current of 3 kn. Its batteries, which also power four light sources, have a theoretical duration of up to 2 h. Additionally, it features a high-resolution (1080p) video camera and depth sensors.

Given the challenges posed by the low quality images due to the instability of the ROV under harsh conditions and limited visibility, and the fact that most pilots were experiencing their first time piloting the ROV onboard in rough seas, we conducted an overall qualitative analysis of the imagery. This approach can be likened to the methodology employed by Baco et al. (2023) where individual scientists shared images of the seafloor in their respective working areas and collaboratively discussed the attributes of the images to determine whether they depicted VMEs.

Bajo San Jorge

The location was visited on December 13th, and 3 exploratory dives were performed. Bajo San Jorge is a small rocky outcrop (35° 16.203′ S-55° 06.347′ W), whose base is approximately 26 m depth, while the summit reaches up to 15 m. This particular rocky outcrop remained uncharted until 1997 when the tanker 'San Jorge' ran aground at this location, causing a significant oil spill that impacted the Uruguayan coast during the summer season. The site is characterized by large, rounded boulders surrounded by sandy mud sediments.

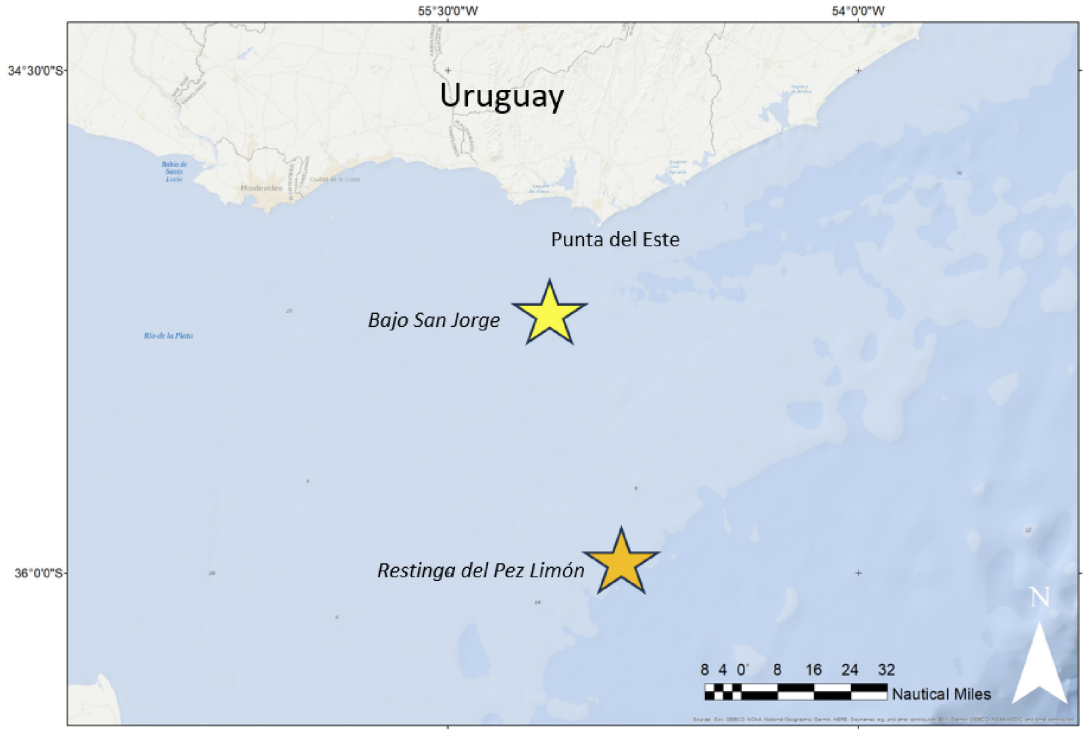

Figure 1. Study area showing surveyed points and localities mentioned in the text.

Restinga del Pez Limón

This area was explored during December 21th, and 2 sites separated 16 nm were visited. At site A, 3 dives were performed, while 1 additional dive was performed at site B. Restinga del Pez Limón is shaped like a 'step' with a very steep slope (10 m elevation from East to West). This 'step' runs in a NE-SW direction, with its northern and southern ends located at 35° 38′ S-54° 19′ W and 36° 00′ S-54° 51′ W, respectively. Its total length is almost 40 nm. On the elevated side (Eastern sector), there is an area of low sandbanks (less than 3 m in height) occupying a strip of variable-width (about 0.5 nm in an E-W direction) along the entire bank. On the other hand, the area near the base of the bank (western sector) appears flat and possibly covered with fine sediments (Madirolas 2006).

Assessment criteria

To guide this analysis, the results and discussion section was structured according to Baco et al. (2023) developed to identify VME from single images. Those authors designed a flow chart to assess whether a faunal community, as depicted in a single frame or image, qualifies as a VME. The protocol is structured in a way that if, at any step of the process, the answer is 'Yes,' then the conclusion is reached that the image indeed represents a VME, and further steps are not necessary. Once a characteristic or condition indicative of a VME is identified in the image, the assessment is considered complete, and there is no need to proceed with additional steps. Subsequent steps in the chart introduce additional factors and decisions that aid in the identification of VMEs. These steps include assessing the presence of reefs, identifying visible functional roles, evaluating the presence of threatened taxa, and recognizing the presence of specific VME taxa. Additionally, the chart considers factors such as threshold density of VME taxa, the presence of chemosynthetic ecosystems, and the occurrence of very large or old individuals of VME taxa.

RESULTS AND DISCUSSION

VME indicators taxa present

As stated above, the first step is to determine whether a VME indicator species is present according to available imagery (Table 1). However, current compilation of VME indicators by Regional Fisheries Management Organizations and Arrangements (RFMO/As) reveals significant regional variation in taxa designated as VME indicators (see table 2 in Baco et al. 2023). Among these, the cnidarian orders Alcyonacea, Scleractinia, and Antipatharia are the sole taxa with representatives acknowledged as VME indicators across all RFMO/A regions. Further, Morato et al. (2018) assessed vulnerable marine ecosystem (VME) indicator types against five criteria outlined by the FAO to define VMEs. The FAO criteria include uniqueness or rareness, functional significance of the habitat, fragility, life-history characteristics making recovery difficult, and structural complexity. Each VME indicator group was scored from 1 (low) to 5 (high) based on how well they fit each criterion, and thus not all VME indicator species are equally important. In this line, 'Soft Corals' and 'Anemones' are taxonomic groups with low VME Indicator Scores, in contrast, for example, with 'Stony Corals' and 'Black Corals'.

In this context, the octocoral *Tripalea* sp. (Alcyonacea: Spongiodermidae) is the most conspicuous VME indicator taxon found during the exploratory dives, although we failed to video-record dense aggregations of the species despite it being observed in Bajo San Jorge (Figure 2). However, both sites surveyed at Restinga del Pez Limón show ubiquitous presence of the species, often in dense aggregations (Figure 3 A and 3 B). Thus, the habitat classification of 'Coral Garden' or 'Hard Bottom Coral Garden' (ICES 2020.) may be useful for categorizing this habitat.

In any case, there has been a tendency, observed in numerous subsequent discussions and literature

Table 1. Fulfillment of criteria for designating Vulnerable Marine Ecosystems (VMEs) from imagery in both sites.

Criteria	Bajo San Jorge	Restinga del Pez Limón
VME indicator	Yes; isolated individuals of *Tripalea* observed	Yes; large abundances of *Tripalea*
Reef	No	No
Chemosynthetic species	No	No
Large/old individuals	Yes	Yes
Functional role	Yes; evidenced with several species of reef fish observed	Yes; evidenced with several species of reef fish observed. Literature supports the area as a feeding ground for *Seriola lalandi*
Threatened taxa	Deserves further analysis	Deserves further analysis
Threshold number/density of VME taxa	Candidate if corallimorpharian anemones or sponges are considered	Yes; large densities of *Tripalea*

related to the issue, as well as in the practical application of guidelines, to obscure the distinction between the concept of indicator species and the ecosystem as a whole. Consequently, when some authors discuss VMEs, they are not solely acknowledging the existence of indicator species but are also implicitly evaluating the vulnerability of the entire ecosystem. The difficulty arises in situations where the occasional presence (i.e. a sparse distribution) of indicator species is inaccurately construed as evidence that the area does not meet the criteria for being classified as a Vulnerable Marine Ecosystem (Watling and Auster 2021). In our case, one could argue that the presence of this species ensures the identification of the area as a VME.

Similarly, sponges (Porifera) are recognized as VME indicators in every RFMO/A region, except for the The North Pacific Fisheries Commission. The challenge arises when the identification of sponges is hindered by the absence of physical specimens for taxonomic analysis. At least two species of sizable sponge were observed in both sites, suggesting the presence of the Ecosystem Type or habitat known as 'Hard-Bottom Sponge Garden' or 'Sponge Aggregation' (Figure 2). In Restinga del Pez Limón, large sponges were interspersed within the soft coral gardens, as well as carpeting the cliffs (Figure 3 C-E).

Finally, it is likely that the criteria of 'Uniqueness or Rarity', implying an area or ecosystem that is unique or that contains rare species whose loss could not be compensated for by similar areas or ecosystems, can be applied to coralimorpharian/actiniarian associations found in Bajo San Jorge (Figure 2). So far, there are no previous records from Uruguay regarding corallimorpharians, a relatively small group of anthozoan cnidarians commonly known as jewel sea anemones. Despite resembling actiniarian sea anemones in their lack of a skeleton and solitary nature, they share external and internal morphological similarities with scleractinian corals (Lauretta and Martinez 2019).

Reef present-chemosynthetic taxa present

The second and third criteria involve identifying the presence of reefs and chemosynthetic taxa. It is probable that neither of these criteria will be met, as no biogenic true reef was observed during the survey, and there were no known, sizeable chemosynthetic species documented. While conventional definitions of reefs often involve the presence of specific biogenic formations, such as coral

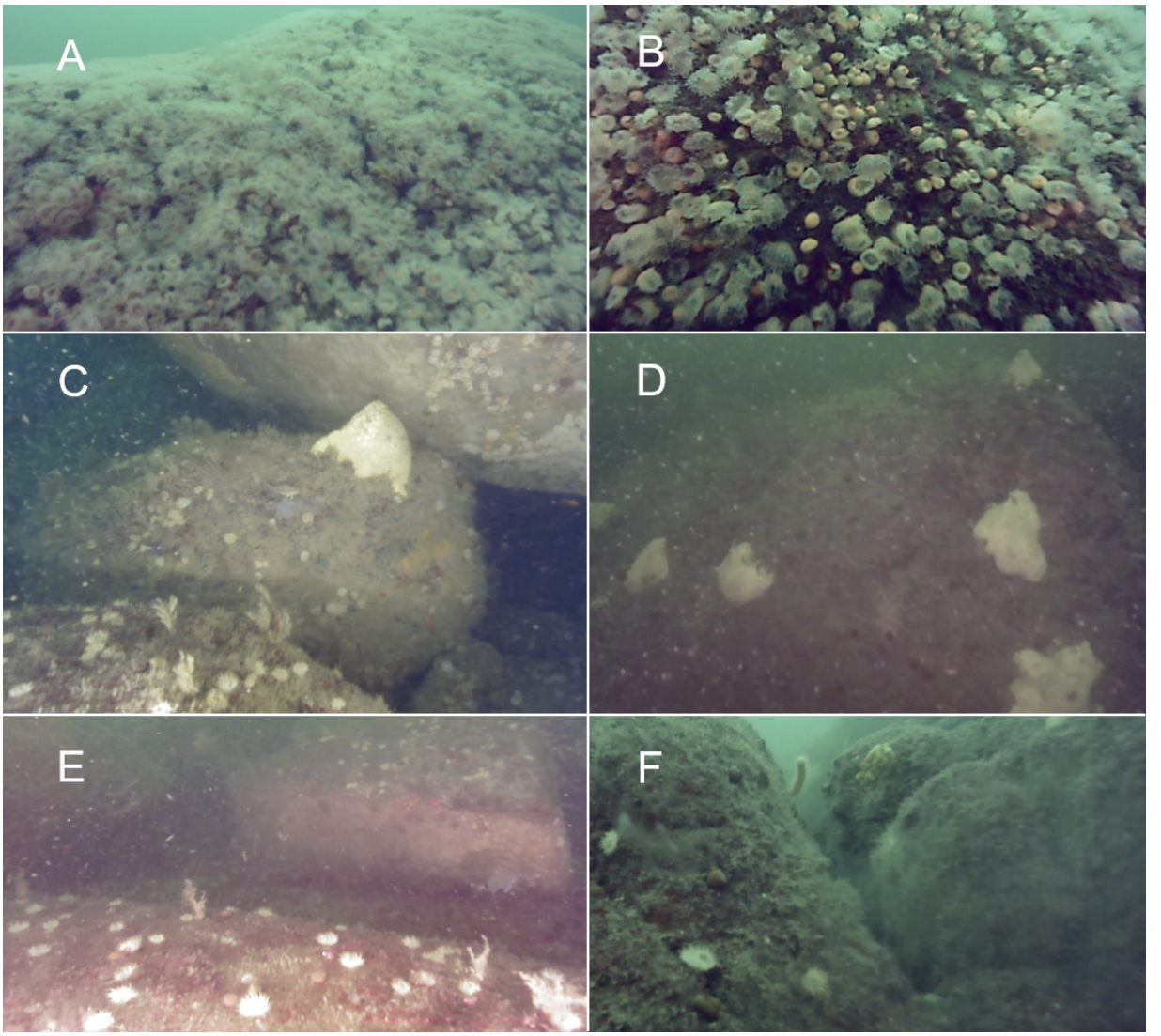

Figure 2. Distinctive elements of the benthic biota present in San Jorge. A) Corallimorpharian hexacorals carpeting large boulders. B) Close-up of the jewel anemones. C) Large sized unidentified sponge and other erect faunal elements. D) Sponge aggregations. E) Anemones and Trochoidean gastropods. F) Single individual of the octocoral *Tripalea* sp.

structures (Roberts et al. 2006; Watling and Auster 2021), the rocky outcrop's characteristics could be argued to align with certain reef-like attributes. The intricate and diverse nature of the rocky substrate may harbor various marine organisms, providing essential niches and habitats for different species. Therefore, one might contend that the rocky outcrop, though not conforming to traditional reef definitions, still functions as a structural foundation that supports marine life and fosters ecological interactions.

Large/old individuals of VME indicator taxa

The subsequent stage involving large/old individuals holds the potential to meet one or more of FAO criteria, including Uniqueness or Rarity,

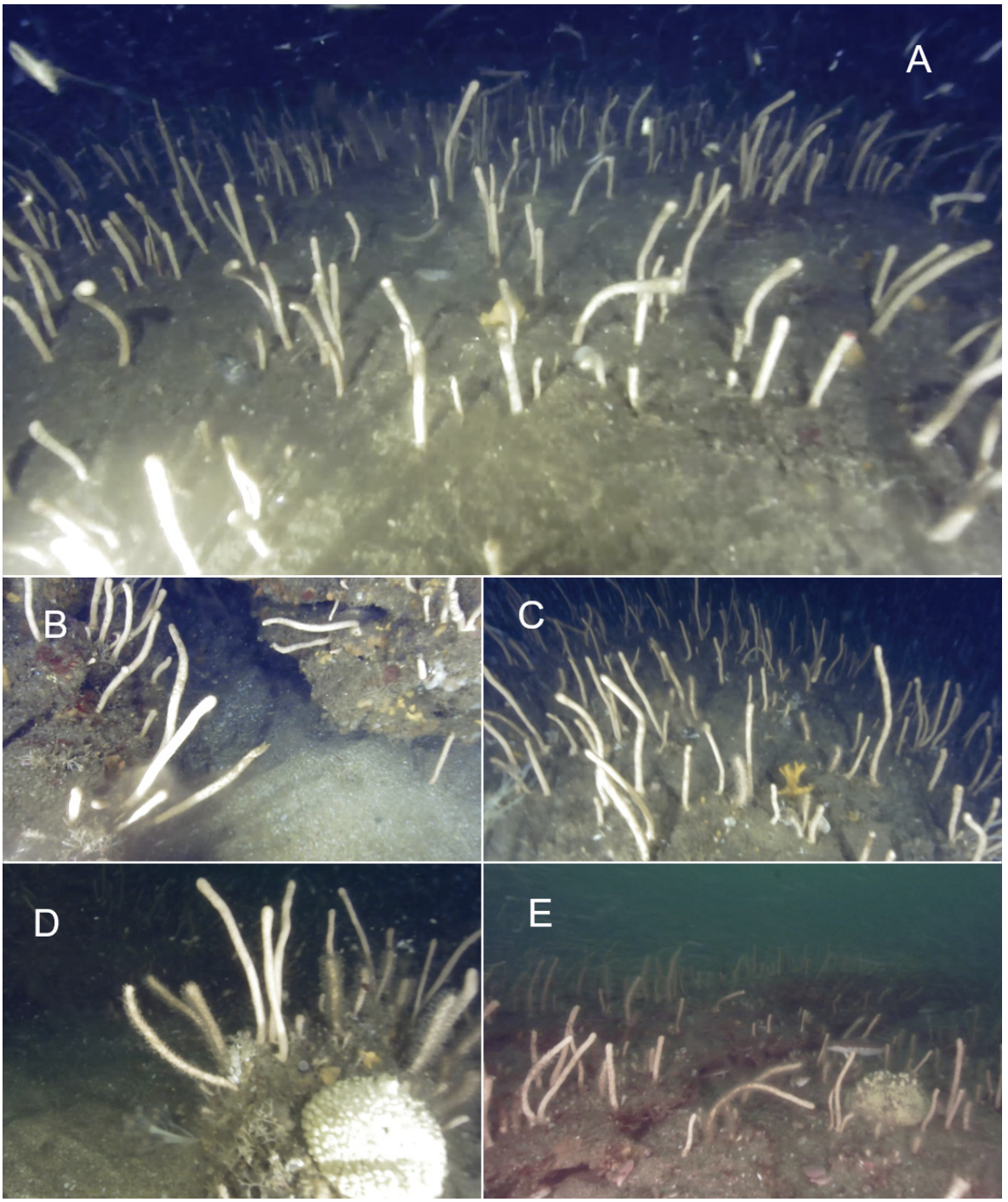

Figure 3. Distinctive elements of the benthic biota present in Restinga del Pez Limón. A) Soft Coral Gardens of the octocoral *Tripalea* sp. on horizontal beds. B) Close-up of *Tripalea* over irregular boulders and associated biota. C) and D) Soft corals and associated large unidentified sponges. E) Functional role evidenced as demersal fish associated with *Tripalea* sp.

Functional Significance, and Fragility. Consequently, the presence of large/old individuals may be regarded as unique or rare for the specific location. Functionally, larger individuals may disproportionately contribute to reproductive success (Beiring and Lasker 2000). Additionally, it is common for large individuals to serve as habitats for various associated fauna. This criterion is likely satisfied by the observation of large sponges, although no biological associations with other species were observed.

Visible functional role

If the specified criteria are not met, but a visible functional role, such as acting as a nursery or feeding areas, is evident, the area can still be deemed a VMEs, also defined by FAO as 'areas or habitats' crucial for the survival, function, reproduction, or recovery of fish stocks. The name 'Restinga del Pez Limón', for instance, is due to the existence of fishing activities related to the lemon fish, *Seriola lalandi*. This necto-pelagic predator is linked to these reef structures, where it forms schools. Beyond these structures, its presence is almost non-existent. There is evidence that supports that this region serves mainly as a feeding area for the species, particularly from November to March during the southern hemisphere summer (Marin 1993). It is worth noting, however, that the nursery role of VME indicators may not always be immediately apparent from survey images, necessitating closer examination of specimens at a finer scale (Baco et al. 2023). In any case, the current evidence of its functional role as a feeding area is sufficient to demonstrate its significance.

Threatened taxa present

In connection with the Functional Significance and Uniqueness and Rarity criteria, specifically concerning the 'Threatened Taxa' category in the flow chart, FAO Guidelines describe VMEs as 'areas or habitats necessary for the survival, function, reproduction, or recovery of rare, threatened, endangered, or endemic species.' Regarding the criterion of threatened taxa, it is emphasized that without accurate taxonomic determinations of species, making definitive statements becomes challenging. Additionally, *Tripalea* has not been evaluated, and the grouper *Acanthisthius* sp. is labeled as data deficient. The guideline implies that areas where rare or endemic species are confirmed or likely to occur should be identified as VMEs, regardless of the presence of biogenic habitat or listed VME indicators. This approach suggests that the discovery of rare or endemic species in an area should be sufficient grounds to designate it as a VME, even if traditional biogenic habitats or recognized VME indicators are absent.

Thresholds (density or diversity)

In the study by Baco et al. (2023), the final three steps involve placeholder 'threshold' values. According to the FAO criteria, 'Structural Complexity' is defined as an ecosystem characterized by complex physical structures created by significant concentrations of biotic and abiotic features. The term 'significant concentrations' necessitates a threshold value, such as defining high enough densities of VME indicators or species diversity for site designation as a VME. In our case, we lack a means to calibrate images in terms of densities or abundances per unit area. However, the ubiquity and abundance, particularly of *Tripalea*, suggest that the abundance threshold would likely be met, at least for the Restinga del Pez Limón. As discussed earlier, the presence of jewel anemones and sponges could be considered candidates in relation to this indicator in Bajo San Jorge.

CONCLUSIONS

The two surveyed sites exhibit significant characteristics that render them potential candidates for designation VME or, at the very least, warrant explicit consideration during spatial prioritization initiatives. Nevertheless, the utilization of imagery

falls short in entirely substituting the significance of whole-organism specimens in scientific research. In-depth and complex studies, which are frequently difficult or unfeasible with nonlethal samples such as recordings or photos, greatly depend on the insights offered by complete specimens (Nachman et al. 2023). In light of the pressing challenges posed by intense international fishing activities and the persistent impacts of climate change on marine ecosystems, the acquisition of such comprehensive baseline data is imperative. This information serves as an invaluable foundation for fostering informed conservation and management efforts aimed at safeguarding these ecologically sensitive areas. By recognizing the potential designation of these sites as VMEs, conservation practitioners and policymakers can proactively address the imminent threats, implementing strategic measures to mitigate the impacts of fishing activities and climate change, ultimately contributing to the sustainable preservation of marine biodiversity and ecosystem health.

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Author contributions

Alvar Carranza: performed investigation, supervision, and writing-original draft and conceptualization. Pablo Limóngi, Rodrigo Gurdek-Bas, Sofia Santos, Aitor Azcárate, and Agustín Loureiro: performed investigation-review and editing. Hernán Pérez Orsi contributed to review and editing as well as project administration. Pablo Muniz: performed investigation-supervision, and contributed to review and editing.

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