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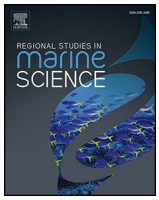

Investigating stakeholders' perceptions regarding seahorses' conservation and conflicts in an European estuarine environment

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ABSTRACT

Estuaries play a vital role in sustaining biodiversity and providing ecosystem services that support ecological and socioeconomic well-being. However, they face numerous anthropogenic threats undermining their resilience and long-term sustainability. The Tagus estuary, located in Portugal and home to five syngnathids species, has been consistently impacted by anthropogenic stressors with adverse impacts on the ecosystem. Syngnathids have been recognized as potentially effective flagship species for estuarine conservation, yet little is known about their populations in the Tagus estuary. This study aimed to investigate the community's interests, perceptions and historical references of the local natural assets, specifically of the local seahorse population. A total of 100 in-person and online interviews were conducted to characterize local stakeholders, their activities, and their Local Ecological Knowledge. Most participants were aware of the presence of seahorses in the local environment. However, sightings were mostly reported by fishermen and related to bycatch incidents. Participants reported seahorse sightings across the estuary and a generalized positive perception of these animals, but there is still a lack of detailed information and consolidated knowledge about them. This case study's results provide information for local seahorse conservation and highlight the great potential of this group as a flagship for estuarine conservation.

1. Introduction

Estuaries are ecologically and socioeconomically vital habitats, offering numerous ecosystem services such as water and food provisioning, transportation, coastal protection, water purification, carbon sequestration, and cultural and recreational benefits (Boerema and Meire, 2017; Donázar-Aramendía et al., 2019; Howe et al., 2009; Martin-Smith and Vincent, 2005). These highly productive environments provide essential habitats, supporting diverse species and contributing to community well-being by promoting physical and mental health and fostering social cohesion (França et al., 2011; Kennish, 2002). Estuaries also play a role in preserving traditional small-scale activities, which have fewer environmental impacts than industrialized methods and reinforce connections between people and their environment (Battaglia et al., 2010). Despite their importance, estuaries face increasing threats from urbanization, agriculture, and industrial activities, which lead to habitat degradation, pollution, overexploitation, and biodiversity loss (Lotze et al., 2006; Morris et al., 2015; Teichert et al., 2016). These pressures are compounded by climate change and extreme weather events, further compromising estuarine ecosystems' resilience (Leal Filho et al., 2022; Zhang et al., 2024). However, biodiversity within estuaries is critical to maintaining ecosystem functions, such as nutrient cycling and food web stability, which underpin their overall ecological health (Li and Liu, 2023). A diverse range of species helps to maintain the overall health of estuarine ecosystems.

Syngnathids are one of the many groups known to inhabit estuaries and coastal waters, yet, despite scientific progress, there is still much to know about their habitat preferences in these environments (L.A. Aylesworth et al., 2015; Tiralongo et al., 2021; Woodall et al., 2018).

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Syngnathids are present in tropical and temperate regions, distributed in shallow coastal or estuarine waters, primarily inhabiting corals, seagrasses, and mangroves (Correia, 2022; Correia et al., 2018; Curtis and Vincent, 2005; Gristina et al., 2015; Vincent et al., 2011). In temperate regions, seahorses are typically found in seagrass meadows, rocky substrates, algal beds, sponges or artificial structures (Correia et al., 2015; Foster and Vincent, 2004; Harasti et al., 2010). Their limited mobility, small home ranges, scattered distribution, low fecundity, and extensive parental care make them vulnerable to natural and human-induced disturbances that are common in these areas (Correia, 2022; Foster and Vincent, 2004). Given the vulnerability of syngnathids, they have been subjected to specific legislation. A new resolution, WCC-2020-Res-095, was approved at the International Union for Conservation of Nature (IUCN) World Conservation Congress, focusing on the conservation of seahorses and other syngnathids. Seahorses (*Hippocampus* spp.) are listed on Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Moreover, both European species of seahorses – *Hippocampus guttulatus* (Long-snouted seahorse) and *Hippocampus hippocampus* (Short-snouted seahorse)- are covered by the Bern Convention and the Barcelona Convention for the Protection of the Marine Environment and Coastal Region of the Mediterranean. In Portugal, seahorses and pipefish are protected by law under the Decree Law n. º 38/2021 to ensure their conservation and appropriate management. These species inhabit estuaries and lagoons (e.g., Ria Formosa lagoon and Sado, Mondego and Tagus estuaries), some of which are part of the Natura 2000 network (Diretiva92/43/CEE).

The Tagus estuary, one of the largest estuaries in Europe, is surrounded by the highly populated Metropolitan Area of Lisbon, which is home to approximately 2.8 million inhabitants. The Tagus estuary has undergone significant anthropogenic changes, with only one percent of its margins consisting of natural areas (Rilo et al., 2012). As in many other estuaries around the world, the Tagus estuary has been continuously impacted by urban development, pollution from various sources, dredging activities, construction and operation of port facilities, as well as commercial, industrial, and fishing activities (Duarte et al., 2014; França et al., 2011). Furthermore, the effects of climate change, including average temperature increase, overall precipitation decrease, and sea level rise, are predicted to be more pronounced in this region compared to the global average (IPCC, 2021). In addition, there is a lack of control and enforcement of fishing regulations, resulting in the frequent use of illegal gear to catch large quantities of fish and molluscs (Coelho et al., 2021; Costa and Cabral, 1999). These threats contribute to habitat loss and degradation, leading to decreased fish abundance, the disappearance of certain species, and the proliferation of non-indigenous species, causing possible ecosystem imbalances (Baeta et al., 2005; Duarte et al., 2014). Five species of syngnathids were previously reported in the Tagus estuary: *H. hippocampus, H. guttulatus, Syngnathus abaster, Syngnathus acus, and Syngnathus typhle* (Neves et al., 2008). The pipefish species (genus *Syngnathus*) are categorized as "Least Concern" according to the latest IUCN Red List Assessment, while both seahorse species are classified as "Data Deficient" (IUCN, 2013, 2014, 2016a, 2016b, 2017). Soft sediment fauna and species without local commercial value, such as seahorses, are generally under-researched (De Brauwer and Burton, 2018). Due to their high dependence on specific habitats and their vulnerability to disturbances, seahorses can serve as key indicator species for estuarine ecosystem health, as their decline may signal broader environmental imbalances and degradation (Gristina et al., 2015). Moreover, Syngnathids have significant potential as efficient flagship species for conservation in estuarine systems due to their charismatic nature and the conservation challenges and opportunities they present (Martin-Smith and Vincent, 2005; Shokri et al., 2009). In fact, seahorses are often used as flagship species to foster support for the establishment of small, community-managed no-take marine protected areas (e.g., the Philippines) (Yasué et al., 2012). These marine fishes receive significant public support and empathy, and conservation actions associated with them are relatively unlikely to generate controversy (Shokri et al., 2009; Stanton et al., 2021).

Little is known about seahorses in the Tagus Estuary, with only a few non-targeted studies reporting occasional occurrences or accidental catches by fishermen. Recently, local fishers in Trafaria, located on the southern bank of the Tagus Estuary, identified a population of conservation interest. This population stands out due to its high densities and larger average body lengths compared to other areas within the distribution range of both species (Silva et al., 2023; Woodall et al., 2018). These findings highlight the importance of integrating Local Ecological Knowledge (LEK) to supplement scientific data, as it can provide valuable insights into species distribution and temporal changes (L. Aylesworth et al., 2017; Costa and Cabral, 1999). Local historical references, such as the seahorse logos of the local newspaper *Notícias da Gandaia* or the water treatment plant, hint at a potential long-standing community bond with these charismatic species. Exploring stakeholders' LEK not only enhances ecological understanding but also identifies areas of agreement and conflict, helping to engage key groups in promoting sustainable practices (de Juan et al., 2017). Studies in other regions have demonstrated that incorporating stakeholder perspectives strengthens conservation efforts by addressing the social, economic, and ecological dimensions of resource use, empowering communities, and fostering long-term sustainability (Davis and Wagner, 2003; de Juan et al., 2017; Gerhardinger et al., 2009; Ternes et al., 2023).

This study aimed to investigate the interests and perceptions of the local community regarding the role of seahorses in the estuarine environment of Almada, located at the river mouth on the south bank of the Tagus estuary. The main objectives of this study were: i) to identify the stakeholders, ii) to profile the stakeholders based on their influence and interest, iii) to pinpoint areas of activity and potential conflicts, and iv) to assess their understanding and perceptions of the local estuarine environment, with a special focus on the seahorse population. The findings from this study shed light on the role of seahorses as flagship species for the conservation of Tagus' estuarine environment, providing insights into conservation priorities and major challenges.

2. Material and methods

2.1. Study area

This study was conducted in Almada, a municipality located in the Lisbon metropolitan area (Fig. 1). Almada is limited to the West by the Atlantic Ocean, and to the North and East by the Tagus estuary. Its privileged riverside and seaside location shaped its socioeconomic development over time (Teixeira, 2019). The riverside area of Almada extends over 10 km of shoreline under the direct influence of the central channel of the Tagus estuary. The central channel, with an average depth of 32 m and predominant sandy bottom, separates the largest area of the estuary from the river mouth. In this zone of the estuary, the salinity exhibits a relatively minimal range of variation, with values ranging from 32.5 to 35.8 PSU, contrasting with larger fluctuations observed in upstream areas (Rodrigues et al., 2020). Furthermore, it has a distinct pattern of current rising prominently along the southern margin and receding along the northern margin (Costa, 2020). This study was carried out in five easily accessible locations that encompass a wide set of socio-economic activities, from fluvial transportation, industry, and recreational activities to small-scale traditional fisheries, coexisting within the estuarine environment (Fig. 1c). These locations include touristic, residential, industrial, commercial, and fishing areas, and therefore, representative of the riverside front in Almada.

2.2. Data collection

Surveys were conducted between January and March 2023 and targeted multiple stakeholder groups that represent the range of socio-economic uses in the area (Noble et al., 2020). In-person surveys were

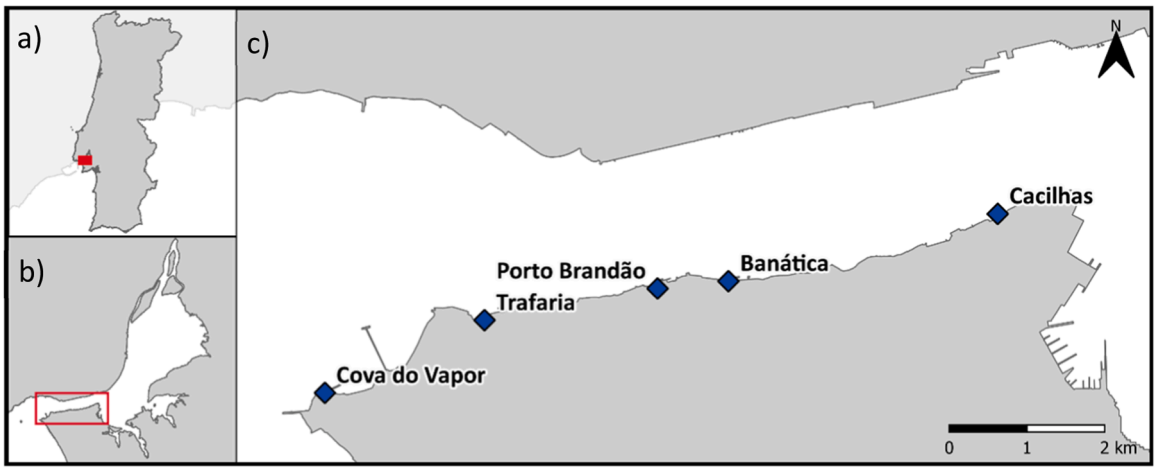

Fig. 1. Map of the study area in the Tagus estuary: a) location of the Tagus estuary in Portugal; b) Tagus estuarine area; c) sampling sites.

conducted in five sites: Cova do Vapor, Trafaria, Porto Brandão, Banática, and Cacilhas (Fig. 1). Additionally, online surveys with the same questions were carried out when in-person was not possible to reach a larger number of responses. While in-person surveys provided stronger engagement through interactions, allowing interviewers to clarify questions and minimize missing data, the online surveys sought to increase the sample size. It is acknowledged that combining these methods may result in differences between the samples that should be considered when interpreting the results. Online surveys were primarily self-administered, but follow-ups via phone, email, or video calls (e.g., Zoom/Skype) were conducted as necessary to clarify or explore specific responses of the open-ended questions. All participants participated voluntarily, providing informed consent after being briefed on the study's background and objectives. The surveys took approximately 15 min to complete and included a mix of open- and close-ended questions.

The interviews followed the General Data Protection Regulation (GDPR) guidelines, ensuring the protection and confidentiality of participants' data. To be included in the study, participants were required to frequent the area or be affiliated with an organization related to the Tagus estuary. Initially, a preliminary list of stakeholders was compiled through web searches. In addition, a snowball sampling methodology, where initial participants referred others, was also used to identify key community stakeholders (Bendtsen et al., 2021; Wang and Aenis, 2019). Snowballing also helped to provide information on the interactions between stakeholders and ensured that sampling saturation was being reached (Bryman, 2016; Noble et al., 2020).

Semi-structured interviews with closed and open-ended questions were used to assess participants' LEK. This methodology ensured the same questions were consistently asked to all the participants while providing a fluid conversation and allowing them to add as much information as they considered adequate (Bryman, 2016). Before starting the surveys, the questionnaire was tested with a group of six stakeholders. Their feedback helped to adapt the questions and the structure of the survey before starting its implementation. All interviews were carried out by two people, one posing questions, and the other taking handwritten notes. The questionnaire consisted of five sections: i) sociodemographic data, ii) fisheries, iii) environmental characterization, and iv) stakeholders (see Table A. 1 in Appendix A). The fisheries section was specific for fishermen and encompassed questions about their main fishing activities and practices. Special attention was given to fishermen because they have the most direct interaction and dependence on the estuarine environment and its biodiversity. The environmental characterization section included close-ended questions concerning the participants' influence and interests in the conservation of the local environment and their perception of the presence and location of seahorse species. It also included open-ended questions to explore participants' perceptions of seahorses, wherein they were asked to name three words to define them and to report memorable stories and events involving these animals. In the last section, participants were asked to identify other stakeholders for the snowballing methodology. Location-related questions were based on a numbered gridded map (see Figure A1 in Appendix A) which allowed participants to indicate the numbers on the map in which they developed their activities and/or in which they have seen seahorses.

2.3. Data analysis

2.3.1. Fisheries

Maps displaying fishing locations were assembled by retrieving the midpoint coordinates of each grid cell indicated by the interviewees. The fishing location layers were created as a heatmap visualization, resulting from interpolation and representing the density of activity reported in each location. The map layers were generated in QGIS v. 3.22.0-Bialowieza (https://qgis.org/en/site/).

2.3.2. Environmental characterization

Responses to the open-ended questions related to participants' perceptions of the seahorses (naming three words) were clustered in categories. This homogenization of the data, resulted in 12 levels of the factor "category", e.g. "conservation" included words like protection and preservation (de Juan et al., 2017). To determine the statistical significance of the participants' response and their sector or activity and age, a Fisher's exact test with Monte Carlo simulations (n = 10,000) was performed, due to the large size of the dataset. Age (years) was distributed in six ranges (25–34, 35–44, 45–54, 55–64, 65–74, >75). The analysis was carried out using the *stats* package v.4.2.3 in R v.4.2.3 (www.R-project.org). In case of significant results, pairwise comparisons were conducted using the *rcompanion* package v.2.4.26 in R v.4.2.3. The Holm-Bonferroni method was used to correct for multiple comparisons. Fisher's exact test was also used to test if there was a statistically significant association between the participants' sector of activity or the time (years) they spent in the area and their sightings of seahorses. The duration of time spent in the area was distributed in four ranges (<10, 10–29, 30–50, >50). The same test was used to assess if these two variables influence the participants' perception of abundance over time. Pairwise comparisons were also carried out in case of significant results. Finally, the seahorse location layer was created in QGIS v. 3.22.0-Bialowieza using graduated symbology. The value being weighted was the absolute frequency of sightings reported at each point.

3. Results

3.1. General characteristics of the participants

A total of 100 surveys were carried out (59 in-person and 41 online). The sampling group included 20 participants from the Administration/Authorities sector, 18 from the Civil Society, 14 from the Commercial sector, 18 members of the Fisheries sector (only professional fishermen), 16 people related to the Recreational Activities sector (mostly represented by recreational fishermen), and 14 members of the Scientific Community. Gender balance was maintained in the interviews conducted with the Civil Society, Administration/Authorities, and Scientific Community sectors, with similar numbers of males and females participating. However, the majority of participants interviewed from the Fisheries, both Commercial and Recreational Activities sectors were males. A significant proportion of interviewees were aged between 45 and 54 years, comprising 25 % of the total participants. Furthermore, 32 % of the interviewees had been frequenting the study area for a period of 30–49 years (Table 1).

3.2. Fishermen

An equal number of professional and recreational fishermen were surveyed. The results showed that 47.4 % of professional fishermen have been fishing in the area for 10–29 years, while most recreational fishermen have been doing it for 10–29 years (36.8 %) or even for 30–49 years (36.8 %). Most professional fishermen (58 %) rely solely on fishing as their primary source of income, while 37 % supplement their income with other sources. On the other hand, 84 % of fishermen with recreational licenses do not rely on fishing as their source of income, although fishing is the sole source of income for 11 % of them. Additionally, a significant number of professional fishermen (63.2 %) come from families with a fishing tradition (see Table B. 1 in Appendix C). Most fishermen, both professional and recreational, use rod and handline as their primary fishing methods, with 47 % and 63 % employing this technique, respectively. Additionally, nets (e.g., gill nets), are amongst the most commonly used fishing gears by professional fishermen, with 36 % reporting their use. Apart from rod and handline, baited jigs and hand-catch while diving are used by both professional and recreational fishermen (Fig. 2a). Recreational fishermen who practice hand-catch while diving reported that they rely on this activity as their means of sustenance. When it comes to targeted species, there is an overlap between professional and recreational fishermen. *Dicentrarchus labrax* is the most targeted species for both professional (63 %) and recreational fishermen (57 %), followed by *Octopus vulgaris* (58 %) and *Argyrosomus regius* (58 %) for the former, and *Diplodus sp*. (32 %) and *Sepia officinalis* (32 %) for the latter (Fig. 2b).

Most of the professional fishermen surveyed operate in the western part of the study area, with the highest fishing activity concentrated in front of Trafaria. The northern margin was also frequently used by participants, while some interviewees reported using the eastern part of the area for their fishing activities to a lesser extent (Fig. 3a). Recreational fishing activities, on the other hand, are concentrated in specific areas in the southern margin (Fig. 3b).

3.3. Perceptions about the seahorse community

Responses to the question *"three words that come to your mind when you think about seahorses"* were grouped into broader categories. Significant differences were detected between participants across different sectors of activity (Fisher's Exact test $p = 0.0024$). Pairwise comparisons identified differences between the sectors Recreational Activities and Commercial, Scientific Community and Commercial, and Fisheries and Scientific Community. "Charisma" was the most selected category by participants in the Recreational Activities and Scientific community sectors, whereas words related to "Conservation" were the most frequent in the Commercial sector. These two categories, followed by "Nature", were the most selected across all sectors (Fig. 4). In addition, significant differences were detected between participants across different age groups (Fisher's Exact test $p = 0.041$). However, pairwise comparisons did not detect differences between any pairs of age groups (Fisher's Exact test $p > 0.05$).

Responses to the questions related to the seahorse population in the Tagus estuary revealed that 34 % of the participants were not aware that seahorses were present in the area. Additionally, 24 % of the participants knew seahorses were present but had never seen them, while 42 % of the interviewees reported having seen a seahorse either in the study area or in nearby locations. Moreover, Fisher's exact test results suggest that there is a significant association between the sector to which the participants belong and their seahorse sightings in the Tagus estuary (Fisher's Exact test $p < 0.001$). Pairwise comparisons revealed that participants in the Fisheries sector are significantly more likely to know seahorses are present and to see them in the Tagus estuary than all the other sectors. No significant differences were found between all the other groups (Fig. 5). In contrast, no significant relationship was found between the time each participant has been frequenting the area and their sightings of seahorses (Fisher's Exact test $p > 0.05$).

According to data collected from 38 participants, seahorses have been mostly observed in the western part of the study area, with most sightings occurring in the surroundings of Trafaria. In addition, sighting locations outside the study area, such as Costa da Caparica, Alcochete, Seixal, and Oeiras, were mentioned (Fig. 6).

Table 1
Overview of the characteristics of the participants from the six different sectors of activity (Administration/Authorities, Civil Society, Commercial, Fisheries, Recreational activities, and Scientific Community). numbers represent percentages. "n" Refers to the sample size. "y" Refers to years.

	Civil Society (%) n = 18	Fisheries (%) n = 18	Administration/Authorities (%) n = 20	Commercial (%) n = 14	Scientific Community (%) n = 14	Recreational Activities (%) n = 16
Gender						
Male	44.4	94.4	50.0	78.6	42.9	87.5
Female	56.6	5.6	50.0	21.4	57.1	12.5
Age (y)						
25–34	11.1	5.6	15.0	7.1	14.3	6.3
35–44	27.8	16.7	10.0	28.6	28.6	12.5
45–54	27.8	38.9	35.0	7.1	28.6	6.3
55–64	22.2	11.1	30.0	35.7	28.6	6.3
65–74	5.6	27.8	0.0	14.3	0.0	37.5
75 and older	5.6	0.0	10.0	7.1	0.0	31.3
Time frequenting the area (y)						
< 10	16.7	5.6	25.0	14.3	28.6	6.3
10–29	27.8	22.2	20.0	21.4	28.6	31.3
30–50	33.3	27.8	35.0	35.7	28.6	31.3
> 50	22.2	44.4	20.0	28.6	14.3	31.3

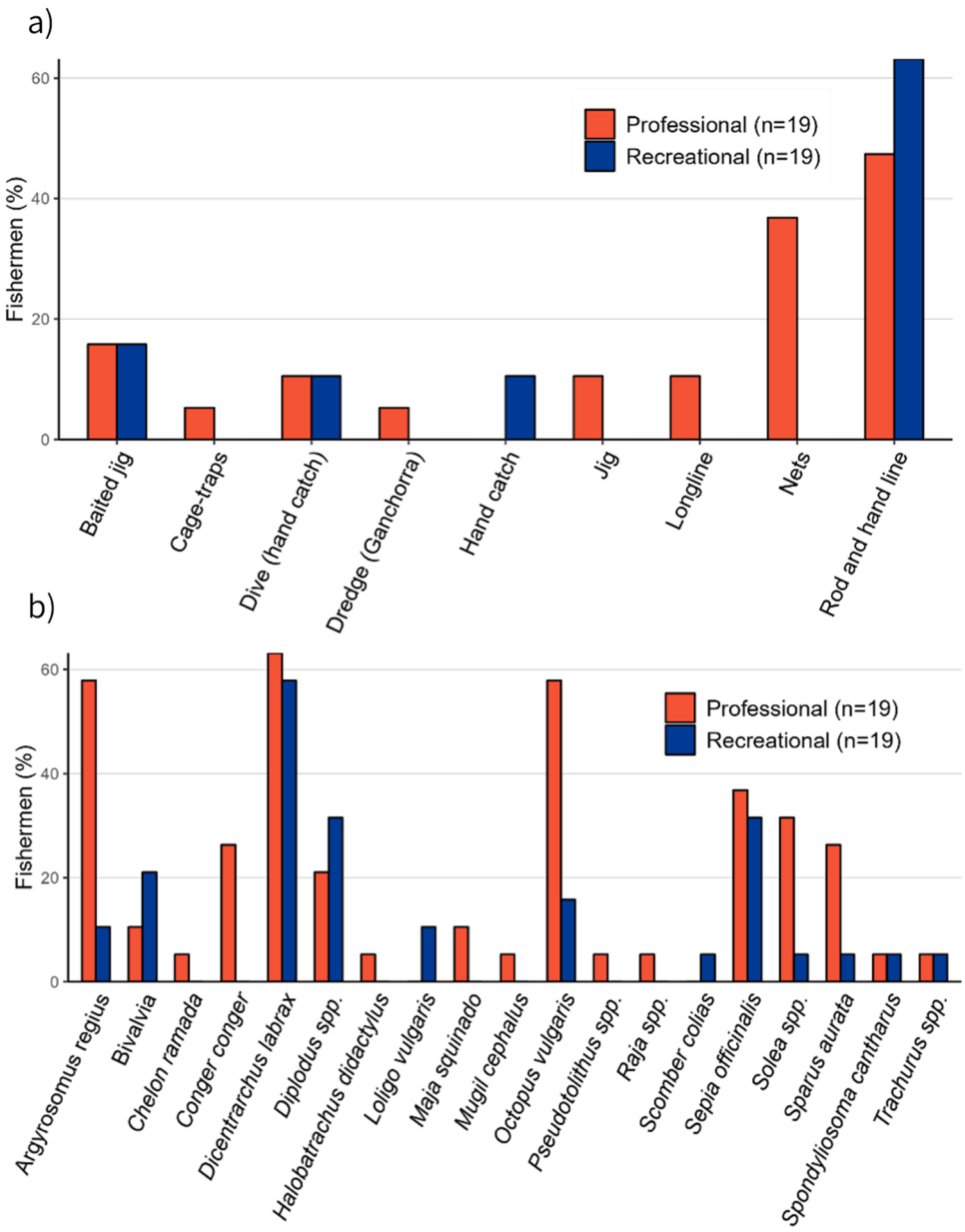

Fig. 2. The main characteristics of the interviewed professional and recreational fishermen, indicated by (a) main fishing gear used: the percentage of fishermen using each type of gear; (b) main target species: the percentage of fishermen fishing each species.

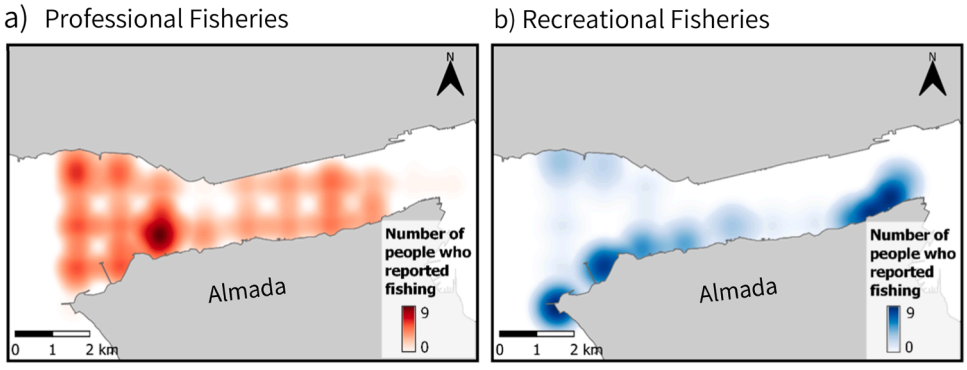

Fig. 3. Map of (a) professional fisheries locations and (b) recreational fisheries locations reported by the fishermen in the central channel of the Tagus estuary. The color scale represents the number of fishermen that reported fishing in each location.

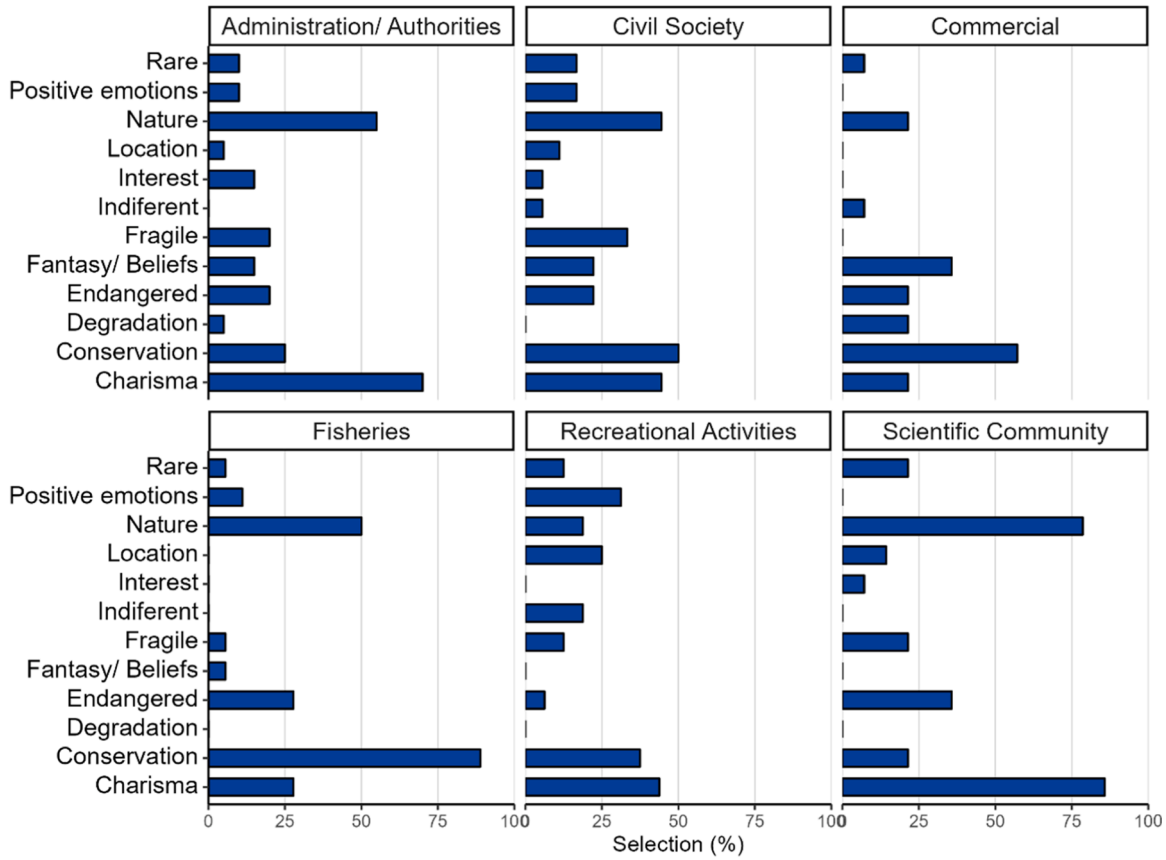

Fig. 4. Percentage of word selection as a response to the question that asked for "three words that come to your mind when you think about Seahorses". words were grouped into broader categories and the percentage of selection of words was calculated for all six sectors of activity (Administration/Authorities, Civil Society, Commercial, Fisheries, Recreational Activities, and Scientific Community).

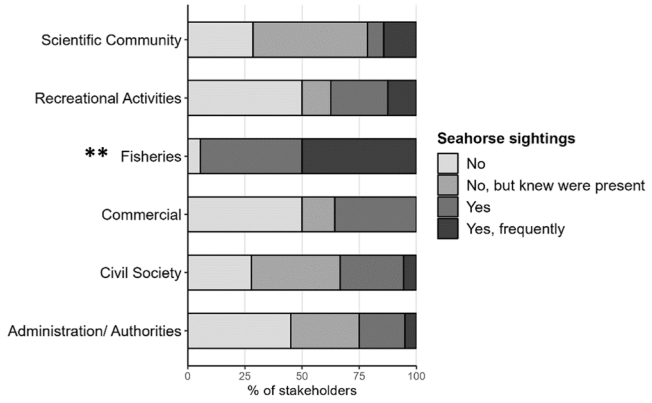

Fig. 5. Percentage of interviewees from all six sectors (Scientific Community, Recreational Activities, Fisheries, Commercial, Civil Society, and Administration/Authorities) of seahorse sightings in the Tagus estuary. ** represents that the fisheries sector is significantly different from all the others for a 95 % significant level.

When asked about the changes in seahorse abundance over time, 17 % of the participants noticed a decrease in seahorse population over time, while only 7 % indicated that seahorses are more abundant now. 5 % did not notice any change, and most participants (71 %) were unsure about the trends in seahorse abundance. Fisher's exact test results revealed a statistically significant relationship between the sector each participant belongs to and their perception of abundance over time (Fisher's Exact test $p = 0.032$). However, no significant differences were found between the different sectors when pairwise comparisons were performed. In addition, no statistically significant association was found between the time each participant has been frequenting the area and their perception of abundance over time (Fisher's Exact test $p > 0.05$).

Finally, a total of 29 participants recounted anecdotes or significant events related to seahorses. Furthermore, 18 participants acknowledged possessing dried seahorses, a practice rooted in cultural beliefs and traditions that associate these creatures with good fortune and affluence. The stories shared by the interviewees shed light on the community's deep connection with seahorses:

> "*Almost all fishermen have dried seahorses at home or in their wallets for good luck.*" (Professional fisherman, 52 years old)

> "*In the old days they were kept in the cap for good luck.*" (Professional fisherman, 49 years old).

> "*Since I saw them and started filming, I have been following their courtship with the females, their feeding, their bellies growing, and the dangers they have been facing. It's impossible not to fall in love with this species. I want to show these animals and make the local community proud of them, but to do so, they must help to protect them.*" (Underwater videographer, 44 years old).

> "*Some years ago, I was fishing octopus in Cova do Vapor and it was only when I got home that I realized I had caught a seahorse, which ended up dying in my house.*" (Recreational fisherman, 80 years old).

Others provide insight into the local seahorse population:

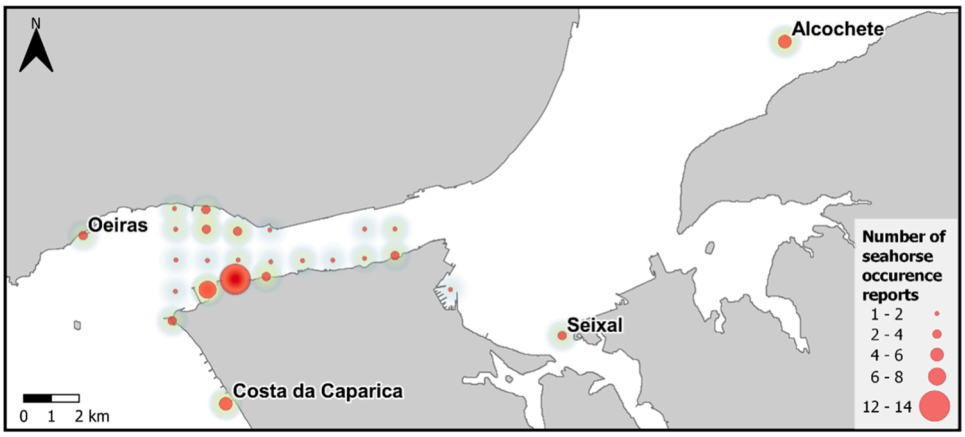

Fig. 6. Map of seahorse sighting locations. The size of the circles represents the absolute frequency of sightings reported by participants in each location.

"*Once, some years ago, we were net fishing in front of Algés and 12 seahorses came in the net.*" (Professional fisherman, 37 and 68 years old).

"*Every year I find dead seahorses on the beaches of Costa da Caparica.*" (Marine wildlife photographer, 58 years old).

"*I often hear from older people living in Trafaria that they used to see a lot of seahorses in the past, nowadays they don't.*" (Member of a local association, 45 years old).

4. Discussion

Seahorses were generally recognized by participants as a part of the local ecosystem. However, their cryptic nature and behavior make them challenging to notice, with most sightings being reported by professional fishermen. Fisheries play a critical role in supporting the livelihoods of local fishermen. However, inadequate enforcement results in illegal fishing practices, gear use, and non-compliance with the regulations in place, which negatively impacts traditional activities, the local economy, and the ecosystem. Although seahorses are not a target species for local fisheries, the former still pose a threat to these populations, as sightings were mostly related to bycatch incidents. Contradicting viewpoints in abundance trends perceptions may suggest abundance fluctuations over time. Moreover, the presence of seahorses in different areas of the Tagus estuary, the challenges they face, and a generally positive perception of these organisms make them potentially effective flagship species for the conservation of the estuarine environment. During this study, there were difficulties in engaging and obtaining collaboration from certain entities, like major industrial companies operating in the study area, as well as some national authorities. Furthermore, although the inclusion of Civil Society participants is crucial for exploring the potential of seahorses as flagship species, the sample was limited due to constraints in time and personnel. This led to a narrower representation of the Civil Society group, which could have provided more diverse sociodemographic perspectives on the knowledge and emotional connections to seahorses. Despite these limitations, the online surveys allowed us to reach a larger and more diversified group of stakeholders, which provided valuable insights into the potential of seahorses as flagship species. However, it is acknowledged that the use of online surveys limited the depth of exploration for certain questions compared to in-person interviews, and future studies could benefit from more in-depth, face-to-face engagement.

4.1. Fisheries scenario

A significant number of professional fishermen diversify their income, reducing economic vulnerability, but most still rely solely on fisheries, highlighting their critical role in livelihoods. Some recreational fishermen also depend entirely on fisheries, raising concerns about potential license misuse and weak enforcement. While both groups target overlapping species, professionals focus on high-market-value catches like octopus and meagre, as described in previous studies (Cardeira et al., 2012; Pilar-Fonseca et al., 2014; Santos, 2022). They operate mainly in the western estuary near Trafaria's fishing port, whereas recreational fishermen use simpler methods in accessible nearshore areas.

Weak enforcement enables illegal fishing, including unauthorized dredging (ganchorra) and hand-catching while diving (Carvalho, 2017; Costa and Cabral, 1999). Dredging is particularly harmful, disrupting sediments and damaging benthic habitats (Cunha et al., 2013). The illegal exploitation of Manila clam fuels a parallel economy, sometimes linked to human trafficking and illegal labor in the estuary's innermost areas (Moura et al., 2017). Meagre fisheries also face illicit practices, with some fishermen using chemical explosives, harming fish stocks, disrupting marine life, and hindering resource management (Batista and França, 2022; Wright and Hopky, 1998). Despite signs of seagrass recovery in intertidal zones (R. Melo, pers. comm., 2023), illegal activities may still impact critical subtidal habitats that are critical for seahorse populations. The persistence of illegal fishing, despite media and scientific attention, underscores the need for stricter regulations and enforcement. However, many professional fishermen, deeply rooted in fishing traditions have demonstrated interest in participating in conservation efforts (see Figure C1. In Appendix C). Engaging fishing communities, who possess valuable LEK could foster stewardship, build trust with authorities, and improve compliance for sustainable fisheries (Davis and Wagner, 2003).

4.2. Perceptions about the seahorse community

Most participants demonstrated awareness regarding the presence of seahorses in the Tagus estuary, emphasizing the recognition of seahorses as a part of the local ecosystem and a major asset to preserve. However, it is important to note that these findings may not represent the majority of the community of Almada's Municipality, as participants were selected based on their connection to the local area. Participants from the Recreational Activities, Commercial, and Administration/Authorities sectors showed relatively low levels of awareness concerning the presence of seahorses in the estuary, while professional fishermen revealed the highest levels of awareness and reported the most seahorse sightings. This can be attributed to the frequent presence and direct interaction of fishermen with the underwater estuarine environment, which increases their LEK and the likelihood of seahorse sightings. Therefore, it is logical that the locations where participants have spotted

seahorses align with fishing areas. Life traits and characteristics of seahorses, such as behavior and cryptic ability, make them challenging to notice even for individuals actively engaged in marine activities (Foster and Vincent, 2004). Therefore, seahorses are frequently "out of sight" and, consequently, they may be "out of mind", "far from the heart", and distant from conservation initiatives and frameworks. The experiences shared by the participants during the semi-structured interviews revealed that most reported sightings are associated with dives (extremely selective fishing arts), the encounter of deceased seahorses washed ashore on the beaches, and, mainly, with bycatch incidents. Nets (gill nets) and dredges (*ganchorra*) have been identified as the main gear associated with seahorse bycatch. This aligns with previous studies indicating that seahorses and their habitats are not only threatened by the destructive impacts of certain fishing gears (e.g. dredges), but are also caught as bycatch in trawls, gill nets, and cage traps (Lawson et al., 2017; Vasconcelos et al., 2019). The differences in fishing methods used by professional and recreational fishermen may contribute to the relatively lower awareness and impact on seahorse populations among the latter group. Moreover, the accuracy of sighting locations varies depending on whether seahorses were observed by divers, found as bycatch, or washed ashore. The results indicated the presence of seahorses throughout the central channel of the Tagus estuary, characterized by a predominantly sandy substrate (Costa, 2020). Additionally, reports from multiple participants indicated that the seabed in the Trafaria bay is littered with debris. During biodiversity assessments conducted for the Municipality of Almada, divers reported a relevant community of seahorses for conservation at the global level, mostly *H. guttulatus,* clinging onto the rubbish (Silva et al., 2023). Other studies previously (Gristina et al., 2015; Tiralongo and Baldacconi, 2014) demonstrated that *H. guttulatus* can thrive in polluted environments and can be found attached to artificial substrates, such as wharves, wooden poles, nets, and ropes, whereas *H. hippocampus* is mainly associated with habitats with low complexity. The presence of seahorses in these areas demonstrates their capacity to coexist in anthropogenically influenced areas and their adaptability to highly altered habitats (Correia et al., 2018, p. 202). It is important to highlight that the number of reported sightings does not necessarily correlate with the actual abundance of seahorses in a given location. For instance, Trafaria bay stands out as the location with the highest number of reported seahorse sightings. However, this could be attributed to a recent mediatic incident, witnessed by some of the participants, where seahorses were rescued following a pontoon collapse. Additionally, the proximity of this area to the fishing port increases its accessibility and frequent visitation by many people, potentially enhancing the likelihood of seahorse sightings. Furthermore, the frequent reports of seahorse sightings outside the designated study area, indicate that seahorses are present in various regions of the estuary, highlighting the importance of considering the estuary as a whole when studying seahorse populations.

The participants' perception of seahorse abundance does not provide a clear understanding of the trends in local seahorse populations over time. While most participants express uncertainty about the abundance trends, there are contradictory viewpoints among them. Some participants believe that seahorse abundance has increased over time due to improvements in the estuary pollution levels. On the other hand, others assert that frequent dredging, illegal fishing activities, and diminishing sightings suggest a potential decline in seahorse populations. There was also one single mentioning the illegal trade of these animals to the TCM market. However, this was an isolated report, thus, no conclusions can be drawn about the prevalence of this illegal activity in the Tagus estuary. Illegal commercialization to the TCM market, despite being internationally banned by CITES, is a common practice worldwide and has also been identified in Ria Formosa, located in the southern region of Portugal (Correia, 2022). The conflicting viewpoints may indicate that seahorse populations exhibit abundance fluctuations over time. In the Ria Formosa Lagoon, a decline in 9 % of the seahorse population has been revealed. It seems mainly associated with a decrease in holdfast availability caused by anthropogenic influences (Correia, 2022, p. 202). Moreover, anthropogenic activities such as illegal fishing and dredging are responsible for altering the seahorses' habitat conditions (Correia et al., 2015). Additionally, small fish species that live in shallow habitats and have intensive parental care, such as seahorses, are particularly vulnerable to bycatch (Lawson et al., 2017). An action plan was developed to safeguard these species in response to declining seahorse populations in the Ria Formosa Lagoon (Public Notice Nº03/2024). The plan aimed to restore populations, implement mooring sites to protect sensitive areas, update knowledge about seahorse habitats, and discourage illegal fishing within the lagoon. However, this plan stands alone in Portugal, where seahorse habitats are covered by only 19–20 % of protected areas, with full protection zones covering less than 0.5 % of the core habitat (Peiffer et al., 2024). Moreover, existing management plans for protected areas do not specifically address seahorse protection, neither surveillance is efficient in these areas. Seahorse population assessments and long-term monitoring are crucial to the understanding of population dynamics and developing effective management plans for these species in the Tagus estuary.

The stories reported by 29 participants evidenced that seahorses hold a special significance or fascination within the community. Traditional practices such as keeping seahorses in the caps or owning dried individuals, indicate that the fisheries community, in particular, associates these animals with superstitions and cultural beliefs. Dried seahorse specimens are frequently associated with good luck, prosperity, and stability, which can have conservation implications that need to be addressed (Filiz and Taşkavak, 2012; Najera-Medellin et al., 2023). Some fishermen ended up disclosing that they do not target seahorses, but when they come as bycatch, they keep them dry instead of returning them to their habitat. This can lead to a population decline and consequent ecological imbalance, as they can be important predators of bottom-dwelling organisms (Bologna, 2007). On the other hand, the identification of this problem may represent an opportunity for implementing education and empowerment campaigns. Some stories also revealed an emotional connection with these animals and a strong motivation for conservation. Moreover, despite some differences in responses to the open-ended questions between sectors, the results do not show any contradictions between groups. Words related to "Charisma", "Conservation", and "Nature" were the most common, indicating recognition of their ecological role, appreciation for their unique characteristics, and concern for their conservation. The participants' perception of seahorses as charismatic species, the consensus among different groups, and their shared conservation concerns suggested the potential of these animals as flagship species in local conservation and restoration of ecologically important habitats that support diverse species groups. Despite different levels of awareness between groups, this consensual perception creates opportunities for engaging the community, inspiring conservation actions, and mobilizing further research, while increasing compliance with regulation (Bennett, 2016).

4.3. Future perspectives and conclusion

The Tagus estuary, just like many other estuaries, is of immense ecological, cultural, and economic importance, requiring its preservation and sustainable management. Efforts over the past three decades have resulted in the improvement of water quality and some natural habitats (e.g. recovery of intertidal seagrass meadows), potentially favoring biodiversity conservation. However, measures targeting subtidal areas, such as fishing regulations and surveillance are inappropriate and insufficiently enforced. Therefore, several challenges persist, underscoring the need for continued action. The present case study highlights the potential of seahorses as a flagship group for the conservation of the Tagus estuary and its ecologically significant habitats. To ensure the long-term sustainability of these animals, adaptive integrated management plans that recognize the feedback between ecosystems and communities are essential (de Juan et al., 2015). In light of the findings from

this study, it is imperative to evaluate the impact of illegal fishing practices on seahorse populations. More research effort is needed to provide solid and precise scientific data to better advise management and implement conservation actions in the field (e.g. ongoing project Eurosyng – Biodiversa+ DivProtect/0005/202). Furthermore, the establishment of a long-term monitoring program is essential to investigate seahorses and their habitats, aiming to elucidate population dynamics and the factors affecting abundance trends within the estuary. Additionally, it is crucial to leverage the potential of seahorses as flagship species to catalyze conservation initiatives and facilitate the restoration of ecologically significant habitats in the Tagus estuary.

Overall, the present case study and the insights gained from the Tagus estuary confirm the previously described potential of seahorses as a flagship group for estuarine conservation and offer valuable lessons and potential strategies that can be adapted and applied to conservation frameworks of other estuaries worldwide.

CRediT authorship contribution statement

Rita Sá: Writing – review & editing, Validation, Supervision, Methodology, Investigation, Conceptualization. **Miguel Correia:** Writing – review & editing, Validation, Supervision, Conceptualization. **Gonçalo Silva:** Writing – review & editing, Validation, Supervision, Investigation, Funding acquisition, Conceptualization. **Joana Macedo Oliveira:** Writing – review & editing, Writing – original draft, Software, Project administration, Investigation, Formal analysis, Data curation.

Declaration of Competing Interest

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

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Appendix A. Summary of the questionnaires conducted with participants

Table A. 1
Content of the questionnaires conducted with all participants. The questionnaire included general sociodemographic questions to describe the participant, a set of specific questions for fishermen, environmental characterization and diagnosis questions, and stakeholder-related questions that were used for the snowball sampling methodology

Sections	Questions
Sociodemographic data	Participants characteristics: 1)Name; 2) Contact; 3) Occupation; 4) Age; 5) Place of origin; 6) Place of residence; 7) Time frequenting the area.
Fisheries	Fishermen characteristics: 1)Type of activity (professional/recreational); 2) Years fishing; 3) Number of previous generations fishing. Fishing practices: 4) Is fishing your source of income? 5) What are the main fishing gear you use? 6) What are your main target species? 7) Where do you fish (map-based question)?
Environmental characterisation	1) Name three words that come to your mind when you think about seahorses. 3) Have you ever seen seahorses in the Tagus estuary? (Select one option) – No – No but knew were present – Yes – Yes, frequently 3) Where have you seen seahorses (map-based question)? 4) Based on your observations, you feel that the seahorse population in the Tagus estuary (Select one option and justify): – Has been increasing – Has been decreasing – Remains the same – I do not know how to answer 5) Do you have any memorable stories or events with seahorses? 6) How much influence do you consider you currently have in the conservation of the estuarine environment within the community? (Select one option) – No influence – Little influence – Some influence – Strong influence 7) Are you interested in actively participating in the protection of the estuarine environment? (Select one option) – Not interested – In keeping informed but not participating – Partially interested in participating – Very interested to participate
Stakeholders	1)What other people or entities do you consider relevant to include in this study and the process of conservation of the estuarine environment of Almada? – Fisheries sector – Authorities

(*continued on next page*)

Table A. 1 (*continued*)

Sections	Questions
	– Scientific community – Commercial sector – Civil Society – Others
Additional information	1)Suggestions/Comments 2)Would you like to receive information on the development and results of this thesis project?

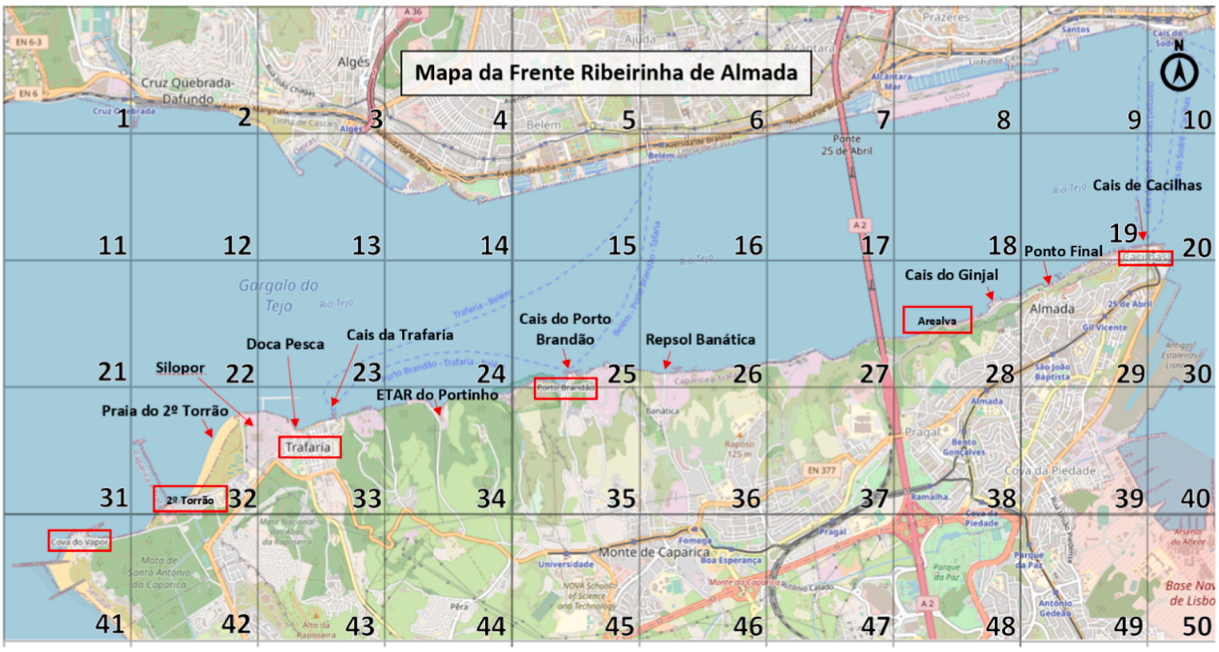


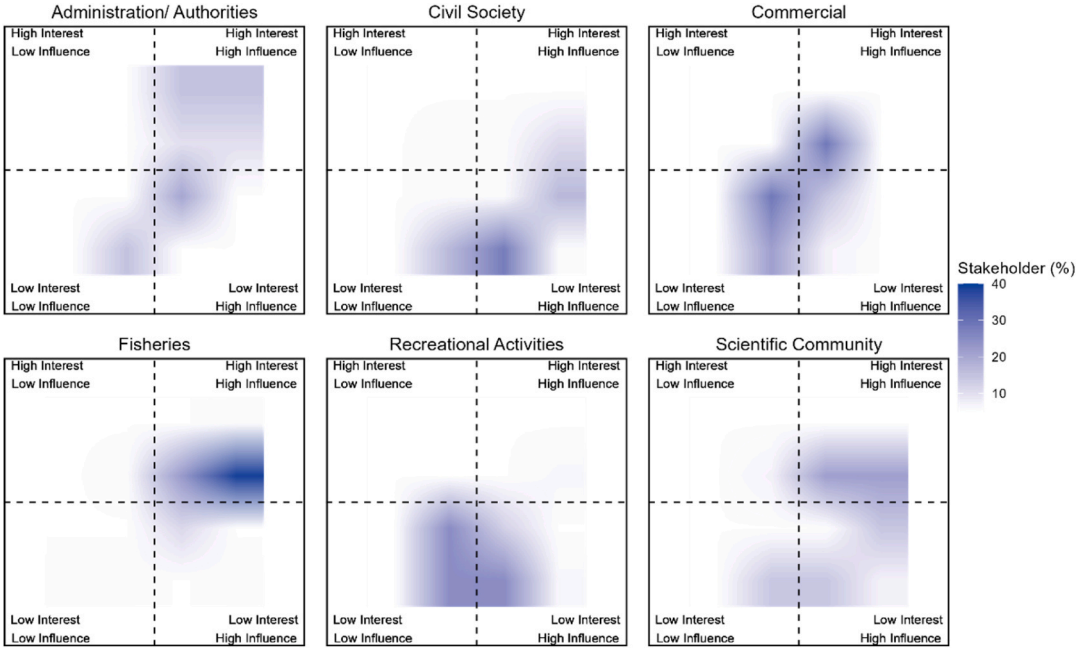
Figure A1. Map of the riverside front of Almada. This map was incorporated into the questionnaire to facilitate map-based questions and collect data about the participants' fishing locations and seahorse sighting locations

Appendix B. Fishermen general characterization

Table B. 1
Overview of the characteristics of professional and recreational fishermen. Numbers represent percentages. "n" refers to the sample size. "y" refers to years

	Professional (%) n = 19	**Recreational (%)** n = 19
Time fishing (y)		
Less than 10	5.3	5.3
10–29	47.4	36.8
30–49	21.1	36.8
50 or longer	26.3	21.1
Source of income		
No	5.0	84.0
Yes, partly	37.0	5.0
Yes, the only one	58.0	11.0
> 1 prior generation in the family fishing	63.2	26.3
Main fishing gear	Rod and hand line	Rod and handline
	Nets	Baited jig
Species most frequently targeted	Sea bass (*Dicentrarchus labrax*)	Sea bass (*Dicentrarchus labrax*)
	Octopus (*Octopus vulgaris*)	Seabream (*Diplodus* sp.)
	Meagre (*Argyrosomus regius*)	Cuttlefish (*Sepia officinalis*)

Appendix C. Power-Interest grids



Data availability

Data will be made available on request.

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