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Are native species of Ria de Aveiro under invasion? The relations between local activities and environmental perceptions on marine biological resources

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Introduction: This study showcases how the end-users of Ria de Aveiro coastal lagoon (Portugal), perceive the threat of invasive alien species (IAS), as well as biodiversity loss, and how it relates to their local activities, environmental identity and risk perception. Previous studies in the region and elsewhere have demonstrated that invasive species might have an impact at the habitats and at the species levels, both with potential negative socio-economic implications for end-users, i.e., for citizens who rely on the ecosystem for their livelihoods. However, this relation is still not well understood.

Methods: Data drew on face-to-face questionnaires run *in situ* at the lagoon intertidal flats. Supported by maps, participants were invited to identify the presence of the habitat *Zostera noltei* (also known as *Zostera noltii*), and the species *Diopatra neapolitana*, *Hediste diversicolor* and *Arenicola* spp., as well as *Ruditapes decussatus*, *Venerupis corrugata* and *Ruditapes philippinarum*, and inquired about the extraction, preference, and preferred areas. Of the 174 participants, 83% were male, and 68% were private citizens. Their main reason to be *in situ* at the time of the questionnaire relates to local traditional activities. This study is driven by three main research questions focusing on the perspective of the Ria de Aveiro local community that rely on the lagoon for their livelihoods: i) How is the threat of IAS to native species perceived? ii) How are the relations between local activities and IAS perceived? iii) What is the impact of environmental perceptions on marine biological resources?

Results: The research questions that drove this study enabled us to conclude that the threat posed by IAS and biodiversity loss is moderate and individuals perceive that most of the species have decreased in the past and/or will decrease in the future. End-user's evidence spatial-distinct preferences in the lagoon area for species-specific harvesting, including alien species, mainly related to market demand and financial gain.

Discussion: The impact of environmental perceptions on marine biological resources, indicate that the inter-relations between environmental identity and risk perception might have unexpected effects that need to be better understood.

KEYWORDS

invasive alien species, questionnaire methodology, environmental assets, environmental identity, risk perception

Introduction

Invasive species can be defined as “*alien species that sustain self-replacing populations over several life cycles; produce reproductive offspring, often in very large numbers at considerable distances from the parent and/or site of introduction; and have the potential to spread over long distances*” (Richardson et al., 2000). Over the past several decades, a large body of research has been devoted to examining the phenomenon of invasive alien species (IAS), namely of marine IAS (e.g., Katsanevakis et al., 2023). While researchers have attempted to understand and explain the invasion process and IAS impact on ecosystems, studies have mainly focused on ecological and economic aspects (e.g., Bacher et al., 2018; Coelho et al., 2021; Vaz et al., 2017). Despite a recent increase on research exploring social dimensions of invasion management (Phillips et al., 2021; Shackleton et al., 2019a) and the impact of knowledge and attitudes on environmental behaviors (Connelly et al., 2016; Kemp et al., 2017), the role of social psychological mechanisms, particularly on the management and surveillance of invasive species remains largely unexplored. In more detail, previous research has documented the negative impact of IAS on native marine and coastal ecosystems and their associated biodiversity (e.g., Anton et al., 2019; Geraldi et al., 2020), their socio-economic effects and even consequences for human well-being (Kourantidou et al., 2021; Lazzaro et al., 2018). Relevant examples are the impact of IAS on human livelihood (abandoning of farming or fishing) and on quality of life through, for example, the spread of infectious diseases by alien pathogens. However, invasive species management remains a complex matter that requires involvement and input from scientists, decision-makers and stakeholders, to build effective and sustainable management solutions (Backstrom et al., 2018; Kueffer, 2017; Phillips et al., 2021; Shackleton et al., 2019a). It has been shown that public perceptions and attitudes towards invasive species do not always coincide with ones from decision-makers and scientists (Fischer et al., 2014; García-Llorente et al., 2008). Therefore, its neglect and misunderstanding can, on one hand, lead to refusal to engage or opposition to management measures from the community (e.g., Woodford et al., 2016). On the other hand, if correctly identified, local knowledge and perceptions can be used to effectively raise awareness, gain support, namely through environmental identity,

and create education resources (e.g., García-Llorente et al., 2008; Novoa et al., 2018; Touza et al., 2014). Pertinent examples are how social perceptions are leveraged to increase support and willingness to pay for IAS eradication programs. Community engagement and awareness of IAS influences the willingness to contribute with labor and financial resources toward IAS management (Blakeway et al., 2021; Kim et al., 2022). Environmental identity is generally defined as the personal association or feeling of connection to a part of the nonhuman natural environment that has an impact on our perceptions and behaviors towards the world (Clayton, 2003, 2012). Environmental identity has been linked to pro-environmental behaviors, policy preferences, greater attention to environmental issues and placement of higher value for the natural environment (Ajibade and Boateng, 2021; Brick et al., 2017; Brick and Lai, 2018; Clayton et al., 2021; Mackay and Schmitt, 2019; Meis-Harris and Kashima, 2020). In this context, the current study aims to understand social perceptions and public experience with IAS, and the role of environmental identity on risk perceptions towards IAS, having the end-users of Ria de Aveiro coastal lagoon, located at the Atlantic coast of Portugal, as case study. Stakeholders include a diverse array of groups and individuals who have an interest in or are affected by management options and activities (e.g., government, regulatory agencies; associations, NGO's, private sector, business, academia, residents, citizens). Residents that are part of the local community of end-users, are citizens who rely on the ecosystem for their livelihoods, and therefore the target group to understand local communities' perceptions and experience with IAS in coastal ecosystems. Residents play a crucial role in the health and sustainability of the coastal ecosystem, namely the ones that depend upon the extraction of biological resources, and therefore, understanding their needs and behaviors is paramount for effective coastal management and conservation efforts.

As in other coastal ecosystems, research in Ria de Aveiro, a Long-Term Socio-Ecological Research (LTsER) platform, has demonstrated that invasive species might have impact at the habitats level and at the species level, both with potential negative socio-economic implications. However, the relations between local activities and environmental perceptions on marine biological resources is still not understood. In the ecological-economics perspective, relevant examples are the dwarf eelgrass *Zostera noltei* (Hornemann, 1832) (also known as *Zostera noltii*

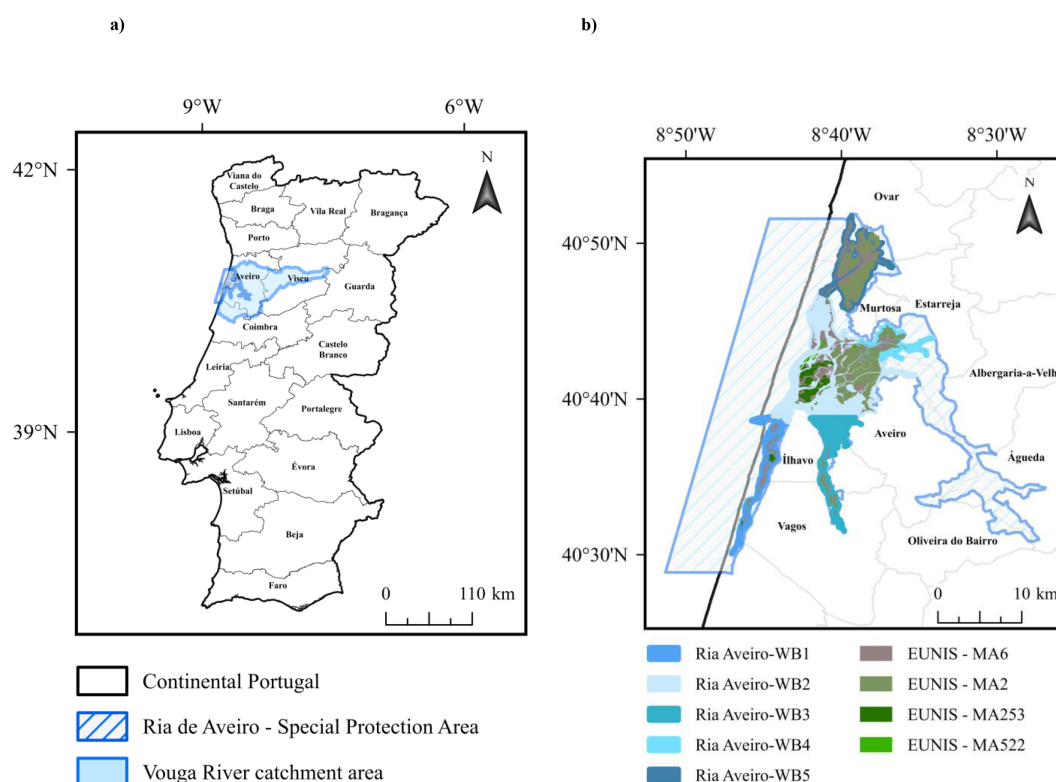


FIGURE 1

The location of Ria de Aveiro (Portugal) (a) and the map used for the *in-situ* data collection through questionnaires, with the identification of the Water Framework Directive (WFD) Water Bodies (WBs) and the EUNIS habitats (b). EUNIS habitats – littoral mud (MA6), salt marshes (MA2), intertidal halophytic communities (MA253) and *Zostera* spp. meadows (MA522).

Hornemann, 1832) meadows, well documented as nursery areas including economically valuable species, endangered by the lugworm *Arenicola* spp. (Lamarck, 1801), i.e., *Arenicola marina* (Linnaeus, 1758) and *Arenicola defodiens* (Cadman & Nelson-Smith, 1993) (e.g., Costa et al., 2022) and the replacement of the native species grooved carpet shell clam *Ruditapes decussatus* (Linnaeus, 1758) by the introduced IAS Manila clam *Ruditapes philippinarum* (Adams & Reeve, 1850) (Pires et al., 2015). Regarding genus *Ruditapes* currently occurring in sympatry in Ria, although the tested functional traits did not differ significantly (e.g., Lopes et al., 2018), the economic value of the IAS is much lower, while the harvesting effort is similar, meaning that new management models have been proposed (Coelho et al., 2021). In Ria, harvesting of seagrasses is part of the local heritage, specifically, until the 1970's, a mixture locally known as 'moliço' including seagrasses (*Zostera* spp. – *Zostera noltei* (Hornemann, 1832) and *Zostera marina* (Linnaeus, 1753)) and seaweeds (*Ulva* sp. (Linnaeus, 1753) and *Gracilaria* sp. (Greville, 1830)) were traditionally harvested for agriculture purposes, but since then this practice has largely decreased namely due to the replacement of this natural fertilizer by industrial chemical fertilizers (see Sousa et al., 2019).

This study is driven by three main research questions focusing on the perspective of the Ria de Aveiro local community that rely on the lagoon for their livelihoods: i) How is the threat of IAS to native

species perceived? ii) How are the relations between local activities and IAS perceived? iii) What is the impact of environmental perceptions on marine biological resources? By understanding how social psychological factors impact attitudes and perceptions of IAS, by a local community that social and economically depends on the system's natural resources, this study aims to reveal how that can be leveraged and become part of the integrated management of the system. The study was supported by face-to-face questionnaires ran *in situ* (intertidal mud- and sandflats) while the local community members were actively extracting biological resources, namely seagrass, worms and/or shellfish. This study showcases how the local community perceives the threat of IAS and how it relates to their local activities, as well as their perception on risk and environmental identity.

Materials and methods

The case study context

The Ria de Aveiro watershed is located at the Portugal Centro Region (Figure 1) and is administratively organized in 11 municipalities and 74 parishes, with a population of 367,455 inhabitants (data from 2021 census by the national statistics of Portugal). According to Water Framework Directive (WFD), Ria de

Aveiro is divided into 5 Water Bodies (WBs), all being classified as natural except for WB2 which is classified as highly modified, due to the location of the harbor and other infrastructures. As these WBs correspond to management units, the maps that supported the surveys follow this structure.

In this study, the socio-ecological context of actively collecting biological resources by Ria local population include seagrass harvesting and traditional collection of bait worms and shellfish. Local communities engage in harvesting seagrass to be used as organic fertilizer in subsistence farming, and engage in collecting worms for bait, namely for recreational fisheries, and shellfish for human consumption. The collected worm species are the native solitary tube worm *Diopatra neapolitana* (Delle Chiaje, 1841) and the common ragworm *Hediste diversicolor* (O.F. Müller, 1776), and more recently the two lugworm species *Arenicola defodiens* and the alien lugworm *Arenicola marina* (from now on mentioned as *Arenicola* spp.). In mudflats the collected shellfish species are the native grooved carpet shell *Ruditapes decussatus*, the pullet carpet shell *Venerupis corrugata* and more recently the alien Manila clam *Ruditapes philippinarum*.

The structure of the questionnaire

The questionnaire was divided into four main sections: i) Activities taking place in Ria de Aveiro; ii) Spatialization of habitats and temporal perception of invasive alien species; iii) Environmental assets; and iv) Risk perceptions towards invasive alien species considering the next decade as time frame, and environmental identity. Regarding the activities in Ria de Aveiro, participants were inquired about the extraction, preference, and preferred areas, including other areas besides the one they were at the moment of the questionnaire: a) three species of worm bait; and b) three species of shellfish. In addition, they were asked if they considered it important to develop a fishing technique or gear that allowed the different species of clam to be caught selectively. Having the map of the Ria de Aveiro as reference for the spatialization of the target species, participants were invited to identify the presence of: a) *Zostera noltei*, b) *Diopatra neapolitana*, *Hediste diversicolor* and *Arenicola* spp., and c) *Ruditapes decussatus*, *Venerupis corrugata* and *Ruditapes philippinarum*. To facilitate this task, participants were presented colored maps with the five water bodies (according to the WFD) of Ria de Aveiro and with four EUNIS habitats – littoral mud (MA6), salt marshes (MA2), intertidal halophytic communities (MA253) and *Zostera* spp. meadows (MA522). Respondents were invited to mark the appropriate letter in tables below the map (Figure 1). The maps were generated using ArcGIS Pro 3.2.2, with the WGS 1984 geographic coordinate system. For the spatial distribution analysis, the Kernel Density function was used which calculates a magnitude per unit area from polyline features. To assess participants' perception on the evolution of environmental assets in Ria de Aveiro, participants were asked *in situ* during their extraction activities how they perceive the distribution of seagrass in the last 20 years and, if appropriate, in the second half of the last

century. For fauna species, including IAS, the time frame considered the last 5, 10, 20, and more than 20 years ago. They were also asked about their expectations regarding the decrease or increase of those species in the next 10 years. Responses were indicated on a 5-point scale that ranged from 1 = *Decreased 50%* to 5 = *Increased 50%*. Risk perception towards IAS was measured by evaluating the level of probability of appearance of IAS in the next 10 years, on a scale ranging from 1 = *Unlikely*, to 5 = *Highly likely*, and its impact on the ecosystems of Ria de Aveiro, on a scale ranging from 1 = *Highly positive* to 5 = *Highly negative*. Environmental identity was measured using a 5-items reduced measure of the Environmental Identity Scale (Clayton, 2003). Responses were rated on a scale ranging from 1 = *Strongly disagree* to 5 = *Strongly agree*. Although this measure had been successfully used before (Lima and Branco, 2018; Lima et al., 2020), in this sample the internal consistency of the scale was not adequate ($\alpha = 0.46$). Exploratory analyses suggested that the only solution with an adequate level of internal consistency had 2 items (Spearman-Brown = 0.68). The items used were “If I had enough resources such as time or money, I would spend some of them to protect the natural environment” and “I have a lot in common with environmentalists as a group”. These two items were retained because they both showed the strongest item-total correlations. These items reflect the dimension ‘Environmentalism’ of environmental identity, which refers to a style of behaving and committing to the environment that appeals to a moral code and an identification with ecologists (Olivos and Aragonés, 2011).

Procedure and measures

Participants were approached *in situ*, during their routine extraction of biological resources at the intertidal flat of the Ria de Aveiro by a trained researcher during weekends between August and February of the following year (seven months) and completed a face-to-face questionnaire. This approach aimed to capture insights from individuals directly engaged with the ecosystem services under study. Due to the *in situ* nature of the data collection, the sampling was non-probabilistic. Participation in the study was voluntary and anonymous, with all participants providing informed consent. The completion of the questionnaire took 20 minutes on average. Afterwards, participants were thanked and debriefed.

Statistical analysis

We conducted mediation analyses using the PROCESS macro for SPSS, Model 4, the standard model for testing simple mediation effects involving a single mediator. This choice aligns with our theoretical framework, which posited a direct and indirect pathway from the independent variable to the dependent variable through a single mediating construct. All continuous predictor and mediator variables were mean centered prior to analysis to reduce multicollinearity and facilitate interpretation of interaction terms where applicable. Standardized coefficients are reported to aid in

TABLE 1 Activities in Ria de Aveiro by the participant end-users of the local community who rely on the ecosystem for their livelihoods.

Information	Worm bait			Shellfish		
Common name	lugworm	solitary tube worm	common ragworm	Manila clam	grooved carpet shell	pullet carpet shell
Scientific name	<i>Arenicola</i> spp.	<i>Diopatra neapolitana</i>	<i>Hediste diversicolor</i>	<i>Ruditapes philippinarum</i>	<i>Ruditapes decussatus</i>	<i>Venerupis corrugata</i>
Usually picked	3.4	52.3	48.9	41.4	54.0	59.2
Preference	1.1	37.4	16.1	4.0	40.8	20.1
Motive of those who have a preference						
Financial	2.4	70.7	7.3	0	80.5	11.0
Facility	1.4	44.4	31.9	12.0	8.0	64
Demand	0	77.8	11.1	18.8	56.3	18.8
Preferred channels (location) to harvest						
Mira (WB1)	2.3	10.3	8.0	12.6	12.1	17.8
Espinheiro (WB2)	0	0	0	0	1.1	0.6
Ílhavo (WB3)	0.6	36.2	32.8	18.4	25.3	25.9
São Jacinto-Ovar (WB5)	0.6	5.2	5.7	4.0	10.3	10.3
Murtosa (WB4)	0	2.3	0	1.7	1.1	1.1

Results in total percentual values (%).

comparison of effect sizes. Indirect effects were tested using 5,000 bias-corrected bootstrap samples with 95% confidence intervals, as recommended by Hayes (2018).

Results

Participants profile

Data were collected from 174 respondents of Ria de Aveiro lagoon watershed, who provided their informed consent to participate in the study. A valid response rate of 90.23% was obtained. Most respondents were male (83%) and their mean age was 55 years old ($SD = 11$). In this participatory study, individuals were from 60 out of 74 parishes in the lagoon watershed area, most of them resided in Gafanha da Nazaré (20%) and Gafanha da Encarnação (10%) (nearby WB1). The sample was comprised of mainly private citizens (68%), with 31% being part of the business sector, and 1% working in public administration. Regarding the main reason why these participants were in Ria at the time they were taking part in the study relates to traditional local activities, namely, 1.7% harvested ‘moliço’ for agricultural purposes, 66.7% caught worm bait for recreational fishing and 75.3% extract shellfish.

Activities in Ria de Aveiro

The activities carried out by respondents (end-users), as well as their preferences, are presented in Table 1. Concerning worm bait,

most individuals reported picking and preferring the solitary tube *Diopatra neapolitana* and very few the lugworm *Arenicola* spp. The motives assigned for this preference were market demand and financial gain. Regarding shellfish, most individuals reported picking all three species, particularly the pullet carpet shell *Venerupis corrugata*. However, most of them reported a preference for the grooved carpet shell *Ruditapes decussatus* because of its financial gain and market demand. Indeed, 73.8% of participants agreed that it was important to develop a fishing technique that allows different species of clam to be caught selectively, against 10.5% that believe it was not (15.7% were undecided).

Spatialization of habitats and IAS as identified by participants

The results evidence the participants are mostly active in WBs 1, 2, and 3 of Ria de Aveiro. The perception of the location of the *Zostera* spp. meadows does not seem to be linked to the specific EUNIS habitat, being mostly identified in WB2 (Figure 2). Residents expressed their preference for Ílhavo Channel (WB3) to pick all species (worms and shellfish), except for lugworm *Arenicola* spp. for which they preferred the Mira Channel (WB1). Worm bait was identified and collected in WB1, 2, and 3 (Figure 3) having a higher frequency corresponding to EUNIS habitat MA6 – littoral mud – described as *shores of fine particulate sediment, mostly in the silt and clay fraction (...). Littoral mud typically forms extensive mudflats, though dry compacted mud can form steep and even*

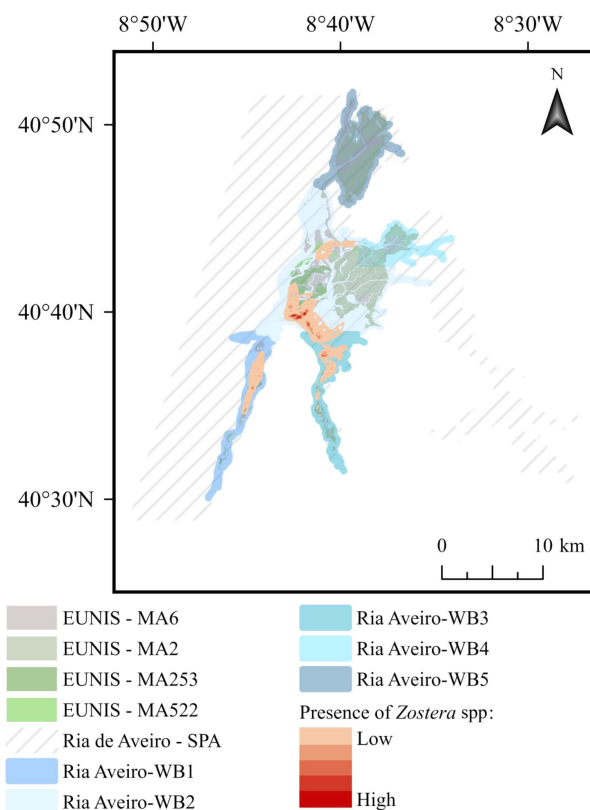


FIGURE 2

End-users' perception of the location of the seagrass *Zostera* spp. meadows at Ria de Aveiro coastal lagoon at each WFD Water Body (WB) and EUNIS habitats.

vertical structures, particularly at the top of the shore adjacent to saltmarshes (...) (<https://eunis.eea.europa.eu>). The end-users identified the presence of shellfish in WB1, 2, and 3, with higher frequency of Manila clam *Ruditapes philippinarum* in WB1, and grooved carpet shell *Ruditapes decussatus* and the pullet carpet shell *Venerupis corrugata* in WB2 (Figure 4). There was no clear correspondence between the presence of the shellfish species and the identified EUNIS habitats.

Environmental assets

Data analysis illustrated that respondents perceived that all species decreased their area of distribution in the past and are expected to continue decreasing in the future, particularly the grooved carpet shell *Ruditapes decussatus* (approximately - 45%) and the pullet carpet shell *Venerupis corrugata* (approximately - 27%). There were two exceptions: the alien lugworm *Arenicola* spp. and the Manila clam *Ruditapes philippinarum*. Although respondents considered that the lugworm area of distribution was smaller in the past, they expect it to increase in its distribution area in the future. The Manila clam area of distribution was perceived to have been increasing in the past and to keep on increasing in the future, although at a slower pace (Figure 5).

Risk perceptions towards invasive species and environmental identity

Central tendency measures and simple correlations between environmental identity and the risk perception towards invasive species are presented in Table 2. Residents of Ria de Aveiro watershed reported medium environmental identity and perceived probability of IAS and biodiversity loss, and relatively higher perceived impact of IAS and biodiversity loss. Higher environmental identity was correlated with lower perceived probability of IAS. It was also tendentially (non-significantly) correlated with lower perceived probability of biodiversity loss. Stronger environmental identity was not significantly correlated to higher perceived impact of IAS but was correlated to higher perceived impact of biodiversity loss. To further explore these results, we tested if the tendentially negative relation between environmental identity and perceived risk probabilities could be explained by the perceived impact of the risks. For individuals with higher environmental identity, estimating environmental risks with higher perceived impacts, such as IAS and biodiversity loss, might be threatening. Reducing the perceived likelihood of these risks may help individuals to better manage their heightened concerns about the potential impacts. These mediation models are presented in Figure 6. We found a significant mediation effect (indirect effect) of

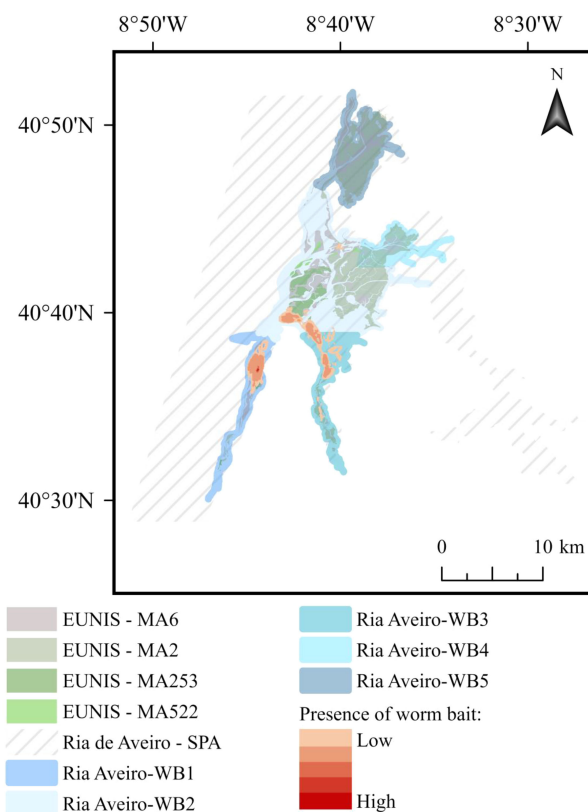


FIGURE 3

End-users' perception of the occurrence and preferred extraction location of worm bait (*Arenicola* spp., *Diopatra neapolitana* and *Hediste diversicolor*) at Ria de Aveiro coastal lagoon across WFD Water Bodies (WBs) and EUNIS habitats.

perceived impact in the biodiversity loss model, 0.06, (95% IC [0.01, 0.12]), but not in the IAS model, - 0.05, (95% IC [- 0.02, 0.12]).

Discussion

Having Ria de Aveiro coastal lagoon as case study, the local community of end-users was invited *in situ* at the intertidal flats to characterize the activities for the extraction of biological resources in mudflats (endogenous and exotic), the spatialization of habitats and invasive alien species (IAS), and share their perception of the lagoon environmental assets, and towards the risk of IAS, as well as their environmental identity.

Previous research shows that environmental attitudes and identity are among the most relevant drivers of pro-environmental behavior (e.g. Brick et al., 2017; Clayton and Czellar, 2023). However, the influence of these factors on the management and surveillance of IAS remains largely unexplored. Our study contributes to further exploration of social perceptions and public experience with IAS and begins to unravel the role of environmental identity on risk perceptions towards IAS and biodiversity loss. It innovates by 1) integrating spatialization of habitats with public perception data, 2) incorporates the perspectives of local community of end-users and 3) explores the role of social psychological mechanisms in a single comprehensive

design. It further contributes to the growing literature on the importance of including social dimensions on IAS management.

Results indicated that, overall participants preferred the same location (WB) to pick all species, except for lugworm *Arenicola* spp. When using worm bait, participants picked and preferred *Diopatra neapolitana*, mainly for market demand and financial gain. Regarding shellfish, while most participants picket carpet shell *Venerupis corrugata*, they reported a preference for grooved carpet shell *Ruditapes decussatus* due to market demand and financial gain. Currently *Diopatra neapolitana*, *Venerupis corrugata* and *Ruditapes decussatus* have commercial values of €7 per kg, €29.99 per kg and €42.95 per kg, respectively. Interestingly, participants' views on the importance of developing fishing techniques that allow different species of clam to be caught selectively are in line with new Portuguese legislation regarding fishing activity, fishing gear and measures for the conservation and sustainable exploitation of marine biological resources (Decree-Law N°. 73/2020, 23rd of September 2020). This has important implications as a higher degree of acceptance of the law aids to avoid conflicts with end-users, it's likely to increase their responsibility towards the protection of biological resources and compliance with laws and regulations (Boonstra et al., 2017; Garza-Gil et al., 2015; Oyanedel et al., 2020). Additionally, local community end-users' perception of fishing techniques provides valuable information on the exploitation status of different species

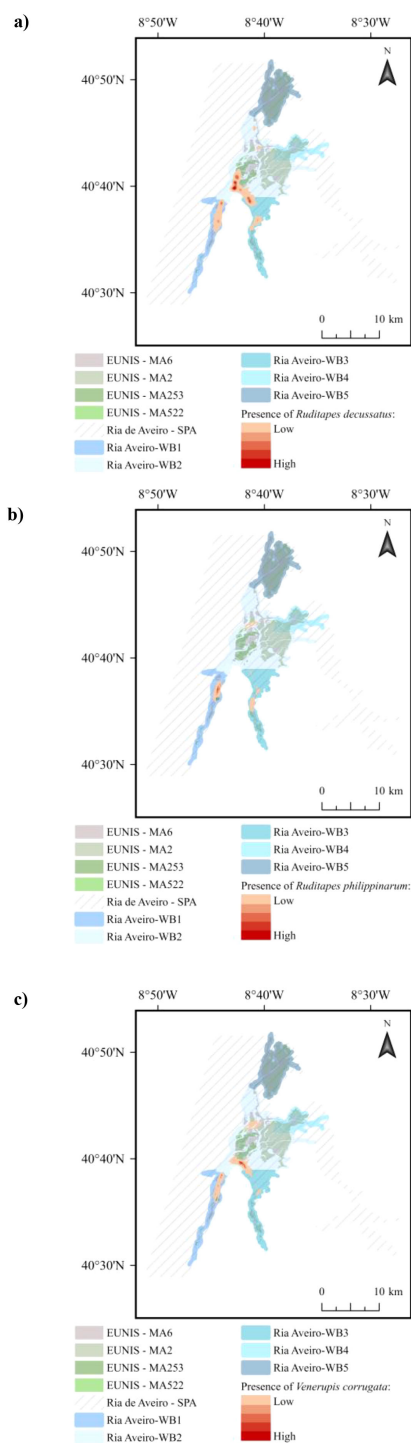


FIGURE 4
End-users' perception of the occurrence and preferred extraction location of the target shellfish species [*Ruditapes decussatus* (a), *Ruditapes philippinarum* (b), *Venerupis corrugata* (c)] at Ria de Aveiro coastal lagoon across WFD Water Bodies (WBs) and EUNIS habitats.

and can be used to increase conservation and management of natural resources (Sordo et al., 2023; Sousa et al., 2022).

Generally, all species were perceived to have decreased their area of distribution in the past and were expected to continue

decreasing over the next 10 years. Lugworm *Arenicola* spp. and the Manila clam *Ruditapes philippinarum* were exceptions as the first was perceived to have decreased over the last ten years but expected to increase at a similar rate in the future and the last was perceived to have been increasing in the past and to keep on increasing in the future. Information from local users represents a valuable source to track historical ecological data regarding species spatial and temporal distribution, specifically in areas where ecological and biological data is insufficient or non-existent (Barbosa-Filho et al., 2020; Braga et al., 2022; Kleespies et al., 2024).

Respondents of Ria de Aveiro reported medium/low perceived probability of IAS and biodiversity loss and medium/high perceived impact of IAS and biodiversity loss, consistent with previous studies conducted in Portugal and other countries (Cordeiro et al., 2020; Kleespies et al., 2024; Rodríguez-Rey et al., 2021).

Invasive species continue to be one of the main drivers of biodiversity loss across the globe (Bellard et al., 2022; IPBES, 2023). Previous research has demonstrated that environmental identity and attitudes are positively related and significant predictors of pro-environmental behavior (Mackay and Schmitt, 2019; Naiman et al., 2021; Whitburn et al., 2020), environmental concern (Lou and Li, 2021), risk and uncertainty perceptions (e.g. Bartczak et al., 2017; Faccioli et al., 2020). In our participatory study, environmental identity, particularly its environmentalism dimension, had unexpected correlations with risk perception. Environmental identity was related to lower perceived probability of IAS and, tendentially, of biodiversity loss, and to higher perceived impact of biodiversity loss and, tendentially, of IAS. This suggests that people with higher environmental identity, although perceiving high impacts of these risks, might estimate the probability of risk occurrence as lower. In the case of biodiversity loss, this was explained by a mediation effect of the perceived impact of biodiversity which increased with higher environmental identity and, therefore, would probability be threatening if one would believe that it would very probably occur in the future. However, in the case of IAS this *ad hoc* explanation did not fit the data, and more research is needed. For IAS, the mediating path of the perceived impact was not observed likely due to the non-significant relationship between these variables. This discrepancy could be explained by several factors. First, invasion of alien species may be less salient than biodiversity loss, even among those with strong environmental identity. Second, unmeasured variables such as positive personal experience with IAS or media exposure may influence probability judgments independently of perceived impact. It is important to consider that IAS can bring social and economic benefits to stakeholders, namely provision of resources through the harvest of those species as valuable food sources that they can eat and sell, making higher profit. Therefore, their risk assessment might be affected by it and lead to a misinterpretation of the magnitude and severity of the impact of invasive species (Kleespies et al., 2024; Waliczek et al., 2018). Greater attention needs to be given to those to whom the environment is an important part of who they are, as they are more likely to have a lower risk perception of invasion by alien species and, therefore, less likely to take protective actions. Our results expand current research

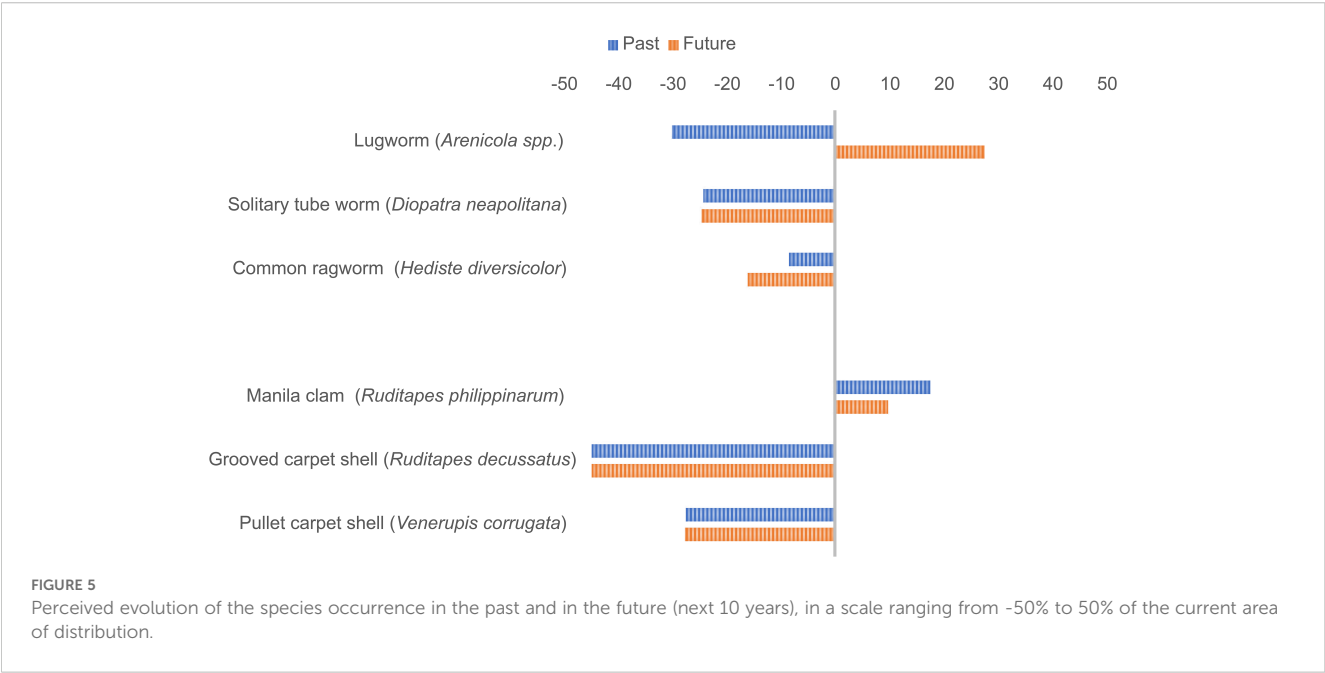


TABLE 2 Descriptive analysis and correlations between environmental identity and risk perceptions (IAS stands for Invasive Alien Species).

Variable	Mean (SD)	1.	2.	3.	4.	5.
1. Environmental identity	3.15 (0.69)	–				
2. Probability of IAS	3.43 (0.77)	-.19*	–			
3. Impact of IAS	3.94 (0.61)	.10	.37***	–		
4. Probability of biodiversity loss	2.99 (0.71)	-.13	.28***	.26**	–	
5. Impact of biodiversity loss	4.06 (0.52)	.25**	.13	.20**	.18*	–

Variables range from 1 to 5. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

that suggests that individuals with a strong environmental identity may not always perceive IAS as a significant threat, despite their environmental concern (Fischer and van der Wal, 2016; Kueffer, 2013; Shackleton et al., 2019b). According to environmental identity and risk perception theories, people with a more salient environmental identity often value naturalness and biodiversity (Clayton, 2003; Selge et al., 2011). However, many IAS do not immediately appear “unnatural” or threatening, especially if they have aesthetically pleasing characteristics (e.g., colorful plants, charismatic animals). This creates a naturalness heuristic, where the perceived “fit” of a species into a landscape can lower risk perception—even if ecologically harmful (Kueffer, 2013; Selge et al., 2011).

This is true in other systems as well, where IAS bring social and economic benefits to locals (e.g. recreation and spiritual value (sources of craft materials); provision of fuelwood, fodder, food products, timber and medicinal products; income through sales of

those products; positive habitat modification) (Kelsch et al., 2020; Pienkowski et al., 2015; Sax et al., 2022; Shackleton et al., 2019c). For example, South Africa residents use *Acacia dealbata* for firewood, tools, fencing or feeding livestock (Ngorima and Shackleton, 2019), while in East Africa Nile Perch (*Lates niloticus*) is used to support industrial fisheries (Shackleton et al., 2018). As disagreements in risk perceptions are one of the factors that contribute to conflicts in invasive species management (Estévez et al., 2015), it is very important that those responsible for invasive species management are aware and try to address those disagreements by increasing participation of local stakeholders and make the decision process transparent. A low-risk perception of IAS significantly undermines the effectiveness of IAS management, as public lack of awareness can hinder public support for control measures and even opposition to government interventions, it can become significant barriers for effective management of IAS (Jubase et al., 2021; Roussos et al., 2021). Our questionnaire targeted residents when they were actively extracting biological resources, therefore the sample was characterized by an overrepresentation of middle-aged men who were private citizens, limiting more a general characterization and conclusions. Environmental attitudes, identity and perception of environmental risk in general change according to individuals’ socio-demographic characteristics. For example, women, younger people, people living in urban areas or who have higher education and income tend to express higher environmental attitudes, have more salient environmental identity and perceive higher environmental risk (Miao and Cagle, 2020; Pienaar et al., 2013; Subiza-Pérez et al., 2020). Nevertheless, these are representative of most local community members that actively extract biological resources, namely seagrass, worms and/or shellfish. The internal consistency reported for some of the measures are relatively low. Subsequent studies would gain from collecting a larger sample not only to potentially increase internal consistency of the measures but

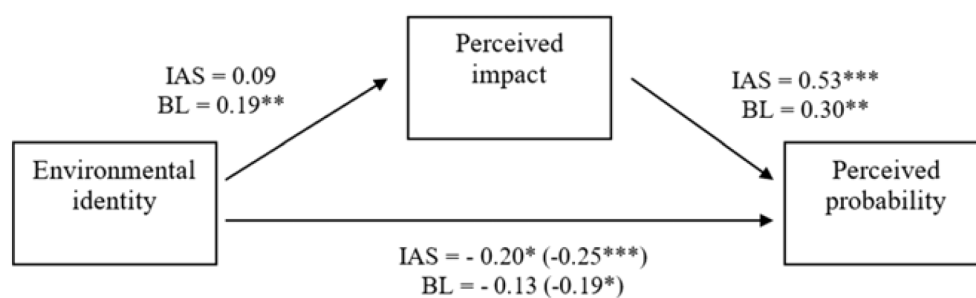


FIGURE 6

Unstandardized regression coefficients (B) for the relationship between environmental identity and perceived probability of Invasive Alien Species (IAS) and Biodiversity Loss (BL), as mediated by the perceived impact of IAS and BL. The direct effects of environmental identity on impact are shown in parenthesis. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$.

also strengthen the generalizability of the conclusions. Specifically, due to low internal consistency, the environmental identity measure in our study was limited to capturing only behavioral commitment and identification with environmentalist values. While these components are central to the construct, we recognize that this reduced version does not fully reflect the broader multidimensional nature of environmental identity. According to Clayton (2003) and Olivos and Aragonés (2011), environmental identity encompasses additional dimensions such as emotional connection to nature and cognitive inclusion of the natural environment in one's self-concept. We acknowledge this limitation in the scope of measurement and its potential implications for construct validity.

Previous research has demonstrated that perceptions and attitudes towards IAS can be influenced by not only socio-demographic characteristics but other factors such as improved knowledge and understanding regarding IAS (Estévez et al., 2015; Nanayakkara et al., 2018; Shackleton et al., 2019d). Therefore, interventions or programs designed to increase literacy and knowledge of the targeted end-users regarding IAS, could change their perception of environmental risk, grow their involvement and support for IAS management.

The reliance on self-report measures represents a methodological issue as single-source self-reports could be affected by social desirability and are thus less reliable than observations or a combination of multiple sources of data. Despite these limitations, the findings from this study strengthen the accumulating evidence of the important role played by transdisciplinary studies, namely the acknowledgement of risk perception and the environmental identity of the local community who rely on the ecosystem for their livelihoods and their knowledge as a valuable tool to track historical ecological data regarding species spatial and temporal distribution, as well as, contributing to the integrated management of ecosystems.

The current study offers a deeper understanding of socio-psychological factors that relate and influence perceptions of IAS and reaffirm the importance of integrating ecological, social, economic information that derived from a diverse group of stakeholders, particularly those who are personally affected by invasive species. Stakeholder involvement plays an essential role in an effective sustainable management of IAS that will translate

into socio-economic development and well-being of local communities.

Conclusions

Coming back to the three key research questions that drove this study, and focusing on the perspective of the Ria de Aveiro local community that rely on the lagoon biological resources for their livelihoods: i) How is the threat of IAS to native species perceived? ii) How are the relations between local activities and IAS perceived? iii) What is the impact of environmental perceptions on marine biological resources? We can conclude that end-users perceived that most of the species have decreased their area of distribution in the past and/or will decrease in the future, expect for *Arenicola* spp. and *Ruditapes philippinarum*, and perceived a moderate risk of IAS and biodiversity loss in the next 10 years. That they have spatial-distinct preferences in the lagoon area for species-specific harvesting, including IAS, mainly related to market demand and financial gain. Regarding the impact of environmental perceptions on marine biological resources, our results indicate that the inter-relations between environmental identity and risk perception might have unexpected effects that need to be better understood. In this vein, the present study begins to unravel the role of environmental identity on risk perceptions towards IAS and biodiversity loss conditions and contributes to a better understanding of sustainable management of invasive species.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by University of Aveiro - Portugal. The studies were conducted in accordance with the local legislation and institutional requirements. The participants

provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

SL: Data curation, Formal analysis, Writing – original draft, Writing – review & editing, Conceptualization, Methodology. MP: Data curation, Formal analysis, Writing – original draft, Writing – review & editing. ML: Conceptualization, Writing – review & editing, Funding acquisition. BO: Data curation, Writing – review & editing. AS: Conceptualization, Writing – review & editing, Funding acquisition. AL: Conceptualization, Funding acquisition, Supervision, Validation, Writing – original draft, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

The author(s) declared that they were an editorial board member of Frontiers, at the time of submission. This had no impact on the peer review process and the final decision.

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