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Socio-economic impacts of the recent bio-invasion of *Callinectus sapidus* on small-scale artisanal fishing in southern Italy and Portugal

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Introduction: The recent and growing bio-invasion of the *Callinectes sapidus* (known as blue crab) is causing damages in the European aquatic ecosystems, and affecting the livelihoods of the fishermen. In this context, this study explores the socio-economic impacts of this bio-invasion on small-scale artisanal fishermen in the Apulia (southern Italy) and Algarve (southern Portugal) regions, analyzing their perceptions and highlighting the repercussions of this bio-invasion on their livelihoods.

Methods: For this purpose, we carried out a field survey with representative small-scale artisanal fishermen based on the “Socio-economic Impact Classification of Alien Taxa” (SEICAT) approach by means of an “Exploratory Factor Analysis” (EFA), and a “Hierarchical Analysis and K-means Cluster Analysis”.

Results and discussion: The findings reveal that the two study areas, Apulia and Algarve, exhibit markedly different perceptions of the impact of the blue crab invasion on the well-being and activity of fishermen. In Apulia, the invasion has led to extensive damage to fishing nets, physical harm, a decline in other commercial species, reduced catch quantities, increased working hours, higher costs, and lower incomes. Conversely, in the Algarve, while net damage is less severe, the primary concerns are physical harm, increased working hours, higher costs, and reduced income. Consequently, this research provides an empirical basis for the adoption of management measures and interventions to mitigate the socioeconomic impacts of the blue crab on the fishing community and local economy, thereby contributing to the well-being of both individuals and the marine ecosystem.

KEYWORDS
aquatic non-indigenous species, bio-invasion, blue crabs, European aquatic ecosystems, socioeconomic assessment

1 Introduction

Invasive alien species represent a critical concern in contemporary biology (Giangrande et al., 2020; Ardura et al., 2021; Vilizzi et al., 2021), posing substantial challenges to biodiversity conservation and the management of natural ecosystems (Simberloff et al., 2013), disrupting ecosystems, and leading to significant alterations in global biodiversity dynamics (Gallardo et al., 2016). In the marine ecosystem, non-indigenous species, which are organisms introduced beyond their native geographic range, have the potential to become invasive and instigate a multitude of ecological alterations. These changes encompass the loss of indigenous genetic diversity, deterioration of habitats, shifts in trophic relationships, and displacement of native species (Albins and Hixon, 2013; Giakoumi, 2014; Vergés et al., 2014). Additionally, invasive marine species can lead to adverse socio-economic consequences, affecting both fisheries and recreational activities (Essl et al., 2020). For instance, they may contribute to the decline of commercially valuable fish stocks (Bax et al., 2003; Katsanevakis et al., 2014). Despite the acknowledgment of marine biological invasions as a significant threat to marine ecosystems (Halpern et al., 2008; Molnar et al., 2008), the implementation of management measures aimed at mitigating their impacts has been insufficient (Thresher and Kuris, 2004; Giakoumi et al., 2016). In addition, anthropogenic influences, including phenomena like climate change, play a pivotal role in the proliferation of species from outside their native ranges, often at the expense of more vulnerable species (Simberloff et al., 2012; Ferrario et al., 2017). The global scope of the invasive alien species issue is evident as they continue to expand rapidly across diverse geographical regions and habitat types. This expansion is exacerbated by the lack of natural competitors, with projections suggesting a 36% increase in the number of established alien species over the next three decades. Moreover, human activities and global changes pose threats to the Mediterranean ecosystem, which is currently one of the most invaded marine regions worldwide (Edelist et al., 2013). In fact, commercial shipping, aquaculture, and major corridors like the Suez Canal significantly contribute to the extensive presence of alien species in the Mediterranean marine environment (Sarà et al., 2018). In recent decades, the Mediterranean Sea and southern European waters (SEW) have witnessed a significant increase in the introduction and rapid expansion of non-native crustaceans (Nunes et al., 2014; Chainho et al., 2015). This surge has raised concerns about the ecological and economic consequences of these introductions in southern European coastal systems (Mancinelli et al., 2017).

In this framework, one prominent example of this concern revolves around the Atlantic blue crab (Figure 1), *Callinectes sapidus* Rathbun, 1896 (Brachyura: Portunidae). This species, native to the western coasts of the Atlantic Ocean, is well-known for inhabiting estuaries, lagoons, and other coastal environments. It displays euryhaline and eurythermal characteristics, exhibits high fecundity, and can be quite aggressive towards humans (Millikin, 1984). *C. sapidus* is a key component of coastal benthic food webs in its native habitats (Baird and Ulanowicz, 1989) and supports significant fisheries in Northern and Central America (Fogarty and Miller, 2004; Kennedy, 2007; Bunnell et al., 2010). Notably, blue crabs primarily display omnivorous behavior, functioning as dominant benthic predators and scavengers. Occasional instances of cannibalism have been documented (Douglass et al., 2011). The expansion of their habitat into new geographic regions is likely influenced by global climate change and increased maritime traffic

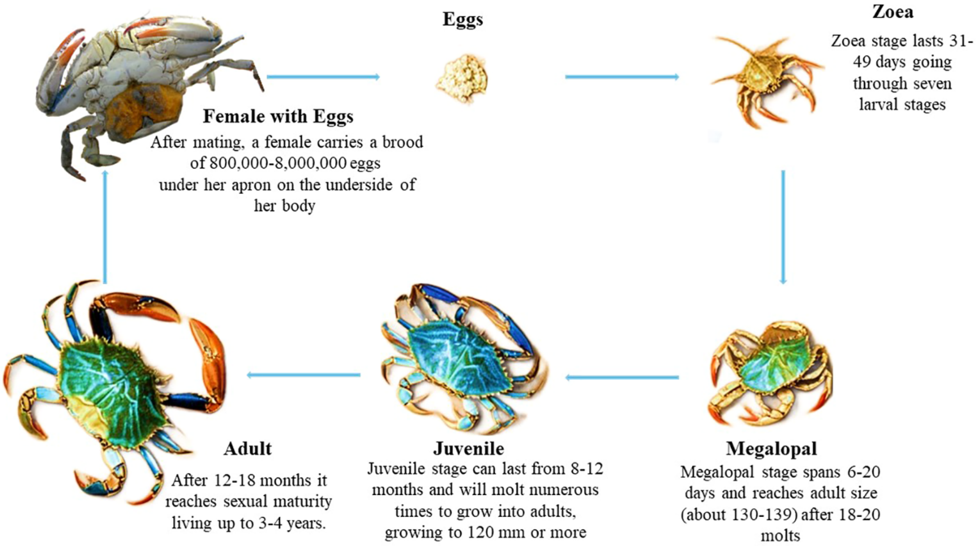

FIGURE 1
C. sapidus life cycle.

between different bodies of water. Some suggest that *C. sapidus* may have been transported from the Atlantic shores of America to European coastal areas and the Mediterranean Sea via the ballast waters of vessels (Nehring, 2011). Anyway, *C. sapidus* is rapidly expanding its presence along the North Atlantic East Coast and within the Mediterranean Sea, leading to significant environmental, economic, and social consequences. In the Mediterranean Sea, negative interactions with endemic biodiversity and the local economy have been documented (Olenin et al., 2014; Kampouris et al., 2019). According to Galil and Zenetos (2002), *C. sapidus* was first observed within the Mediterranean Sea in Venice (northern Adriatic Sea) in 1949. While its spread in the Western Mediterranean basin has been comparatively slower, it has proliferated in various Eastern basin areas (Beqiraj and Kashta, 2010; Mancinelli et al., 2013). Italian records of *C. sapidus* have been documented in various locations (Tiralongo et al., 2021). These include reports from Abruzzi waters in the central Adriatic Sea (Castriota et al., 2012), the Acquatina lagoon in the South Adriatic Sea, and the Torre Colimena basin in the Ionian Sea (Mancinelli et al., 2013; Carrozzo et al., 2014). More recent information indicates the presence of *C. sapidus* in Sardinia (Italy, western Mediterranean) in 2017 and its subsequent spread along the Sardinian coastline in June 2018 (Culurgioni et al., 2020). Several studies have also affirmed that *C. sapidus* is already established on the Atlantic coasts of the southern Iberian Peninsula and is currently expanding its distributional range westward along the southern coast of Portugal (Mancinelli et al., 2017). A population has recently become established in the Guadiana estuary, with approximately 50–60 specimens distributed throughout a 25 km stretch between the upper and lower estuary (Morais et al., 2019). Indeed, the distributional expansion of *C. sapidus* along the southern coast of Portugal indicates a rapid and progressive westward spread, with an invasion route and timeline of consecutive records starting in the Guadiana estuary (July 2017 – June 2018) and extending along the Algarve coast and into the Ria Formosa lagoon (Vasconcelos et al., 2019; Morais et al., 2019).

Over the past two decades, numerous studies have been conducted on alien species in marine ecosystems, encompassing the identification of highly impacted areas, the prioritization of sites, pathways, and species for management actions (Streftaris and Zenetos, 2006). Additionally, research has provided comprehensive overviews of the most invasive species and their implications (Goodenough, 2010). Numerous studies focus on comprehensively studying and analyzing the phenomenon (Pyšek et al., 2020) recommending management and policy strategies globally (Turbelin et al., 2017). Haubrock et al. (2021) explored the economic impacts by quantifying the costs of invasive alien species in Europe, totaling EUR 116.61 billion between 1960 and 2020. Meanwhile, Cuthbert et al. (2021) highlighted that costs associated with aquatic invasive alien species are underestimated, especially in comparison to their ecological impacts and those of terrestrial species that have been more intensively studied. The impacts of invasive alien species on biodiversity (Mollot et al., 2017; Spatz et al., 2017; Shabani et al., 2020), ecosystem services (Vanbergen and Insect Pollinators Initiative, 2013) and human well-being (Pejchar and Mooney, 2009) are widely acknowledged (Pyšek et al., 2020). In fact, in the last decade, economic and social impacts and implications related to biological invasions have been investigated using different methodologies, in different geographical areas. Specifically, some studies demonstrating the negative implications of invasive marine species have focused on the *Pterois volitans* and *P. miles* (Lionfish) and the *Lagocephalus sceleratus* and *Torquigener hypselogeneion* (Pufferfish) (Andradi-Brown, 2019). Thus far, online surveys have been widely utilized in freshwater ecosystems to examine public perceptions regarding invasive alien species biosecurity measures (Sharp et al., 2017), or invasive pathways (Cerri et al., 2020) and also for monitoring and report alien species by the use of Local Ecological Knowledge data collection engaging fishermen, thus showing the importance of the cooperation between researchers and stakeholders in the invasive species monitoring activities (Maggio et al., 2022). Marchessaux et al. (2023) collate and synthesize information collected by Local Ecological Knowledge (LEK) approach targeting artisanal small-scale fishermen from France, Italy and Tunisia to identify the socioeconomics impacts of blue crabs on the artisanal small-scale fisheries. Particularly, three aspects most affected by the presence of the blue crabs, specifically: the fishing activity, the number of catches in the nets and the associated economic revenues. In Italy, Croatia and Montenegro online questionnaires have been used for investigating Tyrrhenian, Ligurian, Ionian and Adriatic Sea on (i) the geographical distribution of *C. sapidus* in these countries; (ii) its perceived abundance and trend; (iii) the perceived impacts (Cerri et al., 2020). In Italy, surveys have been used for the assessment of indirect damage caused by *C. sapidus* where fishermen are aware of the possible damage caused by *C. sapidus* to the lagoon ecosystem, estimating the invasion led to an income decrease of about the 30%, that could be express in a total economic loss equal to about EUR 200,000 per year (Cannarozzi et al., 2023). Additionally, a few studies have explored the socioeconomic impacts of alien species invasion utilizing the "Socio-economic Impact Classification of Alien Taxa" (SEICAT) methodology. This novel standardized approach classifies alien taxa based on the magnitude of their impacts on human well-being, drawing from the capability approach in welfare economics (Bacher et al., 2018). These studies have all focused on terrestrial species such as ants, rabbits, and birds (Evans and Blackburn, 2020; Allmert et al., 2022; Gruber and Wood, 2022). However, only one study has examined the impacts on marine species using this methodology. Indeed, to illustrate the effectiveness of the system, Oussellam et al. (2021) classified the impacts of the *C. sapidus* in the Marchica lagoon, Morocco, revealing a range of effects on human well-being and highlighting the negative impacts of the blue crab on fishing activity in the lagoon, which are certainly concerning.

In this context, the present study will explore the impacts of the recent bio-invasion of *C. sapidus* on well-being and changes in the activity size of small-scale fishers in Apulia region (southern Italy) and Algarve region (southern Portugal), including catch quality, net and physical damages, interactions with other species and changes related to fishery areas. In summary, the uniqueness and significance of this study could be seen in three main dimensions. Firstly, there is a lack of studies that have examined the socio-economic impacts of the invasion of the *C. sapidus* in the invaded European coastal areas. Thus, the present work proposes to make an assessment and a comparative analysis of the socio-economic implications resulting from the interactions between *C. sapidus* and the main craft fishing professions in two regions affected by the invasion: Apulia (Italy) and Algarve (Portugal) as depicted in Figure 2. Second, the integrated approach taken in this study, covering both Apulia and Algarve regions, provides a holistic view of the socioeconomic repercussions of the blue crab's invasion within the affected coastal communities. As such, this comprehensive understanding of local dynamics and socio-economic variables is crucial for devising effective and sustainable management measures aimed at conserving the marine ecosystem and bolstering the resilience of local populations in response to the challenges posed by the blue crab's invasion. Third, the collaboration between researchers and local fishermen in both regions induces a shared interest in understanding and mitigating the impacts of the blue crab's invasion on local economies and marine ecosystems (Ferrarin et al., 2014; Chainho et al., 2015; Morais et al., 2019). For these purposes, this research entails conducting direct interviews with small-scale fishers based on the "Socio-economic Impact Classification of Alien Taxa" (SEICAT) approach by means of an "Exploratory Factor Analysis" (EFA), and a "Hierarchical Analysis and K-means Cluster Analysis" (Bacher et al., 2018; Probert et al., 2023). The study is limited to the socio-economic consequences of the invasion of the alien crab, and does not take into account the ecological consequences on the natural environment. Therefore, the reminder of the paper is divided into 5 sections. The section 2 depicts the: (i) study areas, (ii) a short summary of the SEICAT methodology, (iii) data collection in terms of sampling and field survey, and (iv) multidimensional statistical tools adopted in this study. The findings will be outlined in section 3, with subsequent discussion in terms of: (i) interpretation and comparison of the results, (ii) public and private implications of the findings in making policy decisions about *C. sapidus* to support management, and in promoting marketing strategies, and (iii) limitations of the study and future research directions. The final section emphasizes the concluding remarks.

2 Materials and methods

2.1 Study areas: location and justification

We carried out this research in two southern European countries (Apulia region, southern Italy and precisely in Lesina lagoon as depicted in Figure 3, and Algarve region, southern Portugal and exactly in Faro, Olhao, Moncharapaco, Fuseta, Castro marim, Vila Real de Santo António and Monte Gordo as shown in Figure 4)[1]. We based our selection on several scientific and practical considerations, reflecting the relevance of the two locations for the study of the *C. sapidus*. Concretely, the importance of the two selected study areas could be highlighted by their designations as conservation areas and the active participation of local communities in research and biodiversity conservation.

On the one hand, Apulia region, particularly the Lesina lagoon, offers a unique and diversified environment for studying the impacts of the *C. sapidus*. This lagoon, located along the southern Adriatic coast, is recognized as an area where the blue crab has already proliferated (Cilenti et al., 2015; Renzi et al., 2020), and is a semi-closed system influenced by both fresh and marine waters. Furthermore, this lagoon ecosystem is heavily exploited by humans, with fishing and aquaculture activities serving as significant sources of income (Breber et al., 2010). Consequently, those activities represent important sources for the economy of local fishery, which could be influenced by the invasion of the *C. sapidus* (Manzo et al., 2016).

On the other hand, the Algarve region in Portugal, with particular emphasis on the area between Faro and Vila Real de Santo António, offers a diversified coastal context rich in estuarine habitats. The presence of the blue crab in this area, particularly in the Ria Formosa Lagoon and Guadiana estuary, has already raised concerns for the artisanal fishing industry and the local marine ecosystem. Moreover, the Algarve region has been internationally recognized for its biodiversity and ecological value, further emphasizing the importance of understanding the impacts of the blue crab invasion on this delicate ecosystem (Cartaxana et al., 2009; Morais et al., 2019; Vasconcelos et al., 2019).

2.2 SEICAT approach: magnitude of impacts

For the purposes of this research, we used the SEICAT methodology that is a novel standardized system based on human well-being is proposed for categorizing alien taxa according to their socio-economic impacts (Bacher et al., 2018; Probert et al., 2023) as depicted in Table 1. This approach aims to serve as a practical tool capable of: (i) assessing the magnitude of socio-economic impacts caused by alien taxa; (ii) facilitating cross-regional and cross-taxa comparisons; (iii) predicting potential future impacts of species in target regions and beyond; and (iv) assisting in prioritizing management actions for alien taxa and relevant introduction pathways. Particularly, we selected this approach due to its relevant characteristic of providing transparent and comparable impact measures grounded in clear and explicit definitions (Jeschke et al., 2014).

1 Appendices A, B give an overview about the fishing gear and the target fisheries products in Lesina lagoon and Algarve region, respectively.

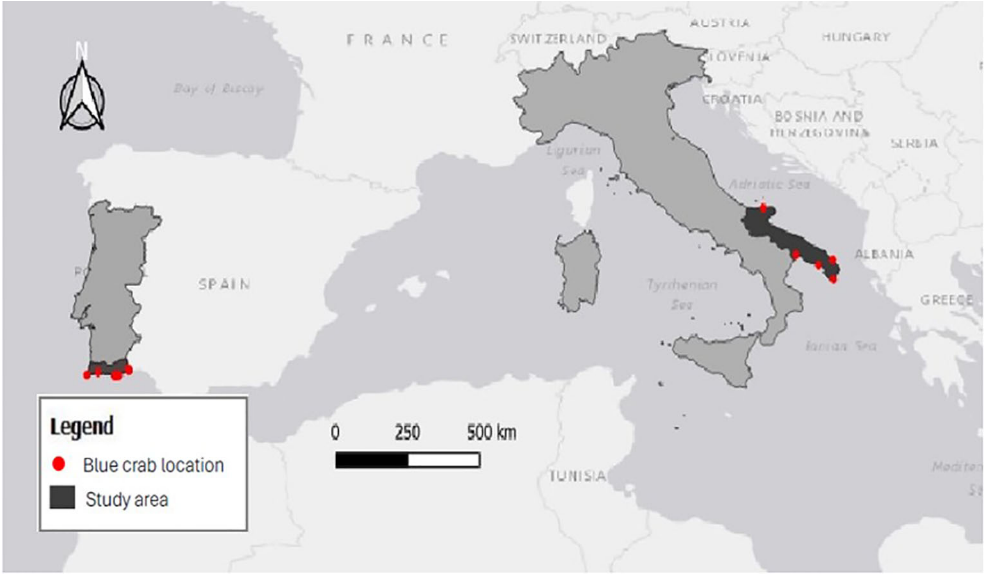

FIGURE 2
Geographical location of the study areas and *C. sapidus* records in Apulia region (southern Italy) and Algarve region (southern Portugal).

2.3 Data collection: interview

We gathered information through an interaction with the fishermen[2], from October 2023 to February 2024, engaging 66 valid fishermen, considering the small-scale and artisanal fishing activities in the study areas and, operating at different fishing sites bordering the Lesina lagoon in Apulia region, Ria Formosa lagoon and Guadiana Estuary in Algarve region. Additionally, we used the Equation 1 (Petrontino et al., 2024) considering a margin of error 10%, and a confidence level of 95%, in which we calculated a sample size of 53 respondents and then we decided to increase this value to 66, divided into equal sizes between the selected study areas. However, we conducted also a rapid appraisal survey, revealing that the number of fishermen engaged in small-scale artisanal fishing and having already at least one contact with the concerned aquatic invasive species was 33 and 36 in Apulia and Algarve regions, respectively.

$$\mathbf{n_i} = \frac{\frac{z^2 * p(1-p)}{e^2}}{\mathbf{1} + \left(\frac{z^2 * p(1-p)}{e^2 N}\right)} \quad (1)$$

Where: n is the least sample size of artisanal small-scale fishermen in the selected study areas, calculated initially at 53 fishermen. During the survey, we succeed to increase this sample size by interviewing an actual number of 66 fishermen. N is the population size in terms of artisanal small-scale fishermen in the selected study areas (N=119: the total population of artisanal fishermen in the surveyed areas in Apulia is 41, while in the Algarve, it is 78, according to the (European Fllet Register - European Commission, 2023). e: is the considered margin of error (percentage in decimal form: 10%). z: is the z-score (z = 1.96 for a desired confidence level of 95%), and p is the standard deviation (p = 0.5)

Accordingly, we designed a questionnaire (Supplementary Material A), to capture SEICAT data, into three different sections. The first section explored the technical characteristics of the fishing enterprise: this section gathered details about the fishing area, duration of professional fishing activity, primary fishing seasons, boat specifications (e.g., registration number, length, gross tonnage, engine power), main fishing gear used, and membership in fishing cooperatives. The second section of the questionnaire focused on collecting opinions and perceptions regarding the consequences of this bio-invasion. It included questions related to well-being implications such as income, expenses, damages to nets and catches, physical injuries, and changes in fishing activity. Specifically, it examined the remodulation of fishing activities in terms of the number of fishers, fishing areas, and the quantity of catch. The third section revealed the socio-economic characteristics of fishermen, including data such as: age, gender, place of residence, family composition, education level, occupations, and annual family income. We ensured that the true impacts based on SEICAT's semi-quantitative scale could be effectively captured with relatively low uncertainty, provided that robust survey methods were adopted (Probert et al., 2023).

2.4 Data and cluster analysis: descriptive and multidimensional statistical tools

On the one hand, the socioeconomic data, including variables such as gender, age, seniority, income, family size, principal tools, and other occupations, were analyzed using descriptive statistics, including mean, standard deviation, and relative frequency with the

2 The information gathered from the in-person survey was solely utilized for statistical analysis and the specific research project. According to Regulation (EU) 2016/679, personal data will not be shared with third parties or used for personal interests, whether one's own or others. The information obtained was solely utilized in a collective manner, ensuring the utmost anonymity of the participant. Additionally, fishermen were asked for their consent at the start of the survey to take part in this research in line with national laws and institutional rules.

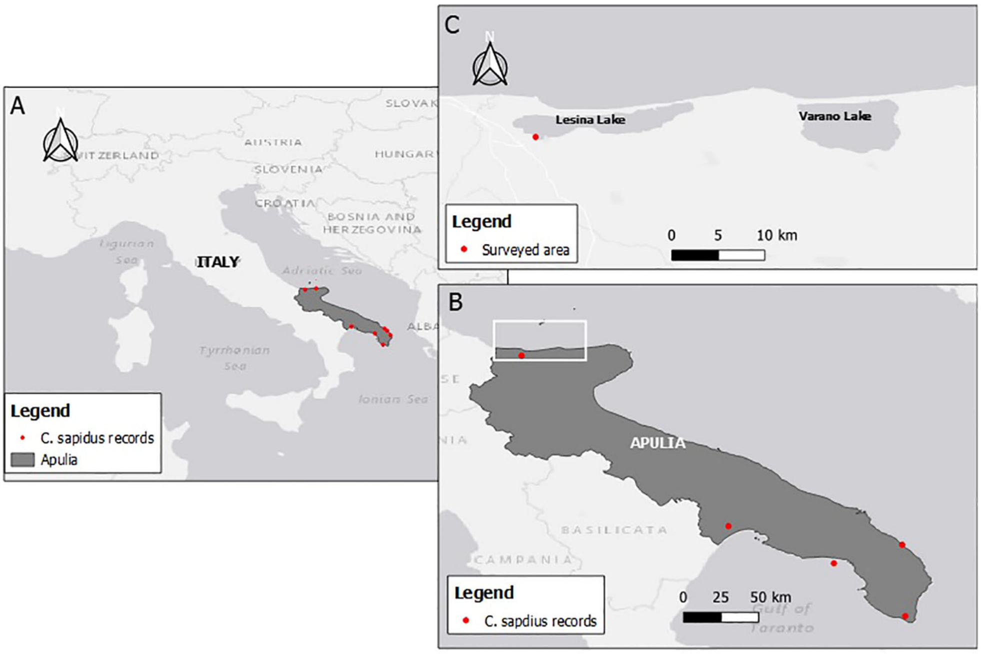

FIGURE 3
C. sapidus records in Apulia region **(A, B)** and surveyed location **(C)**, the lagoon of Lesina that may not represent the whole of Apulia, (nor the entire Adriatic coastline).

IBM SPSS Statistics software version 29. On the other hand, we conducted an Exploratory Factor Analysis (EFA), identifying latent variables, understanding the impact of the blue crab on the well-being and activities of fishermen in the two study areas, and underlying the observed variables in the dataset. In addition, we carried out a Hierarchical Analysis and K-means Cluster Analysis, identifying clusters of respondents with similar characteristics. Before performing the EFA, we also carried out the Kaiser-

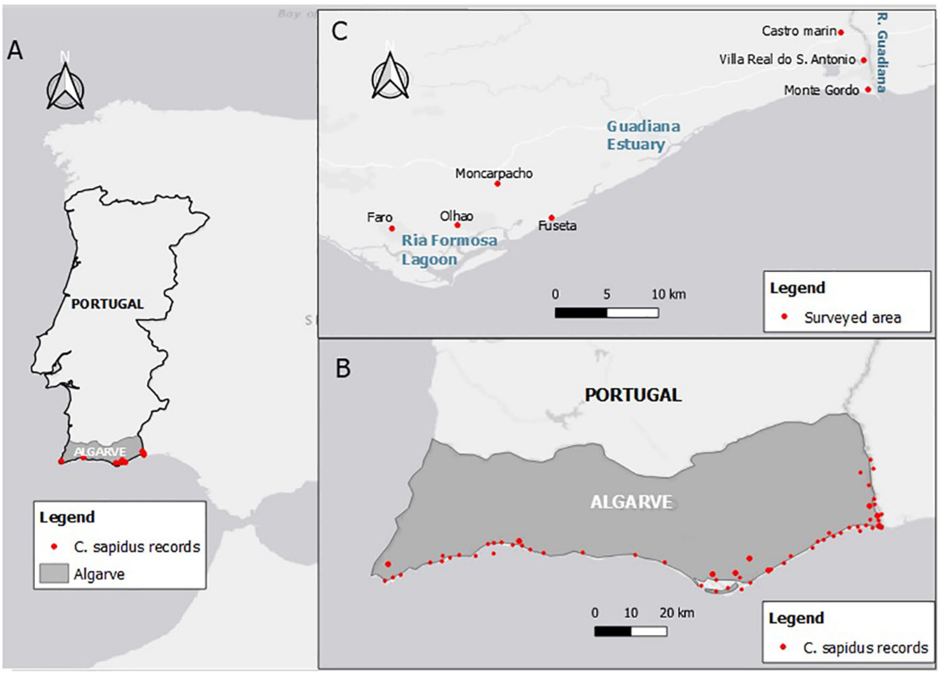

FIGURE 4
C. sapidus records in Algarve region **(A, B)** and surveyed locations **(C)**.

TABLE 1 Description of the SEICAT scale for classifying the socio-economic impacts according to observed changes based on Bacher et al. (2018).

Level	Code	Brief Description
Massive	MV	Local disappearance of an activity, irreversible for at least a decade
Major	MR	Disappearance of activity in part of the area colonized by the exotic taxon, irreversible for at least a decade
Moderate	MO	Decrease in the importance of the activity, but the activity is still carried out (displacement of the activity towards regions devoid of the exotic taxon)
Minor	MN	Difficulties in exercising the activity without a change in size
Minimal	MC	No negative impact reported

The diagram places the species in question on a five-level scale, ranging from massive to minimal impact, and includes the mean values, obtained from the statistical analysis with the SEICAT scale to determine the magnitude and urgency of the impact in different geographical areas.

Meyer-Olkin (KMO) test to verify the adequacy of the sample, determining if the data are suitable for factor analysis, with a p-value less than 0.05, indicating the rejection of the null hypothesis and to conclude that there are significant correlations between the variables. As such, the use of the KMO test and Bartlett's test of sphericity is crucial in cluster analysis, particularly when EFA is a preliminary step. The objectives of the cluster analysis were to identify and compare the different typologies of fishermen to understand which groups perceived the effects of the blue crab invasion more pronouncedly or less pronouncedly and how various factors influence each other. This approach provided an in-depth overview of the various facets of blue crab impacts, as well as identified any significant differences in perceptions between the fishing communities in the two geographic areas under consideration. Consequently, we obtained a KMO value of 0.558 for Apulia study area, suggesting mediocre sampling adequacy, while for Algarve study area, the KMO value was 0.761, indicating a good suitability. In both cases, the p-value is<0.05, indicating that correlations among variables were sufficiently high for factor analysis. These results validate the data structure, ensuring that it is appropriate to proceed with clustering techniques like K-mean cluster analysis. Moreover, we assessed the normality and homoscedasticity of the data using the Shapiro-Wilk test, which showed no significant deviations from normality for the variables analyzed.

3 Results

3.1 Fishermen's socio-economic profile

Table 2 provides a comprehensive overview of the socio-economic and operational characteristics of fishermen in the

TABLE 2 Fishermen's boat characteristics and socio-economic profile in the study areas.

Variable	Descriptive statistic	Study area	
		Apulia	Algarve
Sample size - fishermen			
	Number	33	33
Seniority*			
	Mean	42	41
	Min	10	10
	Max	73	66
	Std. Deviation	17.05	13.539
Fishing seasonal period			
Autumn	%	42	3
All year		58	97
Boat overall length	Mean	8	7
	Min	6	5
	Max	14	7
	Std. Deviation	2.12	0.614
Boat engine power	Mean	32	65
	Min	8	27
	Max	59	100
	Std. Deviation	15.25	17.888
Principal tools			
Small fishing	%	73	100
Trawls nets		27	–
Cooperative involvement			
Yes	%	52	15
No		48	85
Age*			
Less than 30 years	%	–	3
From 30 to 64 years		55	70
Greater than 65 years		45	27
Gender			
Male	%	100	100
Female		–	–
Member family	Mean	3	3
	Min	2	1
	Max	5	5
	Std. Deviation	0.94	1.053

(Continued)

TABLE 2 Continued

Variable	Descriptive statistic	Study area	
		Apulia	Algarve
Level of study			
Primary	%	58	–
Middle		39	85
High School		3	15
Another occupation			
Yes	%	36	18
No		64	82
Area of other occupation			
No response	%	64	88
Agriculture		18	–
Food service		–	6
Trade		–	3
Industry		18	3
Annual household income (in EUR)			
Less than 20,000	%	61	52
From 20,000 to 40,000		39	48

*A consistency exists between the seniority and age of fishermen, particularly in Lesina lagoon (Apulia region, southern Italy), where at least one fisherman was over 80 years old.

Apulia and Algarve areas, highlighting differences in seniority, fishing practices, boat specifications, cooperative involvement, education levels, secondary occupations, and income distribution. It reveals that the sample surveyed was evenly divided between the two areas under analysis: 50% conduct their fishing activities in the Lesina lagoon, while the remaining 50% operate in several municipalities within the Algarve region. Apulian's fishermen had almost the same average seniority (42 years) compared to those in the Algarve (41 years). In Apulia, 42% of fishermen fished exclusively in autumn, whereas 58% fished year-round. In contrast, 97% of fishermen in the Algarve fished year-round. The average length of boats was nearly identical, measuring 8 meters in Apulia and 7 in the Algarve. However, boats in the Algarve had higher engine horsepower. In addition, in Apulia, there was greater participation in cooperatives, with 52% of fishermen involved, compared to only 15% in the Algarve. With respect to the socio-economic parameters, the age distribution showed 55% of fishermen were aged between 30-64 years, and 45% were over 65 years in Apulia. In the Algarve, the age distribution was more diverse: 3% were under 30 years, 70% were 30-64 years, and 27% were over 65 years. Moreover, all respondents in both regions were male, and the average household size was three members. In terms of education, 58% of Apulia fishermen had an elementary education, 39% had middle school education, and 3% had high school education. In the Algarve, 85% had middle school education and 15% had high school education. Regarding the occupation aspects, a higher percentage of fishermen in Apulia (36%) had secondary occupations (18% in agriculture and 18% in industry) compared to the Algarve (18%), where the secondary occupation was primarily in food service. In Algarve, 48% of respondents reported an annual income, from fisheries and secondary occupation, between EUR 20,000 and 40,000 and 52% an annual income less than EUR 20,000, while in Apulia, only 39% fall between EUR 20,000 and 40,000, and the remaining 61% hold an annual income less than EUR 20,000.

3.2 Blue crabs' impacts on fishermen's well-being

The studied areas exhibited markedly different perceptions of the impact of the blue crab invasion on the well-being of fishermen. On the one hand, in Apulia, the invasion had significantly impacted various aspects of fishing. All respondents confirmed damage to nets (DAMN), with 52% rating it as very significant (Figure 5). Also, increased costs (COST, i.e., due to gear damage, increased fuel consumption, and the need for new equipment to handle blue crabs invasion) were noted by 94% of respondents, and 39% considered this increase as very significant. Moreover, physical damage (DAMP, i.e., fishermen's injuries/physical harm, necessitating changes in handles practices and possibly protective equipment) caused by the crabs was reported by 82%, with 33% describing the

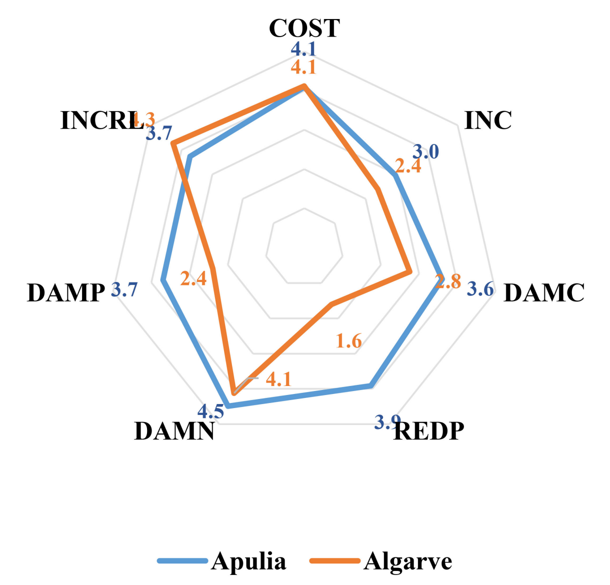

FIGURE 5
C. sapidus impacts on fishermen's well-being in the study areas. Where: "COST" means that the bio-invasion of the blue crabs has increased expenses for conducting fishing activity; "INC" means that the bio-invasion of the blue crabs has implied a reduction in income related to its fishery; "DAMC" means that the bio-invasion of the blue crabs has physically induced damages to catch; "REDP" means that the bio-invasion of the blue crabs has reduced the presence of other commercial species in its fishing area; "DAMN" means that the bio-invasion of the blue crabs has physically induced damages to nets; "DAMP" means that the bio-invasion of the blue crabs has caused physical harm while performing the activity; and "INCRL" means that the bio-invasion of the blue crabs has increased the amount of work during its fishing activity. Scale: 1 = Insignificant; 2 = Not very significant; 3 = Significant; 4 = Quite significant; 5 = Very significant.

impact as very significant. Additionally, 97% perceived a reduction in the presence of other commercial species (REDP), with 33% rating this as very significant. The increase in working hours (INCRL) was noted negatively by 94% of respondents, with 30% rating it as very significant. Lastly, 97% of fishers noted catch damages (DAMC, i.e., changes in fishing techniques in terms of extensive or severe damages to fishing nets, and increase in working hours to maintain the catch levels) with 24% rated as very significant, and 61% perceived a reduction in income (INC) as negative, with 9% considering it very significant. On the other hand, in Algarve, the impact on well-being had a slightly different negative effect. 67% of fishermen confirmed damage to fishing equipment (DAMN), with the majority, 39%, considering it significant. Increased cost (COST) was reported by 88% of respondents, with 48% considering it very significant. Physical damage (DAMP) was reported by 45%, with 30% rating it as significant. Additionally, only 20% perceived a reduction in other commercial species (REDP), with 21% considering it significant. Moreover, 91% perceived an increase in working hours (INCRL), with 58% rating it as very significant. Furthermore, 67% reported damage to the catch (DAMC), with the majority, 39%, considering it significant, and finally, 52% perceived a reduction in income (INC), with the majority, 39%, rating it as significant.

3.3 Blue crabs' impacts on fishermen's activity size

With respect to the impacts on the fishermen's activity size, in Apulia, 64% of respondents claim that the invasion has led to abandonment in some fishing areas (ABAN), while 76% report a reduction (Figure 6) in other areas (REDU1). Furthermore, 79% affirm a reshaping of fishing activities (RESH), while 45% state that some fishermen have also abandoned the activity (RNFI). Moreover, 61% report catching less fish following the invasion (FISH). In contrast, in Algarve, 24% of respondents indicate that the incursion has resulted in abandonment in certain fishing zones (ABAN), while 27% note a decrease in others (REDU1). Furthermore, 15% acknowledge a restructuring of fishing operations (RESH), with an additional 15% stating that some fishermen have also discontinued the activity (RNFI). Moreover, only the 30% perceived a negative impact on the amount of catch reporting to catch less fish (FISH). In Apulia, 40% of fishermen sell the crab while 60% discard it. In contrast, in Algarve, 97% of fishermen sell the crab and only 3% discard it. Summing-up, the Figure 7, based on Table 1, revealed that the *C. sapidus* had an overall average negative activity impact on fishing activities. According to SEICAT rules and guidelines, in Apulia, the overall activity impact was categorized as Moderate (MO) while in Algarve, it was considered as Minor (MN).

3.4 Fishermen's clusters

Based on the EFA analysis, two clustering processes have been performed, based on the criterion of minimizing within cluster variance: each fisherman was assigned to the cluster whose centroid is closest, using Euclidean distance as the measure of proximity. Consequently, in Apulia, four clusters of fishermen (Figure 8) have been identified based on their responses to the impacts of the blue crab invasion. The cluster 1 (36% of respondents) and cluster 3

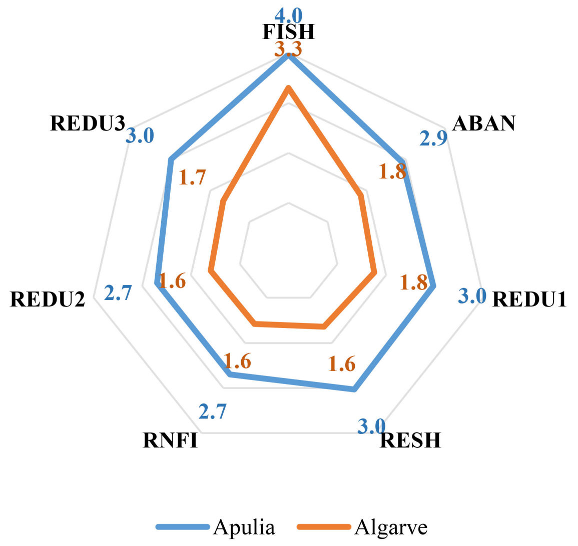

FIGURE 6
C. sapidus impacts on fishermen's activity size in the study areas. Where: "FISH" means that when blue crabs are present in the invaded area you fish: 1. Much more fish, 2. More fish, 3. No differences 4. Less fish, 5. No more fish; "ABAN" means that the bio-invasion of the blue crabs has induced abandonment of the fishermen's activity in a different area from the previous one; "REDU1" means that the bio-invasion of the blue crabs has induced reduction in the fishermen's activity in a different area from the previous; "RESH" means that the bio-invasion of the blue crabs has caused the fisheries to be abandoned or reshaped; "RNFI" means that the bio-invasion of the blue crabs has caused a reduction in the number of fishermen in their fishing area; "REDU2" means that the bio-invasion of the blue crabs has caused a reduction in fishing activity in part of their usual fishing area; and "REDU3" means that the bio-invasion of the blue crabs has caused a reduction in fishing activity over its entire fishing area. Scale: 1 = Insignificant; 2 = Not very significant; 3 = Significant; 4 = Quite significant; 5 = Very significant.

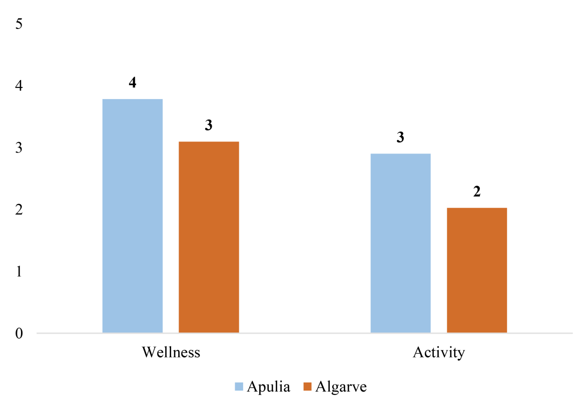

FIGURE 7
C. sapidus overall average impact on fishermen's wellness and activity in the study areas based on Bacher et al. (2018).

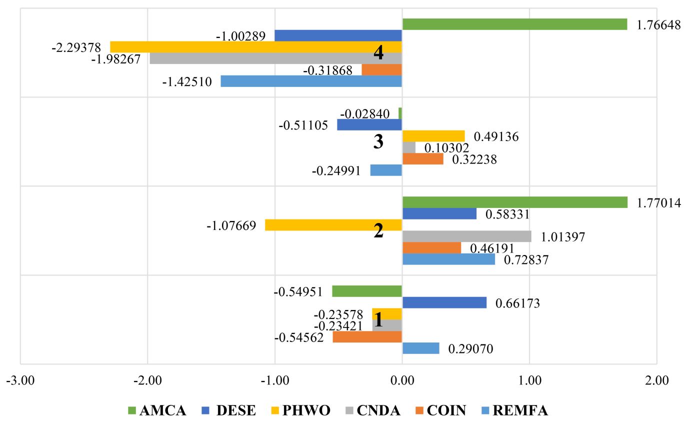

FIGURE 8
Apulia study area: Fishermen's clusters and associated variables. The figure highlights 4 clusters of fishermen dealing with blue crab invasion. Where: "AMCA" means amount of catch; "DESE": means decline in other commercial species; "PHWO" means physical harms and increase of work; "CNDA" means catches and nets damages; "COIN" means increased expenses and reduced income, and "REMFA" means remodeling of fishing activities and areas.

(52% of respondents) are named "Resilient Fishermen" as they both perceive a moderate overall impact. Specifically, cluster 1 is associated with a decline in other commercial species, while the cluster 3 reports physical harm and an increase in work. Cluster 2 (9% of respondents), named "Struggling Fishermen," was the most affected by the invasion, although they did not declare significant impacts on physical harm or an increase in workload. Furthermore, the cluster 4 (3% of respondents), named "Catch-Concerned Fishermen," perceives an overall low impact from the invasion, indicating that catch reduction was not relevant for their income, but reports a significant reduction in the amount of catch. In Algarve, four clusters of fishermen (Figure 9) also have been identified based on their responses to the impacts of the blue crab invasion. Cluster 1 (36% of respondents), referred to as "Resilient Fishermen," experienced a minor impact overall, particularly regarding increased costs, physical harm, and net damage. Cluster 2 (9% of respondents), described as "Moderately Impacted," faced significant challenges related to increased work, reduced income, and decreased catch. The cluster 3 (52% of respondents), termed "Struggling Fishermen," reported a highly significant impact, especially concerning the remodeling of fishing activities and areas. Lastly, cluster 4 (3% of respondents), known as "Not Impacted Fishermen," represents a small group that does not perceive any negative effects. Both in Apulia and Algarve, the most resilient clusters, which were the least affected, had capitalized on new market outlets and valued new market opportunities through the sale of blue crabs. As such, their ability to withstand the initial impacts indicated potential economic adaptation and suggests a capacity for effective response to future challenges posed by the blue crab invasion.

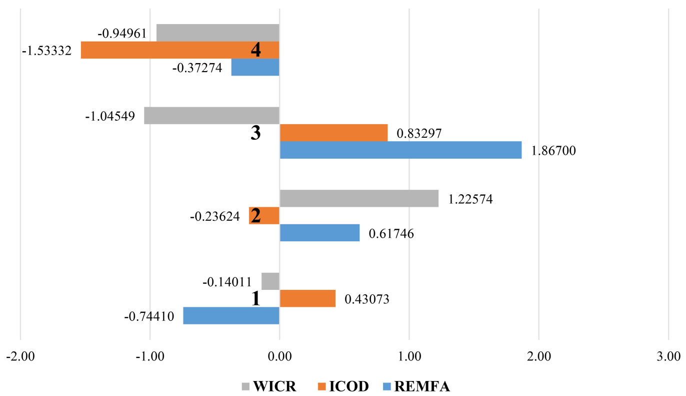

FIGURE 9
Algarve study area: Fishermen's clusters and associated variables. The figure highlights 4 clusters of fishermen dealing with blue crab invasion. Where: "WICR" means increased work, income and catch reduction; "ICOD": means cost, physical and nets damages, and "REMFA" means remodeling of fishing activities and areas.

4 Discussion

4.1 Interpretation and comparison

The two study areas, Apulia and Algarve, exhibit markedly different perceptions of the impact of the blue crab invasion on the well-being of fishermen. In Apulia, the invasion has significantly affected all the aspects, including damage to nets, physical damage, reduction in the presence of other commercial species, reduction in catch quantity, consequently, increase in working hours, increased costs, and reduction in income. In particular, the most significant perceived impact is related to damage to fishing nets, reinforcing the hypothesis that this factor is one of the main damages caused by the invasion for fishing operators, as reported in the study conducted in the Marchica lagoon, Morocco (Oussellam et al., 2021). In contrast, in Algarve, the perceived damage to nets is lower, although the most significant perceived impact is represented by the physical damages as described above, increase in working hours increased costs and reduction in income. These findings highlight the broader importance of significant impacts perceived by fishermen in Apulia compared to those in Algarve, where the effects are more concentrated on specific economic and labor-related challenges. Overall, this invasion has significantly impacted fishing techniques in several ways: (i) damage to fishing gear (In Apulia, the invasion has led to extensive damage to fishing nets, while net damage is reported as less severe in Algarve); (ii) changes in working hours (i.e., both areas reported increased in working hours), (iii) altered catch composition (i.e., in Apulia, there has been a decline in other commercial species, likely due to the competition or predation by blue crabs), (iv) reduced catch quantities (i.e., particularly in Apulia, where fishermen reported reduced catch quantities of their traditional target species), (v) increased costs (i.e., both regions reported higher costs associated with fishing activities, likely due to gear repairs, increased fuel consumption from longer working hours, and potentially new equipment needs), (vi) physical harm (i.e., fishermen in both regions reported concerns about physical harm from handling the aggressive blue crabs, which may necessitate changes in handling practices or protective equipment), and (vii) potential shift in target species (i.e., the abundance of blue crabs could lead to targeting this species a new commercial opportunity, especially if markets develop for blue crabs products).

While some fishermen clusters in both regions reported significant impacts, others demonstrated greater resilience or even opportunities in terms of selling blue crabs due to this invasion. Additionally, these results indicate the hypothesis for differentiated approaches in managing and adapting to the consequences of the blue crab invasion to meet the specific needs of fishing communities in different regions. This hypothesis can be derived from the fact that different types of fishing are practiced in Algarve and Apulia. In Apulia, crab fishing is not selectively practiced (Cilenti et al., 2024), whereas in Algarve, there is already targeted crab fishing, such as for the *Cancer pagurus* known as brown crab (Leitão et al., 2023). Consequently, the blue crab invasion appears to be less significant for those who are already using appropriate gears and are less vulnerable to damage from its presence. In the Algarve, where the product is actively fished, sold, and consumed, albeit to a lesser extent (Minor, according to the SEICAT scale), there is a perceived negative impact on fishermen. Even though the impact is considered minor, it remains negative because not all fishermen are equipped with appropriate fishing gear, leading to damage to catches of other commercial species.

Unlike Algarve, where nearly all fishermen (99% of those interviewed) sell the crabs, in Apulia, only a minority recognize its commercial value, driven by consumer preferences, and consequently market value of this product This suggests that, unlike in Apulia, Algarve has a tradition of crab fishing, where the species is abundant, valued, and widely consumed, making it easier for fishermen to sell their catch. Despite the known organoleptic properties and the well-established and expanding market in areas where it is native (Nanda et al., 2021), economic value varies regionally. In the USA, the blue crab is a well-recognized marine resource of high economic interest (Zohar et al., 2008), and similarly in Asia (Rabaoui et al., 2021). However, along the Adriatic coasts, artisanal fisheries are currently struggling to find solutions to cope with established crab populations since some years, but also growing exponentially in the last two or three years. Unlike the Algarve region, in Apulia there is no established supply chain for this product yet, and it is not widely consumed due to the lack of a consumption tradition. Fishermen are not equipped with appropriate fishing gear, leading to a more significant perceived impact. In this sense, the reduction of its population through commercial exploitation for human consumption in Italy, as has already been developed in several countries such as Egypt (Abdel Razek et al., 2016), Greece (Kevrekidis et al., 2023), Turkey (Ayas and Özogul, 2011; Harlıoğlu et al., 2018), Tunisia (Ennouri et al., 2021), and the USA (Sharov et al., 2003), may constitute one of the best comprehensive management controls of this threat (Marchessaux et al., 2023). Most efforts to measure and compare these impacts typically adopt utilitarian approaches by assigning monetary values to their costs (Zavaleta, 2000; Reinhardt et al., 2003; Born et al., 2005). However, quantifying socio-economic impacts in monetary terms is often challenging and may overlook important dimensions of human well-being. Previous endeavors to standardize socio-economic impacts using non-monetary metrics (e.g., GISS: Nentwig et al., 2010; Harmonia+: D'hondt et al., 2015) have struggled due to diverse descriptions of impact scenarios, complicating comparisons across impact categories.

The findings of this study are consistent with the hypotheses concerning the negative impacts associated with the invasion of *C. sapidus* (Nehring, 2011; Mancinelli et al., 2017), in relation to all the factors considered, as suggested and by the SEICAT methodology of Bacher et al. (2018). Specifically, artisanal small-scale fishermen have been recognized as the key target group to understand the effect of invasive species, considering their background and first-hand experience with the issue (Johnson, 2011; Vidal et al., 2020). Comparing studies conducted in other countries such as France and Tunisia (Marchessaux et al., 2023), where artisanal fishermen have been engaged to estimate the impacts of blue crab invasion, our study also confirms similarities, especially the negative influence on fishing activities and the reduction of other commercial species in the catch and associated income. However, in Portugal, these latter two factors are perceived to a significantly lesser extent. Conversely, our study does not fully align with the observations from the study conducted by Cerri et al. (2020) in Croatia, Italy, and Montenegro, where only a minority of the interviewed fishermen perceived a negative effect on fishing and the environment. This discrepancy is likely related to the positive trend of the invasion over the past five years, which has influenced the intensity and significance of the impacts. Finally, our observations, based on the perceptions of fishermen, align with the assessments of indirect damage caused by *C. sapidus* in Italy where it is estimated that the invasion of *C. sapidus* has led to an income decrease of about 30%, which could translate to a total economic loss of approximately EUR 200.000,00 per year (Cannarozzi et al., 2023).

4.2 Management countermeasures

This study shows that the impacts measured, mainly from a socio-economic point of view – which is treated by the SEICAT protocol – while the ecological impacts on the environment have not been the object of the study, are still perceived as negative, allowing to hypothesize and confirm that limiting the population expansion of *C. sapidus*, or containing it where it is already established, requires urgent management actions (Rotter et al., 2020). The first preliminary action for enabling an effective mitigation plan is early detection and monitoring in non-invaded areas. Informative campaigns on non-indigenous species carried out within research projects have facilitated the collection of initial and subsequent records (Falautano et al., 2020). The solution to the problem and this control management measure must, however, adopt a holistic approach, as suggested by Castriota et al. (2022) for the Pacific blue crab *Portunus segnis*. This includes: (i) the dissemination of appropriate fishing equipment and practices, along with demonstrations of their use, in line with EU Regulation 1380/2013. For example, the adoption of wire traps (Özdemir et al., 2015; Glamuzina et al., 2021), (ii) the promotion of blue crab in the market as a high-value fishery resource, accompanied by awareness campaigns to encourage its consumption, which can help reduce pressure on the local ecosystem (Falautano et al., 2020), (iii) the establishment of supply chains to facilitate the sale of the product by fishermen, reducing waste through circular economy activities such as chitin and chitosan extraction for various applications, primarily in the pharmaceutical and food industries (Hamdi et al., 2018; Casadidio et al., 2019). Moreover, the category of fishermen is generally resistant to change and adaptation to new measures and innovations. Therefore, another important management measure should be to implement: (iv) informative campaigns, training, and awareness programs, and to increase (v) public and private management programs to regulate control measures at national and international levels (Mancinelli et al., 2017). Furthermore, possible solutions and mitigation strategies may include the: (i) use of acoustic traps to track the movements of blue crabs; (ii) managing of the gates in the Lagoons inlet channels, to limit the entry of blue crabs larvae and the exit of adults for spawning; (iii) fishing for blue crabs during the fishing ban period of other species, and, (iv) adopting alternative fishing gears with larger mesh sizes.

4.3 Public and firm-side implications

The public and firm-side implications of a study about the socioeconomic threat posed by the blue crab to fishermen are manifold and significant. With respect to public implications, this includes: (i) public awareness: the study will contribute to informing the public and relevant authorities about the negative socioeconomic impact of the blue crab on the fishing community and local economy; (ii) resource management policies: the study's findings may influence the development of marine resource management policies and strategies to mitigate the harmful effects of the blue crab on the fishing sector (Maggio et al., 2022). In terms of firm-side implications, this includes: (i) economic sustainability of fishermen: the study will help fishermen to understand better the economic challenges they face due to the presence of the blue crab and may provide useful information to adapt their fishing practices (Berkes et al., 2007); (ii) identification of diversification opportunities: the research may suggest diversification opportunities for affected fishermen, such as the development of new fishing techniques or the promotion of alternative income sources (Kasperski and Holland, 2013). In this direction, fishermen may adopt various strategies to market the blue crabs effectively: (i) direct sales to consumers at local markets, roadside stands or through community-supported fisheries, helping them to obtain better process by cutting out middlemen; (ii) wholesale to restaurants and retailers (i.e., establish relationships with them, ensuring a steady demand and often allows for bulk sales); (iii) online sales (i.e., e-commerce, expanding their markets reach beyond local areas); value-added products (i.e., such blue crabs cakes, soups, sauces, diversifying their offer and increasing their income); (iv) sustainable practices by stressing their sustainable fishing practices, leading to attract environmentally conscious consumers); (v) participation in festivals and events seafood to promote their products and connect with potential customers. As a result, these potential marketing strategies would help fishermen to maximize their profit and ensure a sustainable supply of blue crabs. Overall, this provides an empirical basis for management measures and interventions to mitigate the socioeconomic impacts of the blue crab on the fishing community and local economy, thereby contributing to the well-being of both individuals and the marine ecosystem (Kleitou et al., 2021).

4.4 Long-term implications for fishing communities and marine ecosystem

On the one hand, the long-term implications for fishing communities may include an economic impact in terms of: (i) reduced income (i.e., fishermen in both regions have reported lower incomes due to the decline in other commercial species and the increased costs associated with repairing damaged gear and longer working hours); (ii) increased costs (i.e., there are higher operational costs due to gear damage, increased fuel consumption, and the need for new equipment to handle blue crabs; (iii) market adaptation (i.e., some fishermen may need to adapt by targeting blue crabs as a new commercial species, which could require market development and consumer education efforts); (iv) changes in fishing practices as described above, and (v) social and psychological impact (i.e., stress and uncertainty, which the invasion has led to increased stress and uncertainty among fishing communities, impacting their overall well-being and quality of life). On the other hand, the long-term implications for the marine ecosystem may include; (i) biodiversity and species interactions (i.e., decline in native species: the presence of blue crabs has led to a decline in other commercial species, likely due to competition and predation; disruption of trophic relationships: the blue crabs, being omnivorous and aggressive, can alter the food web dynamics by preying on a variety of organisms and competing with native species for resources); (ii) habitat alteration (i.e., ecosystem changes: the aggressive nature and high fecundity of blue crabs can lead to significant changes in habitat structure and function, potentially affecting the ecological balance of the invaded areas) and, (iii) potential for further spread (i.e., rapid expansion, which the blue crab population is expanding rapidly along the southern coast of Portugal and into the Mediterranean Sea, indicating a potential for further ecological and economic impacts in new areas).

4.5 Limitations and future research directions

Interviewing fishermen presents significant challenges, as many are unwilling to participate in interviews, as verified also during this study. Additionally, the methodology relies on participants' perceptions, which can vary and be influenced by the presence or absence of the blue crab at the time of the interviews, in which the Lesina population had been interviewed in an earlier phase of the blue crabs' invasion time course (Cannarozzi et al., 2023). Although seasonal variations and the subjective nature of fishermen's experiences also pose challenges an effective collaboration with stakeholders is crucial for understanding the impacts and consequences of biological invasions (Rayon-Viña et al., 2022). However, a detailed analysis of the extent of damage inflicted by this phenomenon on professional fishing activities remains an area requiring further exploration. Consequently, future research should test various proposed solutions and evaluate the adaptability of fishermen and the market. This includes exploring circular economy solutions and sustainable adaptation practices like alternative fishing methods (Jabeur et al., 2022). Additionally, further studies should analyze the effectiveness of adopted strategies to identify weaknesses and suggest improvements, considering the dynamic economic, social, and environmental differences. Research on the blue crab exploitation, such as the production of soft-shell blue crabs for enhancing the commercial value of the species and the reuse of by-products and circular economy practices, such as chitin exploitation, is recommended (Cilenti et al., 2024; Tamburini, 2024). Furthermore, studying the willingness and capacity of fishermen to adapt to changes, and how this adaptability can be enhanced, is critical. Resistance to change and innovation among fishermen can hinder progress. Evaluating the "willingness to change" and the rapidity of adaptation among fishermen, along with assessing social aspects across different regions, is essential for future research (Rahman et al., 2022). Consequently, future studies should focus on identifying and addressing these challenges, followed by testing the implementation and effectiveness of the adopted strategies. This can be achieved by developing long-term output and outcome indicators, in line with the recommendations of General Fisheries Commission for the Mediterranean - GFCM/42/2018/7 (FAO, 2018). This approach will help evaluate the practical implementation and effectiveness of the measures, ultimately promoting sustainable fishing practices in affected areas. Finally, the determination of the pressure of the invasion would allow figuring out the exact perception by the fishermen of the two studied areas. In this direction, and to the best of our knowledge, there is a lack of statistical data focusing on the estimates of the abundance of blue crabs, and of their density across the two areas that also would be needed to overcome this last limitation of the study.

5 Conclusion

The socio-economic impact of the blue crabs' invasion across two different Mediterranean areas has allowed for a broader understanding of the invasion, highlighting how varying conditions and factors such as fishing equipment and existing market dynamics can influence the impacts of invasions on fishing communities. This comparative study has displayed and confirmed the negative effects of biological invasions on both the well-being of fishing communities and their activities, with varying invasion severity, and perceptions depending on the geographical area. The perception of fishermen regarding the intensity of the impacts is particularly tied to the fishing techniques employed and the target market. Overall, the study suggests the urgent need to adopt context-specific management strategies, as discussed, to minimize the negative impacts of invasions. The study highlights the importance of collaboration with local stakeholders to monitor phenomena and consequences related to biological invasions. This collaboration enables the development of management recommendations tailored to the specific needs of different contexts, influenced by factors such as fishing techniques, target markets, and marine resources. However, the research also displays critical areas that require further investigation. There is a need to understand the gaps and challenges that prevent the full exploitation of fishing in areas heavily affected by invasions. This involves developing concrete actions to promote fishing and the adoption of appropriate equipment. After identifying obstacles related to the implementation of management strategies, it is crucial to actively promote these actions.

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 data gathered from the in-person survey was solely utilized for statistical analysis and the specific research project. According to Regulation (EU) 2016/679, personal data will not be shared with third parties or used for personal interests, whether one's own or others. The information obtained was solely utilized in a collective manner, ensuring the utmost anonymity of the participant. Additionally, fishermen were asked for their consent at the start of the survey to take part in this research in line with national laws and institutional rules.

Author contributions

LN: Conceptualization, Data curation, Formal analysis, Methodology, Software, Investigation, Writing – original draft. VF: Conceptualization, Funding acquisition, Project administration, Resources, Validation, Writing – review & editing. HP: Investigation, Formal analysis, Writing – review & editing. JE: Investigation, Writing – review & editing. AC: Formal analysis, Writing – review & editing. AP: Formal analysis, Writing – review & editing. FB: Funding acquisition, Resources, Writing – review & editing. MF: Conceptualization, Data curation, Formal analysis, Methodology, Software, Supervision, Visualization, Writing – review & editing.

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Conflict of interest

Author MF was employed by Sinagri S.r.l.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2024.1466132/full#supplementary-material

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Appendix A

The fishing gear and the target fisheries products in Lesina Lagoon

Lesina an Italian town in the province of Foggia in Puglia (N 41.88° and E 15.45°), stands as one of the largest wetlands in central and southern Italy, positioned along the southern Adriatic coast within the Apulia region. This semi-closed system is influenced by both fresh and marine waters, encompassing an area of 51.36 square kilometers with a maximum depth of approximately 1.5 meters. The lagoon's catchment area covers about 600 square kilometers. Similar to other Mediterranean lagoons, Lesina Lagoon is characterized by shallow waters and limited exchanges with the sea. In comparison with Atlantic systems, it experiences less tidal influence and lower freshwater input (Breber, 2002; Manzo et al., 2016). The Lesina Lagoon serves as a crucial habitat for various plant and animal species, making significant contributions to the local economy, particularly in the realms of fisheries and tourism (Ferrarin et al., 2014). Within the lagoon, numerous fish species are harvested through small-scale artisanal fisheries and extensive aquaculture practices that have been in operation for many years. Effective lagoon management is thus essential for preserving its ecological characteristics, preventing the depletion of valuable aquatic resources, and safeguarding sensitive habitats (Manzo et al., 2016). Consequently, the Lesina Lagoon, located within the Gargano National Park, holds designations as both a Special Protection Area (SPA-IT9110037) and a Site of Community Importance (SC-IT9110015), aligning with the provisions of the Birds and Habitats Directive (2009/147/EC, 92/43/EEC). The most recent official data available for the Lesina Lagoon pertains to the 2016-2017 fishing season, during which a total catch volume of approximately 31.07 metric tons was recorded. In 2016, a total of 30 operators were reported, with average catches per operator for the 2016-2017 fishing season amounting to approximately 1,035.7 kg. The most prevalent species caught were eels (29.1%), followed by sea bream (26.6%), mullets, representing approximately 14.3%, and sand smelt, accounting for 11.8%, alongside other species. Shrimp and sea bass made up smaller proportions, representing 3.5% and 2.9% of the total catch, respectively. About 11.8% of the catch consisted of alien species such as Nile tilapia (*Tilapia nilotica*) and blue crab (*C. sapidus*), with the latter gaining increasing prominence among the Lagoon's catches. The main fishing Lesina gears are Bertovelli (i.e., traditional nets, Figure A1), which also emerged from the surveys.

FIGURE A1
Bertovelli (traditional nets) used in Lesina Lagoon, Apulia (southern Italy). These nets are designed for the capture of various fish and crustacean species, including eels (*Anguilla anguilla*) Source: Ludovica Nardelli, 2023.

Appendix B

The fishing gear and the target fisheries products in Algarve region - Ria Formosa to Rio Guadiana

The Algarve region, specifically from Faro to Vila Real de Santo António, encompassing the Ria Formosa and the Guadiana River, emerges as a crucial study site for investigating the invasive Atlantic blue crab, *C. sapidus*. This coastal area, situated between the latitudes 37°01'N and 36°58'N and the longitudes 8°56'W and 7° 53'W, boasts a diverse range of estuarine and coastal ecosystems, making it an ideal location for studying the ecological dynamics of this invasive species (Cartaxana et al., 2009). Characterized by a Mediterranean climate with mild, wet winters and hot, dry summers, the Algarve coastline features sandy beaches, rocky cliffs, and several estuarine systems, including the Guadiana estuary, which serves as the border between Portugal and Spain. These estuarine environments provide a unique habitat for the blue crab, which has thrived in the region since its introduction in 2016 (Morais et al., 2019; Vasconcelos et al., 2019).

The Guadiana estuary has been a focal point for blue crab research in the Algarve. This 80-kilometer-long estuary is fed by the Guadiana River, which originates in Spain and flows into the Atlantic Ocean. The estuary is characterized by a diverse array of habitats, including mudflats, saltmarshes, and submerged aquatic vegetation, which provide suitable conditions for the blue crab to establish and proliferate (Vasconcelos et al., 2019).

The fishery industry in the Algarve region, particularly in the areas from Faro to Vila Real de Santo António, plays a vital role in the local economy. Artisanal fishing is a primary socio-economic activity, providing employment and sustenance for many local communities. The presence of the invasive blue crab has raised concerns within the fishing community regarding its potential impact on local catches and the necessity for effective management strategies to mitigate these effects. Recognized for its rich biodiversity and conservation significance, the Algarve region has been designated as a Site of Biological and Ecological Interest (SIBE) and a Ramsar site for wetland conservation and protection. These designations underscore the international and national recognition of the region's ecological importance, emphasizing its role in biodiversity conservation efforts at both local and global levels (Chainho et al., 2015; Morais et al., 2019).

In the Algarve region, small-scale artisanal fisheries are predominant, employing various traditional and modern fishing gears. The fishing gear used in the Ria Formosa region is primarily associated with small-scale artisanal fishing practices. These often include various types of nets, traps, and handlines, which are adapted to target specific species that are abundant in the estuarine and lagoon environments of the Algarve region. Similar to the Ria Formosa, fishing gear in the Rio Guadiana is characterized by the use of small-scale artisanal methods (Tursi et al., 2015). This includes nets, traps, and handlines that are suited for the estuarine and riverine environments of the Guadiana estuary. The main types of fishing gear based on the analysis of Pita and Gaspar (2020) include: (i) Trammel Nets (Redes de tresmalho): These are widely used in the Algarve for catching a variety of fish species. They consist of three layers of netting, which trap fish in the middle layer; (ii) Gillnets (Redes de emalhar): These nets are set vertically in the water column and are designed to entangle fish by their gills; (iii) Longlines (Palangres): used for targeting specific species, longlines consist of a main line with baited hooks spaced at intervals; (iv) Traps and Pots (Covos e armadilhas): These are used for catching crustaceans like crabs and lobsters. They are baited and left on the seabed to attract and capture the target species, and (iv) Handlines (Linhas de mão): simple fishing lines with baited hooks, used from boats or the shore, primarily for catching smaller fish species. The Algarve's artisanal fisheries target a diverse range of species, reflecting the rich biodiversity of the region. The main target species include: (i) bream (sparidae): various species of bream are highly valued and commonly caught using trammel nets and gillnets; (ii) mullet (Mugilidae): Mullet are another important target species, often caught with gillnets; octopus (Octopus vulgaris): Octopus is a key species for the Algarve fisheries, typically caught using traps and pots; sole (soleidae): sole is a high-value species targeted by trammel nets and gillnets; seabass (*Dicentrarchus labrax*): Seabass is caught using a variety of gear, including longlines and gillnets; bivalves: Such as clams and oysters, which are prevalent in lagoon systems; crustaceans (Crustacea): Various crabs and lobsters are targeted using traps and pots, with blue crabs (*C. sapidus*) becoming increasingly prominent due to their invasive nature, and eels and Shad: traditionally important species in the estuarine fishery of the Guadiana.