



Recreational harvesting of the wedge clam (*Donax trunculus*) in southern Portugal: Characterization of the activity based on harvesters' perception and local ecological knowledge

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ABSTRACT

This study was the first attempt to characterize the recreational harvesting of the wedge clam (*Donax trunculus*). For this purpose, 403 face-to-face interviews were performed in the summers of 2018 and 2019 in southern Portugal. The majority of the harvesters frequented the selected beaches during holidays and collected wedge clams as a hobby for an appetizer. The respondents reported an inter-annual variation in their catches of wedge clam with a decreasing abundance in 2018 followed by a recovery in 2019, but with more recreational harvesters collecting undersized individuals. Although most harvesters declared to consume *D. trunculus*, only a few bought wedge clams being the clams' size a secondary factor in their valorization. The majority of the recreational harvesters did not know the species' minimum conservation reference size nor the legally allowed maximum daily catch. It was estimated that recreational harvesters can collect 13 tonnes of wedge clams during the summer season along the southeastern coast of Algarve. Even though manual harvesting is not an efficient fishing technique, the lack of selectivity of harvesters can eventually compromise the resilience of *D. trunculus* populations. Despite most respondents affirmed to get informed about marine biotoxins, most surveys were done during periods of interdiction for shellfish harvesting. The present results revealed that the population is still unaware of the health risks of consuming shellfish contaminated with biotoxins. Educational activities and awareness campaigns are required to further inform recreational harvesters about the regulations in force for this activity and the sanitary threats of marine biotoxins.

1. Introduction

Shellfish harvesting for human consumption is an ancestral activity in most coastal regions worldwide, in part because shellfish remains an open-access source of seafood in many countries [1–5]. Marine bivalves play an essential role in coastal ecosystems, filtering suspended particles and feeding on phytoplankton, regulating water clarity, cycling nutrients, and therefore, contributing to the resilience of coastal areas to harmful algal blooms [6]. Despite its popularity and importance, the dynamics of clam harvesting, environmental impacts, and social and economic value for local communities are still poorly known and not well understood [4], namely because studies on shellfish recreational harvesting are scarce [7]. Therefore, a better understanding of the dynamics of clam harvesting and socioeconomic aspects related to its

consumption is needed, as well as perceiving the role of recreational harvesting in terms of the sustainability of this activity [5].

Data collection on marine recreational fishing (MRF) has been a requirement in European fisheries legislation since 2002 (Council Regulation No. 1639/2001 of 25 July 2001). Despite this regulation, only recently MRF studies have been developed in Portugal. However, most of these works focused mainly on shore angling and hand harvesting using gears in rocky shores, estuaries, and salt marshes, and there is still an information gap about hand harvesting without gears of wedge clams and other intertidal resources [8]. The lack of data on recreational catches hampers the estimation of their representativeness in relation to overall commercial catches and the assessment of eventual impacts of recreational harvesting on bivalve population dynamics. Recreational harvesting effort and catch data are challenging to assess

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due to the human interaction and biological characteristics of the collected species [9], and this absence of information hinders stock assessment and resource management [9,10]. In order to overcome these challenges, Local Ecological Knowledge (LEK) and Traditional Ecological Knowledge (TEK) have been used in fisheries research to characterize and assess the harvesters' perception of fishing activities, providing relevant information on the exploitation status of target species [11–13]. However, although LEK and TEK studies are still globally scarce, these have already demonstrated to contribute to the conservation and management of diverse natural resources [14].

The wedge clam (*Donax trunculus* Linnaeus, 1758) is a warm-temperate species distributed throughout the Atlantic Ocean and the Mediterranean Sea, from the British Isles and northern France to the African coasts from Morocco to Senegal [15–17]. This species inhabits highly energetic environments on exposed sandy beaches [18,19] and is mainly distributed at shallow depths, within 0–6 m in the Atlantic and 0–2 m in the Mediterranean [20–23]. Due to their shallow distribution, *D. trunculus* populations are mainly shaped by environmental drivers, such as wave exposure [10], seawater temperature, primary productivity (chlorophyll-*a* concentration), wind, rain, and salinity fluctuations [24–26]. The wedge clam distribution also reflects changes in sediment features and water quality and is, therefore, considered a suitable sentinel species for monitoring the environmental status of sandy beaches [27,28]. In addition, *D. trunculus* displays a depth segregation behavior that determines its vertical distribution in intertidal and subtidal areas, with juveniles at shallower areas and adults at greater depths [20,21,29,30]. This distributional pattern is reflected in differences in individual size, population structure, and growth performance [26,31].

The wedge clam has significant commercial importance for artisanal fisheries in different European countries, namely Portugal [20,32–35], Spain [25,36–42], France [43], Italy [21], and also in Turkey [22,44,45]. However, since the 1990s, catches have decreased in most of these countries [25], and in the long term, wedge clam populations from the Atlantic Ocean (Gulf of Cádiz), Alboran Sea, and the northwestern Mediterranean Sea could be threatened [46].

The exploitation of bivalves is an ancient activity in Portugal with social, economic, and cultural importance [3]. Shellfish harvesting and commercialization play a significant socio-economic role in several coastal communities throughout the country. In the Algarve coast (southern Portugal), this activity involves 8,000–10,000 people due to the local suitable environmental conditions to harvest shellfish species [3] such as the wedge clam *D. trunculus*, the razor clam *Solen marginatus*, or the cockle *Cerastoderma edule*, and the aquaculture production of bivalve species such as for instance the oyster *Magallana gigas*, the clam *Ruditapes decussatus*, and the mussel *Mytilus galloprovincialis*. The Algarve is also one of the Portuguese regions with a higher seafood consumption [47]. In Portugal, bivalves are commercially exploited by an artisanal dredging fleet comprising 78 vessels and the Algarve region presents the largest fleet, with 49 vessels targeting the wedge clam and other bivalve species, mainly the surf clam *Spisula solida*, the striped venus clam *Chamelea gallina* and the razor clam *Ensis siliqua* [48]. In the last years, wedge clam landings experienced important fluctuations [49], reaching the lowest levels in 2017 with an overall catch of 178 tonnes and an average price of 3.39 €/kg [50]. During 2018 and 2019, wedge clam landings increased to 290 and 293 tonnes, respectively, and the price reached 3.41 €/kg in both years [51,52]. In 2020, after prolonged interdiction periods in the fishing/harvesting activity due to marine biotoxins and the restrictions applied during the COVID-19 pandemic, the total landings of *D. trunculus* reached 811 tonnes in Portugal [53].

The wedge clam is also commercially exploited by professional harvesters, using hand-operated dredges in intertidal areas, and recreationally harvested, through hand-picking, especially during summer [20]. Recreational harvesting activities are regulated by national legislation and defined in the framework of fishing activities targeting marine species for recreational purposes [54,55]. In this context, the

recreational harvesting of *D. trunculus* is limited to a maximum daily catch of 2 kg per harvester, respecting the species' minimum conservation reference size (MCRS = 25 mm in shell length). The use of fishing gears is not allowed, being the harvesting restricted to using the hands or feet, and using a bag or bucket is only allowed for transporting the catches. Contrary to other harvesting modes, such as shore angling, boat angling, spearfishing (including hand harvesting using gears as dip nets or handled hooks for octopus), wedge clam harvesting using only bare hands does not require a specific MRF license.

The reproductive season of *D. trunculus* along the Algarve coast occurs from March to August, with two major spawning peaks in March and between May and August [32]. Accordingly, aiming to protect the spawning stock and larval settlement, the mandatory seasonal closure in the wedge clam fishery applies from May to June, being periodically adjusted and updated based on the scientific data available on the resource status [56]. This seasonal closure encompasses not only the commercial fishing (dredging fleet and hand-dredging), but also the recreational harvesting (hand-picking). Additionally, and following EU regulations [57–59], hygiene rules for seafood products and public health were established in Portugal, namely the classification of bivalve production areas [60], resulting in interdiction periods in the harvesting and consumption of bivalves due to the presence of marine biotoxins [61].

The present study was performed in the context of the EU Interreg project VENUS (Spain-Portugal), which aimed to develop an integral assessment of the natural banks of bivalve mollusks in the Gulf of Cadiz for a sustainable management and conservation of their associated natural habitats (Ref. 0139_VENUS_5_E. 2017–2019). Currently, there is a gap of knowledge on the recreational harvesting of the wedge clam in Portugal, and to the authors' best knowledge, this is the first study providing relevant and diverse information on this activity. Accordingly, the present work aimed to characterize the recreational harvesting activity of *D. trunculus* in the Algarve coast (southern Portugal) based on the harvester's perception and LEK in order to: 1) assess its potential impact on wedge clam populations, 2) ascertain the perceptions of recreational harvesters on this activity, 3) estimate the wedge clam annual catches by recreational harvesters in the Algarve coast, and 4) inform and raise awareness on the regulations in force and health risks of consuming bivalves during interdiction periods due to marine biotoxins.

2. Methods

2.1. Study area and data collection

The face-to-face interviews with recreational harvesters of wedge clams were performed during the summers of 2018 and 2019 along the eastern area (leeward or "Sotavento") of the Algarve coast (southern Portugal) (Fig. 1).

The interviews were conducted by one to five interviewers on eight pre-identified sandy beaches where this recreational harvesting activity is a traditional and frequent practice, especially during the summer tourist season. The wedge clam harvesting is performed mainly during the lowest spring tides. Therefore, the face-to-face interviews took place invariably during the first half of the day (8:30–15:00). All individuals interviewed were previously informed of the questionnaire objectives, anonymity, and confidentiality.

During the low tide period (~2–3 h), the interviewers walked individually in different directions along the selected beaches in order to interview the maximum possible number of harvesters and cover the largest possible area. Whenever harvesters were gathering wedge clams in a group (often families), only one individual was interviewed but the opinions of the remaining family members were also considered. Recreational harvesters were classified as residents if living in the Algarve region and the remaining respondents were categorized as tourists.

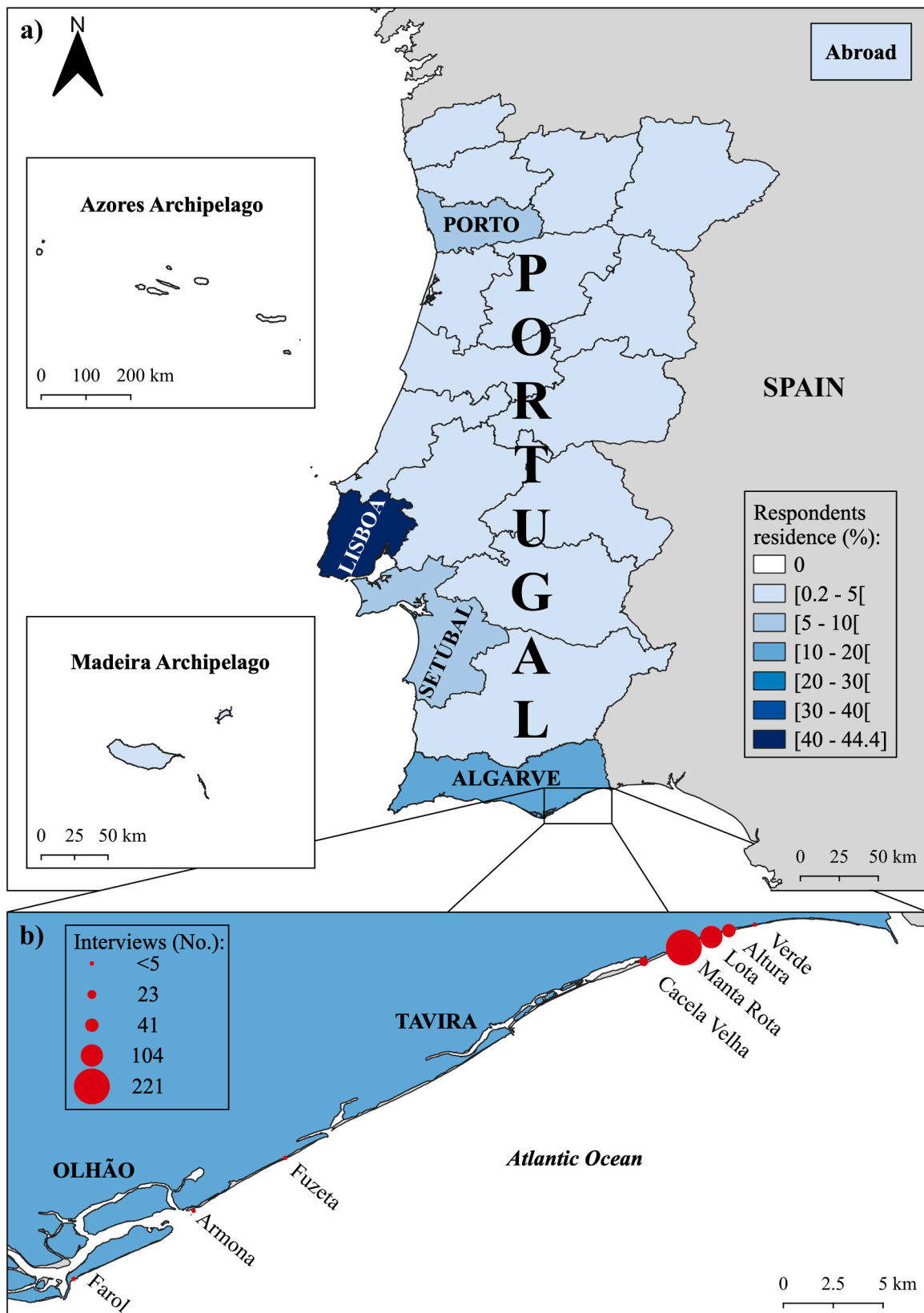


Fig. 1. Map of the study area highlighting the beaches where the face-to-face interviews were performed: a) Respondents' place of residence (%), and b) number of questionnaires made in each beach surveyed.

2.2. Face-to-face interviews to recreational harvesters of wedge clams

The questionnaire model, format, type, and content of the questions were previously revised and validated by experts on socioeconomic surveys from the University of Algarve. Overall, these voluntary interviews aimed to compile relevant information on the recreational fishery of *D. trunculus* on the Algarve coast based on the harvester's perception and LEK (please see the English-translated questionnaire provided as [Supplementary material S1](#)).

The questionnaire addressed diverse aspects directly related to the practice of this activity, namely the socioeconomic and demographic characterization of the recreational harvesters, the exploitation and conservation status of the resource, the valorization of the seafood product, and the regulations legally in force for the recreational harvesting of wedge clams. The questionnaire had diverse and complementary sections to classify the importance and value of this resource, comprising a total of 41 questions (31 multiple-choice questions complemented by ten open-answer questions). This broad set of questions aimed to gather information on the following topics: socio-demographic characterization, beach experience, wedge clam harvesting experience and annual frequency during weekdays and holidays, wedge clam valorization, temporal variation of this activity, and regulations in force for recreational harvesting.

After finishing the survey, the recreational harvesters that responded to the questionnaire and showed the collected wedge clams to the interviewer were rewarded with advertising gifts duly labeled with the logos of the project VENUS and respective funding entities. The respondents could choose one of the following items: a t-shirt, cap, cloth bag, cell phone neck strap, or a caliper-shaped pen to measure the wedge clams.

2.3. Data treatment and statistical analysis

The information gathered through the face-to-face interviews is anonymous, confidential, and an exclusive property of the Portuguese Institute for Sea and Atmosphere, I. P. (IPMA, IP). In addition, the information was analyzed and presented in an aggregated way in order to avoid the association of the data with any of the respondents. Each response to the questionnaire was numbered individually, and the data was treated and presented as percentage and/or mean \pm standard deviation. The graphical illustration of the harvesters' answers to their main reasons for collecting wedge clams was generated using the open-access word cloud generator (www.wordclouds.com). For this purpose, the most common expressions were English-translated and standardized into 14 more generic terms (comprising diverse synonyms).

The information on the level of marine biotoxins present on the wedge clams on the dates of the surveys was retrieved from IPMA's website (<https://www.ipma.pt/pt/bivalves/biotox/>), which allows consulting if the professional and recreational fishery of diverse commercial bivalve species exploited along the Portuguese coast is permitted or interdicted due to marine biotoxins.

The software package SigmaPlot (version 12.5) was used to perform most statistical analyses. The difference in harvesting activity between residents and tourists (number of harvesting days and catch amount) was assessed using a one-way ANOVA. However, due to the great difference in numbers between resident and tourist harvesters, data presented equal variance but did not meet normal distribution (Kolmogorov–Smirnov test), not even after a square root- or log-transformation thus, an ANOVA on ranks (Kruskal–Wallis test) was applied. The Pearson correlation coefficient was used to assess eventual relationships between the catch amount, the holidays duration, and the number of harvesting events. The chi-square test (χ^2) was performed using the statistical software XLSTAT to assess whether harvester's knowledge about the legislation depended on their age, harvesting experience, level of education, and gender.

3. Results

A total of 403 face-to-face interviews were performed with wedge clam recreational harvesters during the summers of 2018 (156 interviews in 11 days) and 2019 (247 interviews in 6 days). Most interviews occurred on the eastern coast of the Algarve ([Fig. 1a](#)), namely on the beaches of Manta Rota (221), Lota (104), Altura (41), and Cacela Velha (23). Together with Praia Verde, all these beaches constitute a continuous and extensive coastal stretch without any physical barriers among them. At Manta Rota and Lota beaches, there was a high concentration of recreational harvesters due to the large sandy area, easy access, and parking space. For logistic reasons, only two interviews were performed at Praia Verde and 12 interviews in the barrier islands of Farol, Armona, and Fuzeta ([Fig. 1b](#)).

Most of the selected beaches display the “Blue flag certification” (e.g., Lota, Manta Rota, Altura, Praia Verde, Armona, Fuzeta), which is one of the most recognized international awards for sustainable beaches and indicates their high environmental and quality standards. To qualify for this certificate, a series of environmental, educational, safety, and accessibility criteria must be met and maintained (please see <https://www.blueflag.global/>).

3.1. Recreational harvesters' sociodemographic characterization

Most recreational harvesters were tourists on holidays and only 10.9% resided in the Algarve region. More than half interviewees were men and 42.7% were women. The majority of these tourists were Portuguese citizens that regularly spend holidays in the Algarve region. Approximately 50% were from the Lisbon district, of which 44.8% lived in the city of Lisbon. The same percentage of individuals (12%) came from the north (mostly from the cities of Porto, Aveiro, and Braga) and central regions of Portugal (mainly from Coimbra and Leiria). The residents came from different cities in the Algarve region, but most lived in cities close to the surveyed beaches, namely Faro, Olhão, and Tavira. In addition, 19 respondents (4.8%) were foreigners or Portuguese emigrants on holidays living in countries such as Canada, England, France, Germany, Italy, Luxemburg, Netherlands, Spain, and Switzerland ([Fig. 1a](#)).

Overall, 37.8% of the recreational harvesters had an upper secondary level of education, 28.2% had a tertiary level of education, and only 15.2% and 18.8% of the respondents had a primary or lower secondary level of education, respectively. The most represented demographic group belonged to the age interval of 60–70 years old, and most had a household of two family members. The educational level in this demographic group was heterogeneous, with more than one-fourth of the respondents having an upper secondary level of education. The second group with more harvesters belonged to the age interval of 40–50 years old. In this group, almost 50% had a tertiary level of education and a household of three or more family members ([Fig. 2](#)). More than a quarter of the recreational harvesters interviewed were retired (32.5%), and 2.0% were unemployed. The most common professions of the respondents were civil servants (7.2%), senior technicians in different areas (4.7%), salespersons (4.0%), teachers (2.7%), businesspeople (2.7%), professional drivers (2.2%), and bank clerks (2.2%).

3.2. Recreational harvesters' beach experience

Most recreational harvesters already knew these beaches (91.3%) and were tourists that spent their summer holidays in the Algarve region. Most respondents spent less than 45 days on holidays, corresponding to a mean duration of 12.5 ± 6.6 days, whereas only 4.3% spent more than 60 days during summer in that area. Most recreational harvesters (73.8%) spent holidays on that beach for more than five years, distantly followed by those who frequented that beach area for two to five years (19.5%), and only 6.7% were on that beach for the first time. In summer, most respondents (86.8%) went to the beach four days

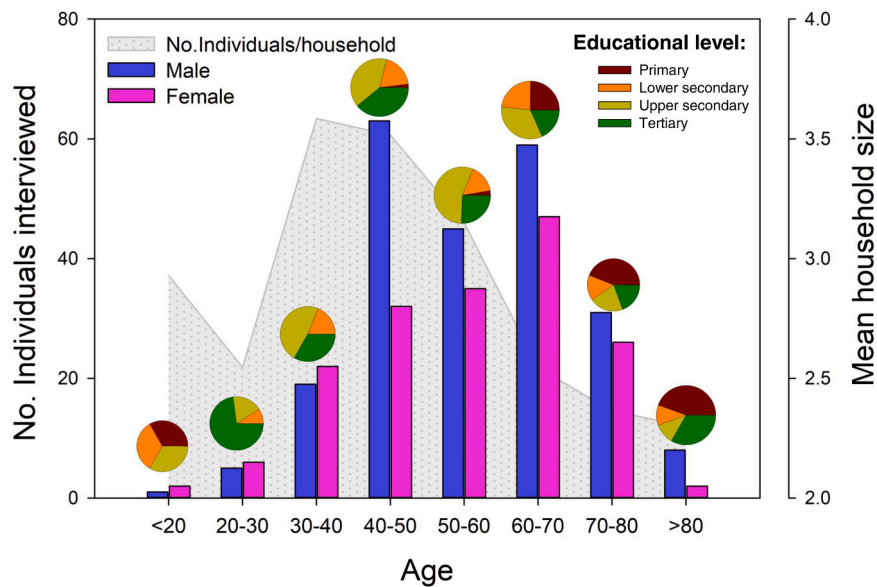


Fig. 2. Age, sex, household size (bar chart and area plots), and educational level (pie charts) of the recreational harvesters interviewed.

or more per week, and only a minority went three (5.2%), two (1.8%), or only once per week (6.2%).

The main features of the surveyed beaches most valued by the

recreational harvesters were the seawater temperature (25.0%), extensive sandy area (20.8%), and the quality of the beach (14.7%). Other highly appreciated characteristics were accessibility (8.8%), number of

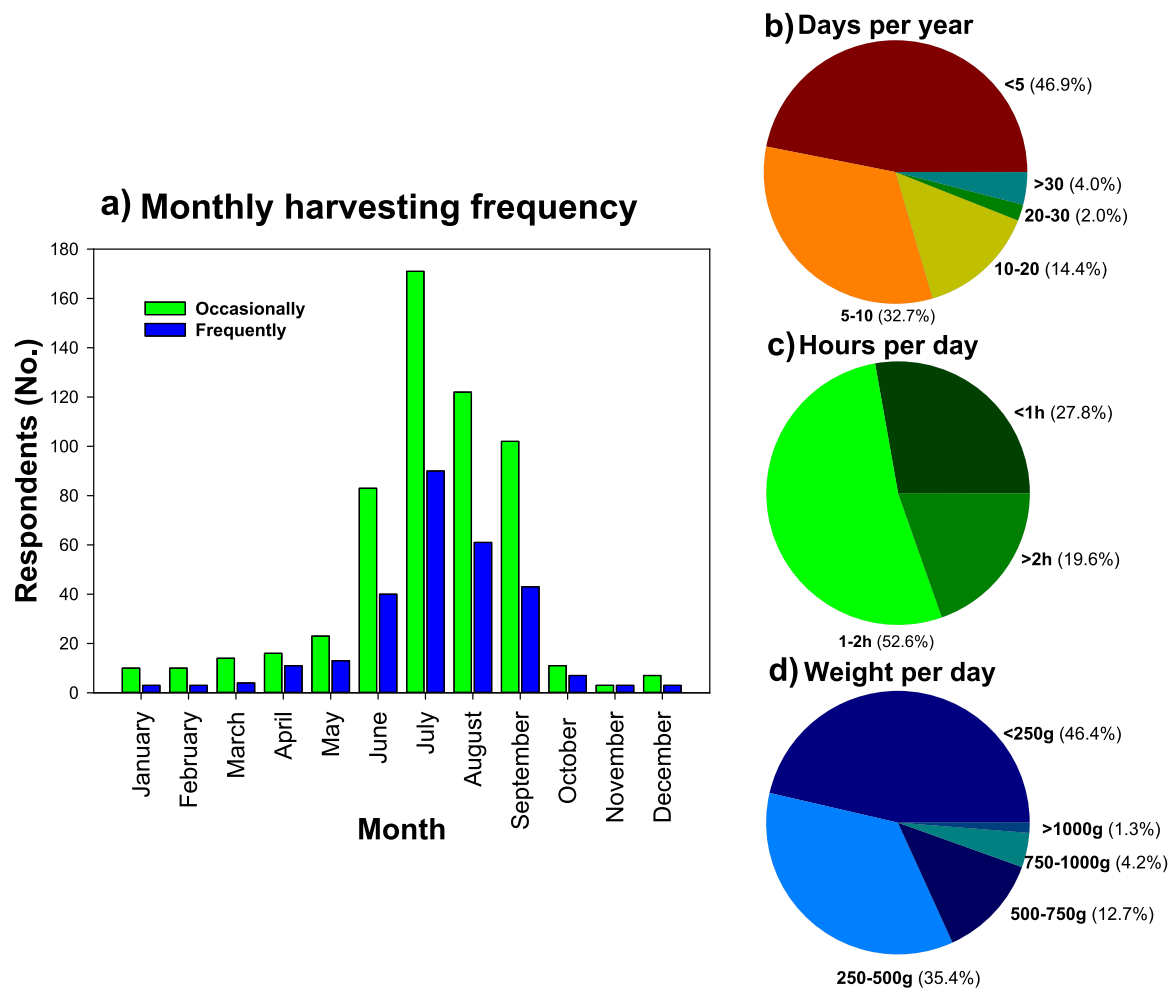


Fig. 3. Wedge clam recreational harvesting effort: (a) monthly harvesting frequency; (b) harvesting days per year; (c) harvesting hours per day; (d) wedge clam weight harvested per day.

users (6.9%), the “blue flag” certification (6.7%), parking space (6.5%), facilities (5.4%), and safety (5.2%). Although being a traditional activity in the Algarve region, only 19 respondents chose that beach due to the presence of wedge clams.

3.3. Recreational harvesting experience

More than half of the recreational harvesters (54.9%) collect wedge clams on that beach for less than ten years (4.2 ± 3.0 years), 32.7% from 10 to 30 years (21.1 ± 5.5), and 12.5% for more than 30 years (42.6 ± 7.3). Only 4.7% of the respondents were harvesting wedge clams on that beach for the first time. A total of 22.0% of the recreational harvesters also collected wedge clams on other beaches in the Algarve region (Albufeira, Monte Gordo, Portimão, Tavira, and Vila Real de Santo António), as well as in other locations along the Portuguese coast (Aveiro, Cascais, Costa da Caparica, and Sines).

Most recreational harvesters collect wedge clams from June to September. More wedge clams were harvested in July, both occasionally and frequently, followed by August, September, and June (Fig. 3a). Regarding their harvesting frequency, 46.9% of the respondents collected wedge clams less than five days per year, 32.7% from 5 to 10 days, and only 4.0% for 30 or more days per year (Fig. 3b). Concerning harvesting activity, there were no significant differences for the catch amount between residents and tourists (ANOVA on ranks; $H = 0.20$; $p = 0.65$) and the number of harvesting days reported ($H = 0.23$; $p = 0.63$). However, since these surveys occurred during summer, when most harvesters interviewed were tourists, it was impossible to make a proper comparison among groups. It was also found that the number of harvesting events was positively correlated with the holidays' duration (Pearson correlation; $R = 0.40$; $p < 0.0001$) and the catch amount ($R = 0.20$; $p < 0.0001$).

Most recreational harvesters (52.6%) spent 1–2 h per day collecting *D. trunculus* and only 19.6% spent more than 2 h (Fig. 3c). Most respondents harvested less than 250 g or 250–500 g per day, with only 4.2% collecting 750–1000 g per day and 1.3% more than 1 kg per day (Fig. 3d). Overall, 65.8% of the respondents harvested wedge clams accompanied by two other people (1.9 ± 1.1), and 27.5% harvested alone. Most recreational harvesters (88.6%) confirmed selecting the wedge clams by size, discarding undersized individuals in the collecting site (69.4%) or alternatively throwing the juveniles to deeper areas (30.6%). Despite this, the five interviewees also observed that the majority of the harvesters collected undersized individuals because they were unaware of the regulations.

More than half of the interviewees harvested wedge clams for personal consumption (51.1%). From these, 24.8% only collected to eat as an appetizer, while 22.1% also mentioned harvesting wedge clams as a hobby. The other half collected wedge clams only as a hobby and stated to give them away to other harvesters, offer them to family or friends, or throw the clams back to the water at the end of the low tide. The harvesters also referred to other reasons for this activity, such as physical exercise, addictive distraction, fun and curiosity, relaxing activity, family tradition, or simply for being an accessible and freely available resource (Fig. 4).

3.4. Valorization of wedge clams

Although most recreational harvesters (90.1%) confirmed eating wedge clams, more than half of the respondents (51.7%) never bought *D. trunculus*. The majority consumed wedge clams at home (67.8%), in restaurants (22.0%), or both (10.1%). According to the harvester's perception, the main factors that influence the price of wedge clams were the season (27.7%), the supply and demand in the seafood market (24.9%), and the wedge clams' size (19.0%). In addition, 6.9% of respondents mentioned other factors that could influence *D. trunculus* price, such as the harvesting effort for collecting a small catch, and the increasing demand during certain periods of the year (for e.g., holidays).



Fig. 4. Graphical word cloud illustrating the relative frequency of keywords answered by recreational harvesters to describe their main reasons for collecting wedge clams (lettering size is proportional to the keyword frequency).

Among those recreational harvesters that bought wedge clams, 68.1% did it on average four times per year at the seafood market, 27.3% at the black market (illegal shellfish trade), and 4.6% directly from local professional harvesters of wedge clams. Most respondents considered buying medium-sized wedge clams for a fair price (62.3%). Overall, 79.4% of recreational harvesters would pay ~ 10 €/kg, and 20.6% referred to paying 5 €/dose (dosing cup or the bottom part of a 1.5 L plastic bottle ~ 500 –750 g).

3.5. Temporal variation in the recreational harvesting activity

Several recreational harvesters reported an inter-annual variation in the abundance and size of wedge clams. In 2018, most respondents stated that the abundance decreased but the wedge clams size increased compared to previous years, resulting in fewer recreational harvesters observed along the beach (Fig. 5a). Most respondents noted that during 2018 juveniles were scarce and small individuals were only observed/collected in September. However, during 2019 most recreational harvesters mentioned an increasing abundance of wedge clams available on the beach accompanied by a decrease in their size, therefore with a higher proportion of *D. trunculus* juveniles compared to 2018. Apparently, the respondents observed more recreational harvesters along the beach due to this increasing abundance of wedge clams in 2019 (Fig. 5b). Some recreational harvesters also reported more bivalve dredge vessels operating a few meters from the shore in 2019 than during the previous year.

3.6. Estimation of wedge clam recreational summer catches

A rough estimation of the summer catches was done based on the number of recreational harvesters interviewed on the day when more questionnaires were completed (57) by the highest number of interviewees (five). Along a beach extension of 5 km most harvesters were interviewed and using the most frequently reported mean catch weight (250–500 g/harvester/day), the daily mean catch was estimated to be around of 21 kg (range: 14.0–28.5 kg). Therefore, only along the “Sotavento” (leeward) coast of the Algarve (51 km coastline between Olhão and Vila Real de Santo António) and knowing that most harvesters stated to collect wedge clams 5–10 days during holidays, the mean gross estimate every 15 days would be 1.6 tonnes (range: 1.1–2.1 tonnes), which extrapolated to the summer season (from June to September) when most interviewees affirmed to collect more frequently wedge clams, would amount to over 13 tonnes of *D. trunculus* (range: 8.8–16.8 tonnes).

3.7. Recreational harvester's knowledge of the regulations

The harvesters' knowledge about the legislation was not related to

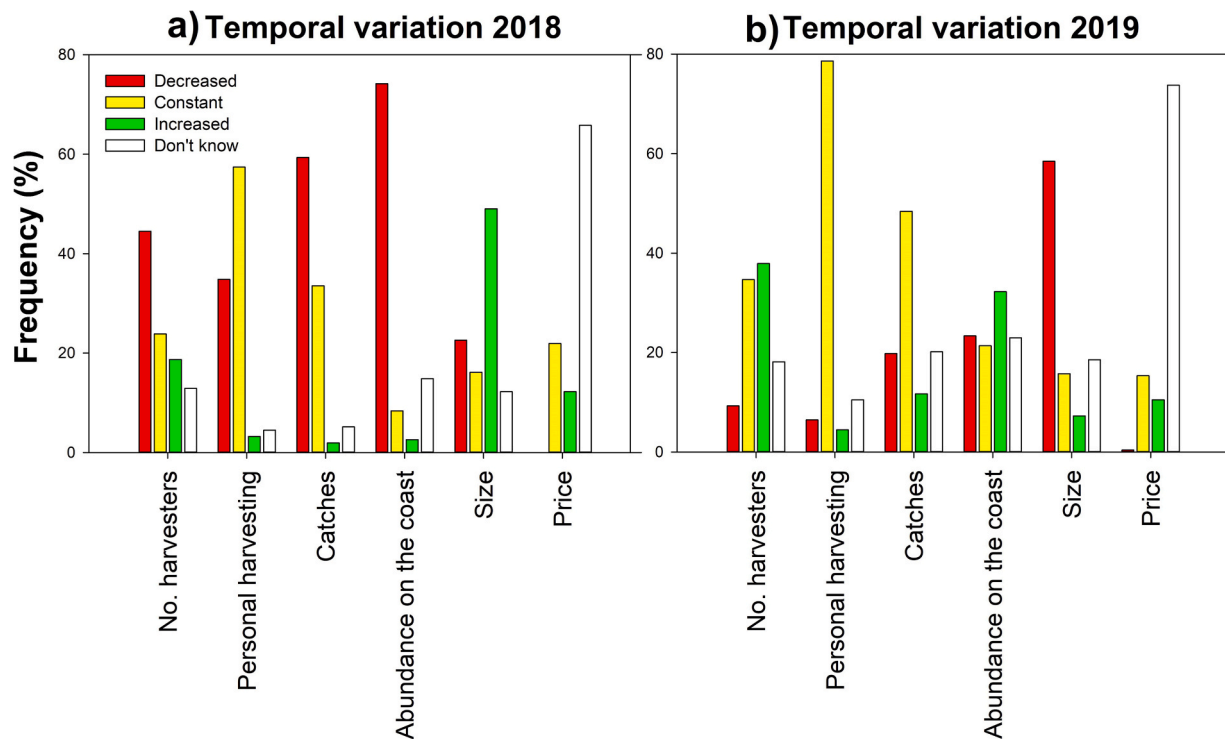


Fig. 5. Harvesters' perception of the inter-annual variation of the recreational wedge clam fishery between 2018 (a) and 2019 (b) for the number of recreational harvesters, personal harvesting activity, wedge clam catches, abundance, size, and price.

their level of education (Chi-square test; $\chi^2 = 4.40$; $p = 0.221$), gender ($\chi^2 = 0.41$; $p = 0.521$), age ($\chi^2 = 279.37$; $p = 0.517$) or harvesting experience ($\chi^2 = 49.69$; $p = 0.224$). The vast majority of recreational harvesters (71.5%) were unaware of the regulations legally in force for this activity (Table 1). Although half of the respondents (50.1%) stated knowing that there is a closed season for fishing and harvesting *D. trunculus* during the species' reproductive period, only five recreational harvesters knew its exact period (May-June). Most respondents (55.3%) were unaware of the species MCRS or the maximum daily catch for recreational harvesting (75.4%). Among those respondents that affirmed knowing, only ten harvesters (5.5%) gave the correct answer on the MCRS (25 mm in shell length), and nineteen harvesters (19.1%) knew that the maximum daily catch is 2 kg.

During the present study, as reported on the biotoxin database available at IPMA's webpage [62], the fishing, harvesting, and commercialization of wedge clams were interdicted in most of the surveyed days due to the presence of marine biotoxins, except for four days in September 2018, June and August 2019. On the day when more

face-to-face interviews were performed (57 questionnaires by five interviewers in July 2019), the activity was interdicted due to biotoxins (DSP ~227 $\mu\text{g}/\text{kg}$). The wedge clam fishing/harvesting in the area of Lota and Manta Rota beaches, where most surveys took place, was interdicted for more days in the summer of 2018 than in the summer of 2019. The levels of biotoxins were anomalously elevated in July (287 to >550 $\mu\text{g}/\text{kg}$) and in August of 2018 (173–573 $\mu\text{g}/\text{kg}$) [62]. In contrast, in July 2019, the level of biotoxins was higher than 550 $\mu\text{g}/\text{kg}$ in only one day and ranged from 217 to 264 $\mu\text{g}/\text{kg}$ during the remaining days, while in August 2019, the fishery was interdicted only two days with levels of biotoxins between 147 and > 550 $\mu\text{g}/\text{kg}$ [62].

Despite the general practice of harvesting wedge clams during periods of interdiction due to biotoxins, most respondents (80.4%) said to be informed about those interdictions and only 19.6% were unaware of the consequent public health risks. Overall, 37.2% of the recreational harvesters mentioned being informed about the presence of biotoxins associated with harmful algal blooms through the traditional media (television, radio, or newspapers), word-of-mouth (20.0%), or via the

Table 1

General knowledge of the respondents on the regulations in force for the recreational harvesting of wedge clams (harvester's response intervals: 0–25% ■; 25–50% ■; 50–75% ■; 75–100% ■).

	Yes (%)	No (%)
Harvesting legislation	28.5	71.5
Closed fishing season	50.1	49.9
Minimum Conservation Reference Size (MCRS)	44.9	55.3
Maximum daily catch	24.6	75.4
Interdictions for biotoxins	80.4	19.6

internet (19.8%). Only 12.8% of recreational harvesters consulted the IPMA's website (the only official source for such information: www.ipma.pt/bivalves/) to ascertain if there were interdictions due to biotoxins before harvesting wedge clams.

4. Discussion

The wedge clam is an important fishing resource along the southern coast of Portugal and constitutes a valuable species for regional gastronomy. In the Algarve coast, besides being exploited by the commercial dredge fleet and by professional hand dredgers, this species is also harvested by locals all year round and by tourists mainly during the summer. The present study assessed for the first time the importance of recreational harvesting on the overall catches of *D. trunculus* on diverse beaches along the Algarve coast.

The present results showed that most respondents were Portuguese tourists who came from large urban areas (mainly from Lisbon, Porto, and Setúbal) and residents in the Algarve region. The most valued features that made interviewees return to the same beach every year were the warm seawater temperature, the quality and extension of the beach, and the overall services that facilitate the access to the seashore by families with children and senior citizens. Almost half of the respondents were women, contrary to the findings of similar studies on shellfish harvesting in Brazil [5], the USA [63], and northwestern Portugal [13], where most harvesters were men and collected clams both recreationally and for subsistence. However, this is not a pattern in all shellfish harvesting activities, with women prevailing among shellfish harvesters for subsistence in locations such as South Africa [64], northeast Brazil [12], and northwestern Spain [65], where in some cases, this activity is their main income for financial autonomy. The present results suggest that when beach clams are collected only recreationally, the harvester's gender tends to be more heterogeneous. The demographic range of the more regular/frequent recreational harvesters was from 40 to 70 years old, being similar to other locations in Portugal [13], France [66], Brazil [5,12], USA [63], and New Zealand [67]. This is probably related to the fact that recreational harvesters in this age interval have more financial independence to spend holidays with their family and friends.

More than half of the recreational harvesters never bought wedge clams because most ate at home their *D. trunculus* catches. These results corroborate the general trend observed in previous studies in northern France [66], and New Zealand [67], where the highest consumption of shellfish was also self-harvested. For this reason, some respondents were not aware of the factors that influence the commercial value of wedge clams. Interestingly, for those who bought wedge clams, the season and the supply and demand in the seafood market were more important factors for the valorization than the size of the wedge clams. Additionally, one-fifth of the respondents would pay only 5 € per dose (the measure used by illegal sellers), which suggests that several harvesters bought *D. trunculus* illegally from ambulant sellers nearby the seafood market or even at the beach. In fact, the existence of a black market is one of the most relevant factors in the devaluation of fishing products (e. g., gooseneck barnacles in SW Portugal [11]), decreasing the demand in the legal seafood market and causing the depreciation of the product's value.

The overall education level of recreational harvesters in southern Portugal was high. Most respondents had an upper secondary or tertiary level of education, and only a small percentage had a primary level of education. The present results suggest that recreational harvesters that collect wedge clams only as a hobby and do not depend on the exploitation of this resource tend to have higher educational levels. However, despite their high level of literacy, most respondents revealed a lack of knowledge and interest in the regulations in force for harvesting *D. trunculus*. Indeed, only a few respondents were aware of the species' MCRS (25 mm), the closed season in place (May-June), as well as the weight of wedge clams they are allowed to collect (2 kg). Moreover, although harvesters seemed to be concerned of the risks associated with

the consumption of biotoxins-contaminated bivalves, only a few were aware of the periods of interdiction due to the presence of marine biotoxins and where this information was available. This is an issue for both recreational harvesters and professional or illegal hand-dredged harvesters that collect wedge clams during interdicted periods even after being informed that the fishery is closed due to marine biotoxins putting at risk the consumer's health. Interestingly, when comparing these results with a previous study on the Portuguese angler's perceptions of novel recreational fishing regulations, Veiga et al. [68] found that the recreational fishers with a higher level of education were more likely to agree with the implementation of regulations. However, hand-picking harvesters do not require a license and the present study assessed the knowledge of the regulations and not their conformity with those rules. Similar socioeconomic studies performed in Portugal [69], Brazil [4,5], and the USA [70] also revealed the recreational harvesters' little awareness of the public health risks associated to the consumption of shellfish contaminated with biotoxins. In contrast, 98% of the shellfish harvesters in northern France were aware of the temporary bans in contaminated areas [66], and the local population significantly valued the potential health risks [2], while in northern New Zealand 61% of the harvesters reported being aware of biotoxins alerts and changing their harvesting/collecting behavior [67]. In the USA, it was observed a decrease in harvesting trips during periods interdicted for marine biotoxins and pollution, even though some level of bivalve harvesting would continue at closed beaches and some effort would shift to nearby beaches open for harvesting [63].

Prolonged harvest bans were implemented in 2018 due to sharp increases in paralytic shellfish poisoning (PSP) toxins in diverse bivalve species along the coast of Portugal, and this phenomenon has been happening more frequently than in previous years [62,69,71]. However, according to Vale [69], such bans are not usually placed in time, are not properly disseminated to the general public, and are disregarded by most recreational harvesters. Due to the lack of controls and available information, self-harvesters are more prone to suffer illness or even death from consuming biotoxins-contaminated shellfish, whereas PSP cases associated with retail sellers or seafood restaurants are rare [72].

Both paralytic and diarrhetic shellfish poisoning (PSP and DSP) toxins are more abundant during summer [69,72], coinciding with the seasonal peak in the shellfish harvesting activity in Portugal [69,73], due to the sunny weather and the holidays period. The wedge clam *D. trunculus* is an ideal sentinel species, resistant to different contaminants and with a high bioaccumulation capacity [27,28], displaying slower elimination rates for biotoxins than other bivalve species [69]. On several occasions, anomalous toxic levels of DSP and PSP have been recorded in the Portuguese coast, ranging between 30 and 47 times the regulatory limit (RL) [69]. In these cases, even though most respondents stated collecting a small catch (250–500 g), the ingestion of only 10 g of non-fatal DSP contaminated flesh (i.e. the edible content of about 10 wedge clams) would be enough to trigger a mild diarrhea, whereas 100 g of PSP contaminated flesh 30 times de RL could lead to a 70% probability of developing mild symptoms, such as light neurological and gastrointestinal effects, to severe symptoms or even death through respiratory paralysis in extreme cases [69,74]. However, most cases of intoxication from biotoxins are usually unreported, only when there are serious consequences to human health. The recreational catch is usually eaten in a family environment, where the biotoxin poisoning could pose a bigger threat to children and senior citizens.

Considering that shellfish harvesting is an open-access and free activity involving numerous people [2], environmental protection is required for effective management to regulate the recreational harvesting activity and prevent public health risks. For instance, during interdicted periods in France, criminal penalties are applied to offenders and recreational harvesters bear the responsibility of being informed about the sanitary classification of the exploited area [2] and if the fishery is closed due to marine biotoxins.

The general lack of awareness of the respondents on the risks

associated with the consumption of biotoxins-contaminated bivalves further confirms the need for additional studies and the implementation of educational programs and awareness campaigns to inform recreational harvesters. The promotion of outreach and participatory activities should be performed with the recreational harvesters and the fishing community in order to increase trust among all stakeholders involved [13]. Adequate signaling in local communities and recreational areas highlighting the biotoxins risks, current levels, and interdicted periods would improve public communication in relevant areas for recreational harvesting [72]. To raise awareness during the present study, all harvesters who were unaware of this publicly available information were advised to consult the results of the analyses of marine biotoxins carried out by IPMA [62]. In addition, an informative poster resuming the main regulations and the public health risks of this practice was produced to inform recreational harvesters in future communication activities/awareness campaigns (please see the poster provided as [Supplementary material S2](#)). Efficient communication of the legislation and risks associated with biotoxins would contribute to better-informed harvesters, promoting a more sustainable recreational harvesting activity. In addition, this activity can benefit both the harvesters' well-being and public health, especially of senior citizens, due to the associated physical and mental advantages and the positive relation between harvesting engagement and higher seafood consumption [75].

Although it was not possible to quantify the exact catch of each recreational harvester, their perception of the inter-annual variability in the abundance and size of the wedge clams was recorded. In 2018, the feeling among the respondents was that *D. trunculus* clams were large, but the abundance of both juveniles and adults was low. Whereas in 2019 the opposite was reported, and recreational harvesters observed a higher abundance but with smaller wedge clams. Despite the smaller size of *D. trunculus* in 2019 than in 2018, the harvesting activity was higher, suggesting that recreational harvesters are not size-selective and collect wedge clams independently of their abundance and size. According to Hartill [7], recreational gatherers tend to adapt their pickings to the abundance and size structure of the population available for harvesting and might even harvest all sexually mature individuals, and then gradually collect smaller individuals including juveniles.

Surveys directed at recreational harvesters could reflect changes in size-frequency distributions of harvested populations that may indicate shifting patterns in species recruitment and exploitation [67,76]. The inter-annual variability in abundance and size reported by shellfish harvesters worldwide suggests that beach clam populations experience large temporal variations in both abundance and recruitment [4,9]. In southern Portugal, this was confirmed by a three-decade-long series of bivalve monitoring surveys performed by IPMA along the Algarve coast, which detected substantial fluctuations in the distribution and abundance of *D. trunculus* and other bivalve species [6]. Additionally, and parallel to this study, bivalve fishing monitoring surveys were performed by IPMA in 2017, 2019, and 2020 on the southern coast of Portugal. In particular, the surveys done between 2017 and 2020 recorded the lowest biomass of *D. trunculus* in 2017, followed by an increase in the biomass and a higher fishing yield of wedge clams along the coast, reaching the highest values in 2020 [49]. These results corroborate the general trend observed in a recent assessment of the COVID-19 pandemic's impacts on global marine recreational fisheries, where the general perception in France was that the local shellfish stocks benefited from the reduced recreational fishing activity during the pandemic [77]. Despite this, a recent LEK study performed in the northwestern coast of Portugal reported the general discontent across shellfish harvesters due to the strict restrictions applied during the pandemic [78].

The inter-annual variability in wedge clam abundance and size can also be related to abiotic factors in combination with biotic processes. The beach profile, wave regimes, storms, environmental conditions, fishing effort, predator abundance, harmful algal blooms, parasitism, or the quantity and quality of food sources can all affect the bivalve

population dynamics [6,79]. However, in a review to assess the principal causes of sharp declines of mollusk species in the northeastern USA, it was concluded that environmental factors have a dominant role in controlling the production level of commercial bivalve species [80]. In fact, diverse environmental factors control larval production, survival, and successful settlement, indirectly influencing stock biomass [24]. Therefore, the inter-annual differences on wedge clam populations observed by the respondents between 2018 and 2019 could also be related to climate variability and changing environmental conditions that affected differentially the species' recruitment.

The assessment and management of beach clam harvesting are hampered due to the natural- and environmental-driven variability in inter-annual recruitment and abundance of the species [7,9,10,24]. In the particular case of the wedge clam fishery in southern Portugal, the situation is even more complex due to the simultaneous exploitation of *D. trunculus* by the commercial fishery (bivalve dredge fleet), by professional and illegal hand-dredge harvesters, and by recreational harvesters (hand-gathering) whose catches are quite difficult to account, making accurate stock assessments virtually impossible [9,10,20,64].

Previous studies in diverse locations revealed that recreational harvesting can extract significant amounts of beach clams. In Brazil, it was estimated that recreational harvesters collected 25 tonnes of beach clams (*Tivela mactroides*) each year in an area of 4 km [4]. In southeastern Australia, the recreational catches of *D. deltooides* can reach up to 46.5 tonnes per year in an area of 32 km [9]. Although the recreational fishing efforts and catches are believed to be considerable in Algarve [20], there are no published studies on *D. trunculus* catches by recreational harvesters in Portugal [35]. For this reason, with the information gathered in the present study through face-to-face interviews it was possible to make for the first time a rough estimate of the wedge clam summer catches collected by recreational harvesters only in the Algarve coast (13 tonnes). Although it is a rough estimate that can be either underestimated or overestimated depending on the harvesting area, this appraisal is the first approach and stepping-stone for future studies to fill the information gap on the impact of this activity. These highly significant catches constitute an intense fishing pressure on wedge clam populations because most recreational harvesters were not size-selective, ignored which was the MCRS (25 mm), and therefore directed their harvesting effort mainly towards commercially undersized *D. trunculus*.

In addition, previous studies in other locations [21,29] and also in southern Portugal [20] detected a depth segregation between size classes of *D. trunculus*, with smaller individuals predominating at the renewal area or surf zone (0.5–1 m depth) and adults (≥ 25 mm) prevailing at greater depths (4–6 m), which explains the high proportion of juveniles in the catches of recreational harvesters. During the recruitment period, the adults migrate to deeper areas, while larval settlement occurs at shallower depths [20]. This depth segregation is a survival strategy of *D. trunculus* to avoid intraspecific competition between larvae and adults, to increase the protection of juveniles from predators, and to promote an efficient burrowing behavior of the bivalve seeds in high hydrodynamic areas such as the surf zone [20,21,29].

During the present study, due to the COVID outbreak, it was impossible to record the most realistic number of recreational harvesters and catch weight under normal circumstances. Thus, further research is needed to ascertain the recreational effort on this shellfish resource annually. Because this is a legal and ludic harvesting activity in Portugal, the present face-to-face interviews had a very low refusal rate. Nevertheless, in future studies the refusal rate should be recorded, and whether any of the consumers of the collected catch ever suffered any form of shellfish intoxication should also be reported. As previously suggested by Gaspar et al. [20], an educational program should be implemented to inform the local inhabitants and tourists about the fragile nature of this fishing resource and the crucial importance of not harvesting undersized individuals. In fact, as evidenced in other studies worldwide, recreational overfishing can reduce the sustainability of

exploited bivalve populations [7,13,67,73,81]. Despite this, only 2% of the MRF in Portugal are performed under the due fishing / harvesting licenses [8,82]. On a recent national survey on recreational catch estimations, it was found that hand harvesting with gears is a minor activity responsible for only 0.3% of the total MRF catch [83]. However, bare hand harvesters were outside of the scope of this study because there are no licenses for this type of activity, therefore their contribution to the overall harvesting rate is unknown. In contrast, in other European countries like France, this activity has been assessed on a national level and is subject to limited regulations but also there is no licensing system. Herfaut et al. [84] found that shellfish gathering in France is practiced by the majority of the recreational fishers (71%) and estimated a total catch of 3,100 tonnes of shellfish per year. In addition, given the interannual variability due to the highly dynamic nature of beach clam populations, localized extirpation can rapidly occur when periods of low recruitment coincide with high recreational harvesting pressure [7], further confirming that recreational harvesting should not remain unmonitored and unmanaged.

5. Conclusions

The present study further corroborates that LEK can generate reliable information on exploited resources and that managers can benefit from such information to improve the management of bivalve's recreational harvesting [13]. Also, the LEK of most-experienced recreational and professional harvesters should be considered whenever developing new management approaches [5,12]. Moreover, an assessment of how effort and catch are partitioned between commercial and recreational fisheries is required for an accurate stock assessment and effective management [9,10,20]. In fact, although the present study provided only a rough estimate of wedge clam catches by recreational harvesters, clearly confirmed that such data must be incorporated in the respective stock assessment and fishery management. For this purpose, novel methodologies could be tested to assess the number of recreational harvesters, namely through visual censuses by observers along the beach complemented with images recorded from a boat or aircraft.

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CRediT authorship contribution statement

Laura Sordo: Conceptualization, Methodology, Investigation, Data curation, Formal analysis, Writing original draft and Review & Editing, Visualization. **Paulo Vasconcelos:** Conceptualization, Methodology, Investigation, Review & Editing, Project Administration. **David Piló:** Conceptualization, Methodology, Investigation, Review & Editing. **André N. Carvalho:** Conceptualization, Methodology, Investigation, Review & Editing, Visualization. **Fábio Pereira:** Conceptualization, Methodology, Investigation, Review & Editing. **Miguel B. Gaspar:** Conceptualization, Supervision, Methodology, Review & Editing, Funding acquisition, Project Administration.

Data availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105694.

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