




Recreational shellfish harvesting on a sandy beach in the Algarve coast (southern Portugal): First appraisal of the annual catch of wedge clams (*Donax trunculus*)

Fábio Pereira^{a,*} , André N. Carvalho^{a,b,c}, David Piló^{a,b}, Paulo Vasconcelos^a, Miguel B. Gaspar^{a,b}

^a Instituto Português do Mar e da Atmosfera (IPMA, I.P.), Avenida 5 de Outubro s/n, Olhão 8700-305, Portugal

^b Centro de Ciências do Mar (CCMAR), Universidade do Algarve, Campus de Gambelas, Faro 8005-139, Portugal

^c Departamento de Biología, Facultad de Ciencias del Mar y Ambientales, Universidad de Cádiz, Avda. de la Universidad, Campus de Excelencia Internacional del Mar (CEIMAR), Puerto Real, Cádiz 11510, Spain

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ABSTRACT

This study aimed to characterise the recreational harvesting of wedge clams (*Donax trunculus*) in the Algarve coast (southern Portugal) and estimate its annual catches by recreational harvesters (RHs). For this purpose, 50 harvesting surveys were performed along the sandy intertidal during one-year (May 2022 - April 2023), roughly on a weekly basis during suitable tidal ranges (≤ 1.0 m). Overall, RHs were gender-balanced and older harvesters (≥ 65 years-old) prevailed. RHs were clearly more numerous from late spring to summer, especially in August, with most RHs collecting wedge clams with foot / hand and only a minority ($\approx 20\%$) also using a shrimp-net. RHs catches comprised mostly *D. trunculus* below the minimum conservation reference size (MCRS = 25 mm in shell length) legally stipulated for this species. The estimation of RHs annual catches of *D. trunculus* was based on standardised catches per harvester (number and weight hour⁻¹), extrapolated using the total number of RHs and suitable tides for wedge clams recreational harvesting during the one-year study period. Collecting and processing geolocated data on RHs activity allowed mapping the spatial-temporal distribution of the recreational harvesting effort targeting wedge clams, further confirming the importance of spatial data as a support tool for management and decision-making processes. This study further confirmed the need to raise awareness and inform RHs about the best harvesting practices, aiming ultimately to improve the assessment and promote the long-term sustainable management of this recreational activity and shellfish resource.

1. Introduction

Sandy beaches constitute two-thirds of the Earth's shorelines (Wooldridge et al., 2016) and provide essential ecosystem services (e.g. breeding, feeding and nursery habitats, nutrient recycling, water purification and storm protection), but also face important and varied threats including the sustainable use of services and resources (McLachlan and Brown, 2006; Defeo et al., 2009; Nel et al., 2014). Marine recreational fishing (MRF) is a widespread coastal activity that involves highly diverse spatial-temporal fishing / harvesting activities, both active and passive (Hyder et al., 2017a,b, 2020), which might impact the target species abundance, biomass, size distribution and demographic structure (Lewin et al., 2019). Indeed, MRF strongly

contributes to fishing mortality and stock reduction of some target species (Haase et al., 2022) and the contribution of these activities for the total catches is getting increasingly important as commercial exploitation (Ihde et al., 2011; Hyder et al., 2017a; Lewin et al., 2019). The temporally and spatially dispersed and heterogeneous nature of MRF (Hyder et al., 2020), with fishing effort often concentrated in small areas (Navarro et al., 2020), makes their study difficult and laborious (Signaroli et al., 2024), therefore contributing to poor data collection (Hyder et al., 2020; Navarro et al., 2020; Audzijonyte et al., 2023; Signaroli et al., 2024).

In most countries, recreational fishers are not required to report their activities and/or catches (Lewin et al., 2019; Audzijonyte et al., 2023), which greatly complicates estimating MRF catches, mapping fishing

* Corresponding author.

E-mail address: fpereira@ipma.pt (F. Pereira).

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effort, performing stock assessment and implementing management measures (Murray-Jones and Steffe, 2000; Pawson et al., 2008; Hyder et al., 2017a,b). The combination of poor fisheries data with inadequate spatial scaling for MRF management, contributed for inadequate strategic plans and subsequent decision-making, with social and economic negative repercussions (Chollett et al., 2022). Although MRF is an ancestral activity, traditionally important for coastal populations in Portugal, there is scarce information available on this activity in the national program for fisheries data collection (Diogo et al., 2020). Unavailability or non-inclusion of estimated MRF catches in stock assessment is an important challenge for managing fisheries with significant recreational catches (Diogo et al., 2020). Shellfish harvesting for human consumption is an ancestral MRF activity with cultural heritage and socio-economic relevance (Oliveira et al., 2013), although poorly understood and undervalued (Defeo, 2003) and practiced with limited or without management (Turra et al., 2016).

Marine bivalves play a key role in coastal ecosystems, filtering suspended particles, regulating water transparency and recycling nutrients, thus contributing to the resilience and sustainability of coastal areas (Ruffino et al., 2018). In particular, wedge clam's distribution reflects changes in both water and sediment quality, being considered suitable sentinel species to assess the environmental quality of sandy beaches (Tili and Mouneyrac, 2019). The wedge clam (*Donax trunculus* Linnaeus, 1758) is a fast and efficient sediment burrower inhabiting warm-temperate, exposed and hydrodynamic sandy beaches (McLachlan and Brown, 2006; Gaspar and Chicharo, 2007), throughout the Atlantic Ocean from the British Isles and northern France to Senegal, as well as in the Mediterranean, Marmara and Black Seas (Tebble, 1966; Bayed and Guillou, 1985; Deval, 2009). This filter-feeding bivalve occurs mainly at shallow depths, within 0–6 m in the Atlantic Ocean and 0–3 m in the Mediterranean Sea (Neuberger-Cywiak et al., 1990; Gaspar et al., 2002; Zeichen et al., 2002; Deval, 2009; La Valle et al., 2011). Along the European coasts, *D. trunculus* displays depth segregation in its vertical distribution in the shoreline, i.e. juveniles occur in shallower waters and adults at higher depths (Ansell and Lagardère, 1980; Guillou and Bayed, 1991; Gaspar et al., 2002; Zeichen et al., 2002). This depth distributional pattern was associated to larval passive displacement by waves and currents to shallower areas (Gaspar et al., 2002), as well as a strategy to avoid competition for space and food between larvae and adults (Ansell and Lagardère, 1980).

Wedge clams are fished worldwide (McLachlan et al., 1996) and *D. trunculus* is commercially important for both artisanal fisheries and harvesting activities. However, since the 1990s, catches of *D. trunculus* decreased markedly or even became threatened in diverse areas (e.g. Marie et al., 2016; Patiño et al., 2021), similarly to other commercial bivalve species exploited by unmanaged fisheries (e.g. Baeta et al., 2021). In Portugal, wedge clam landings displayed substantial variation in recent years (Gaspar et al., 2021, 2025) and during the study period reached 481 tonnes in 2022 and 437 tonnes in 2023, with average prices of 3.54 €/kg in 2022 and 4.48 €/kg in 2023 (INE, 2022, 2023). In addition, in recent years professional harvesting was responsible for the capture of 77.3 tonnes (average catches declared at wholesale market during 2015–2023), corresponding to an economic value of 330.3 k€ (Gaspar et al., 2025). Wedge clam fishing and harvesting occurs on the north-western, south-western and south coasts of mainland Portugal, is a relevant activity for local economies, has high socio-cultural value and contributes to territorial and social cohesion, particularly in small fishing communities (Gaspar et al., 2025). Along the Algarve coast, wedge clams are fished by a commercial fleet of 49 bivalve mechanised dredging vessels (DGRM, 2021), by professional harvesters using hand-operated bivalve dredges (155 licenses in 2023) and by recreational hand-pickers (especially during summer) using hands and/or feet to collect the catches (Gaspar et al., 2002, 2025; Sordo et al., 2023).

The recreational harvesting of *D. trunculus* is regulated by national legislation, being limited to a maximum daily catch per harvester (2 kg) and by the species' minimum conservation reference size (MCRS =

25 mm in shell length) (DR, 2013, 2014). In addition, a mandatory seasonal closure is established annually from 1 May to 15 June to protect spawning and settlement of larvae (DR, 2023), being periodically adjusted based on updated scientific data on the stock status collected during IPMA's annual fishing surveys, whereas interdictions in bivalve's harvesting due to the occurrence of harmful marine biotoxins (DR, 2006) are implemented depending on the shellfish health conditions (EU, 2004a,b,c).

Following a recent study focused on the wedge clams recreational harvesting in the Algarve coast leeward zone - "Sotavento" (Sordo et al., 2023), the present study provides information on this activity in the Algarve coast windward zone - "Barlavento". To the author's best knowledge, no previous studies aimed to quantify the harvesting effort and catches of *D. trunculus* by recreational harvesters in Portugal, nor even in Europe, only rough estimates based on face-to-face interviews that hampers estimating the catches and respective impact on wedge clam populations. In this context, the present study aimed to contribute for further improving the sustainable management of wedge clams in Portugal, by including temporal- and spatial-scale analyses of recreational harvesting effort and catches. Accordingly, this work characterised the recreational harvesting of *D. trunculus* in the Algarve coast "Barlavento" in order to: 1) assess the suitability of experimental recreational harvesting (RH_{exp}) to replicate the typical activity of local recreational harvesters (RHs) and constitute a representative proxy of their catches; 2) map the spatial-temporal distribution of estimated recreational harvesting effort and catches; 3) estimate the annual catches of wedge clams by recreational harvesters in the study area.

2. Materials and methods

2.1. Study area

The Meia Praia in Lagos is an extensive sandy beach with approximately 4 km, located in the Algarve coast "Barlavento" (southern Portugal) (Fig. 1). Along ≈ 70 km of coastline (from Sagres to Olhos d'Água), Meia Praia beach and the immediately adjacent Alvor beach are the only sandy areas with conditions for wedge clams' exploitation, because the rocky substrata on the remaining coastline (Faria and Almada, 2006; Marques et al., 2011) does not allow the larval settlement and successful establishment of this bivalve species. The shallow and uniform slope of the bay of Lagos, combined with the lack of strong currents, provides a very calm and safe environment, although the scarcity of underwater obstacles makes it quite susceptible to waves from S, SW and E (Baço, 2014). The summer is stable and mild, with predominant SW winds from June to August, whereas NW winds prevail from March to May (Baço, 2014). The tidal regime is semi-diurnal, with average spring tides of 2.9 m (Mateus et al., 2016). Three watercourses flow into this bay and influence its hydrodynamics, namely the Arade river, the Odiáxere-Bensafrim creek and the Alvor-Arão creek (Relvas and Loureiro, 1976).

2.2. Harvesting surveys and sample collection

During one-year study period (May 2022 - April 2023), experimental recreational harvesting (RH_{exp}) surveys were performed roughly once per week in the same area where RHs usually operate, by a researcher making gentle movements with hands / feet to dislodge these shallow burrowing species (0–7 cm depth), i.e. replicating the typical recreational harvesting of wedge clams by local RHs. This approach was adopted for estimating RHs catches because such non-intrusive method does not require personal interactions or enquiries, which might eventually influence RHs collecting behaviour and sorting criteria.

The original sampling plan included 4–5 random harvesting surveys per month (i.e., 48–60 samplings ≈ once per week) in the available tides during the study period (277). However, due to logistic constraints, only two surveys were carried out in December, whereas six surveys were

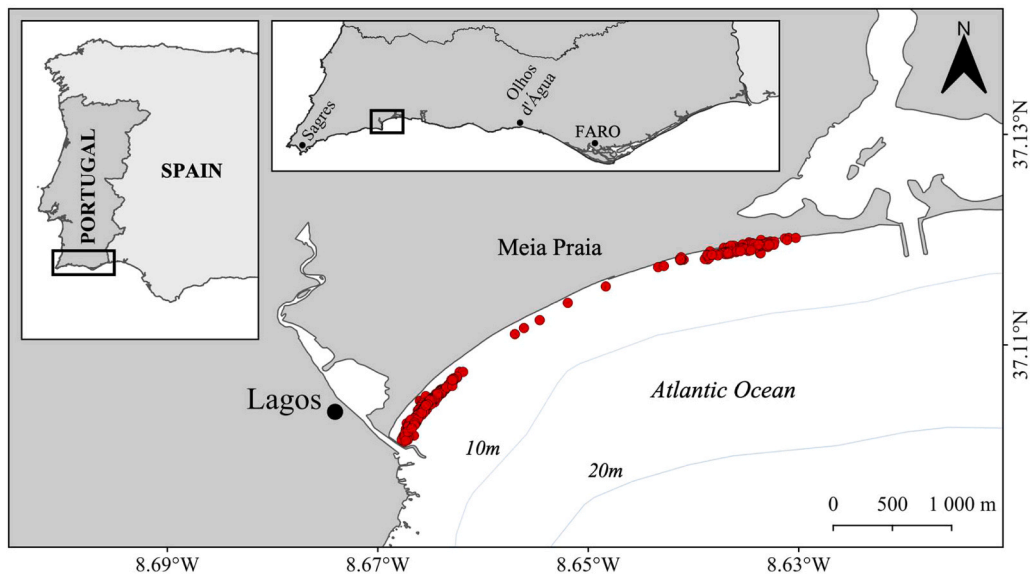


Fig. 1. Map of the study area along the Meia Praia beach in Lagos (Algarve coast - southern Portugal). Location of wedge clams recreational harvesters (●) georeferenced using a GPS device throughout the study period.

performed in May, corresponding to a global average of 4.2 samplings per month. Therefore, the study comprised 50 random surveys, performed on varied days of the week and always after the low tide peak, when local RHs are harvesting wedge clams. Sample collection occurred within the time window during which the tidal height allows harvesting wedge clams. According to a previous description of RHs collecting behaviour (Sordo et al., 2023), further confirmed in the present study, RHs usually have an average harvesting duration of 45 min. – 1.5 h., therefore 1 h was established as standard harvesting duration.

Harvesting surveys along the sandy intertidal were made whenever the sea conditions allowed for manually collecting wedge clams with tidal ranges ≤ 1.0 m (suitable tidal amplitude for this activity and when most recreational harvesters are on the beach). Overall, the whole study area has extensive bivalve beds with suitable and similar characteristics for performing this harvesting activity. Although the easternmost area is more distant from the city of Lagos and slightly more isolated, such distance does not prevent many harvesters from operating in that area. In each harvesting survey, all RHs observed on the beach were counted, georeferenced using a GPS device and briefly characterised by the RH_{exp} regarding their gender, age group (<18 years, [18–65] years, ≥ 65 years) and harvesting method (only with the foot/hand or also using a shrimp-net).

Independently of the harvesting duration, all *D. trunculus* observed on the sand were collected by the RH_{exp} using hands / feet (i.e. without sorting and discarding any juveniles / small individuals) and the respective catches were standardised for one hour of harvesting activity. In order to assess whether the catches made by the RH_{exp} were comparable and representative of those made by local RHs (i.e. ascertain if RH_{exp} catches constitute a suitable proxy of RHs catches), some of them were randomly asked to voluntarily allow the RH_{exp} to photograph their catches with a digital camera for subsequent analysis and comparison.

2.3. Biological sampling

In the laboratory, the wedge clams collected by the RH_{exp} were counted, measured for shell length (SL) using a digital caliper (precision of 0.01 mm) and weighed for total weight (TW) on a top-loading digital balance (precision of 0.01 g).

In addition, the wedge clams collected by local RHs and photographed by the RH_{exp} were also counted and measured for SL using the free image processing and analysis software ImageJ (version 1.43), in

order to compare the catches size-frequency distribution and *D. trunculus* mean size between the RH_{exp} and RHs. This method was previously tested on samples harvested prior this study, by placing a ruler and 1€ or 2€ coins (of known diameters) at different points on the sampling tray when photographing the wedge clams collected by RHs, in order to calibrate the digital photo to be analysed using the ImageJ software, providing estimates very similar to the real measurements made in the laboratory (differences invariably lower than 1 mm). Subsequently, aiming to reflect RHs sorting criteria and discarding practices, the unsorted *D. trunculus* collected by RH_{exp} that were below the SL of the smallest individual caught and sorted by RHs (i.e. 11 mm SL) were excluded from further calculations (in both number and weight).

2.4. Data treatment and statistical analyses

The RHs gender ratio (i.e., relative proportion between male and female RHs during the study period) was compared with parity (1 M:1 F) using the chi-square test for expected frequencies in the samples (χ^2 -test).

Following the image-based measurement of wedge clams collected by RHs, the demographic structure (size frequency distribution) of the catches by RH_{exp} and RHs was compared using the Shapiro-Wilk goodness of fit test (S-W test). In addition, the corresponding catches total weights were estimated using the weight-length relationship ($TW = 0.0003SL^{2.698}$), previously established for intertidal populations of *D. trunculus* collected between March and June from the Algarve coast by Gaspar et al. (2002). According to these authors, in this time of the year individuals with diverse gonad maturation stages co-occur, being therefore the period with more variable shell sizes and most suitable for reflecting the whole year. Consequently, that weight-length relationship was applied to estimate the total weight of wedge clam catches by RHs in the present study.

Harvesting yield (i.e. catches per unit effort) in both abundance (CPUE in number) and biomass (BPUE in weight) were standardised for one hour of harvesting activity. The monthly variation in both CPUE (inds. hour⁻¹) and BPUE (g. hour⁻¹) during the study period was analysed by one-way analyses of variance (ANOVA). Alternatively, whenever data normality and homogeneity of variances were not achieved, the non-parametric Kruskal-Wallis test (ANOVA on ranks) was performed. Each time significant differences were detected among groups, pairwise multiple comparisons were made using Dunn's post-hoc tests

with Bonferroni corrections ($\alpha' = \alpha/c$, where α' is the readjusted significance level, α is the significance level and c is the number of comparisons) to minimise type-I errors.

Subsequently, monthly catches by RHs (in both number and weight) were estimated by multiplying the monthly mean CPUEs or BPUEs by the mean number of RHs observed on the beach and by the number of suitable tides in each month for harvesting wedge clams (Th), after consulting the tidal tables for the study period available at the Portuguese Hydrographic Institute (<https://www.hidrografico.pt/m.mare>):

$$\text{RHs monthly catch (N or kg)} = \text{mean CPUE (N) or mean BPUE (kg)} * \text{mean RHs (N)} * \text{Th (N)}$$

Accordingly, annual catches by RHs (in both number and weight) were estimated as the running total (cumulative sum) of the successive monthly catches throughout the one-year study period.

All statistical analyses were performed following Zar (1996) and using the R statistical language (R Core Team, 2024), with significance level considered for $p < 0.05$. The spatial-temporal distribution of observed RHs was mapped using the open-source Geographic Information System (GIS) software QGIS v.3.20.2 (QGIS Development Team, 2024). Recreational harvesting data were spatialised with a grid resolution of 250 m in the Datum World Geodetic System 1984 (WGS 84). This high-resolution scale is used in diverse methodologies explored in EUSeaMap, such as for instance EUNIS habitats (Populus, 2017), thus appears suitable for monitoring recreational harvesting activities aiming to contribute for their management and support decision-making.

3. Results

From a total of 227 tides potentially suitable for harvesting wedge clams (≤ 1.0 m) during the one-year study period (May 2022 – April 2023), 50 harvesting surveys ($\approx 22\%$ available tides) were performed under a mean tidal height of 0.7 m (range: 0.4 – 0.9 m), in order to characterise the recreational harvesting activity, describe the catches of *D. trunculus* and estimate RHs annual catches.

3.1. Recreational harvesting activity

During 50 harvesting surveys (May 2022 – April 2023), ranging from 2 campaigns in December 2022 to 6 campaigns in May 2022, were counted 629 RHs with a balanced gender-ratio (53.2 % M vs 46.8 % F; $\chi^2 = 2.544$, $p > 0.05$), of which 5.1 % < 18 years, 36.9 % [18–65 years] and 58.0 % ≥ 65 years. RHs were clearly more numerous in late spring (June = 18.6 %) and during summer (July = 17.1 %; August = 24.2 %; September = 11.2 %), with negligible recreational harvesting activity from October to January (altogether representing only 4.4 % of total RHs) (Table 1).

Table 1

Wedge clams recreational harvesters (RHs) in total number (N) and respective proportion (%), subdivided by gender (F – female, M – male), age group (< 18 , [18–65], ≥ 65) and harvesting method (H/F – hand / foot, Snet – shrimp-net), based on the monthly number of harvesting days (H days) (%) of RHs in the Meia Praia beach in Lagos (Algarve coast - southern Portugal). In each column, values above the mean are highlighted in bold.

Month	H days	RHs		F		M		< 18		[18–65]		≥ 65		H / F		Snet	
		N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
May–2022	6	54	6.0	20	2.2	34	3.8	1	0.1	22	2.4	31	3.4	39	4.3	15	1.7
Jun	5	140	18.7	73	9.7	67	8.9	12	1.6	56	7.5	72	9.6	128	17.1	12	1.6
Jul	5	128	17.1	65	8.7	63	8.4	7	0.9	53	7.1	68	9.1	119	15.9	9	1.2
Aug	3	109	24.2	60	13.3	49	10.9	8	1.8	44	9.8	57	12.7	97	21.6	12	2.7
Sep	4	67	11.2	37	6.2	30	5.0	3	0.5	26	4.3	38	6.3	60	10.0	7	1.2
Oct	4	6	1.0	2	0.3	4	0.7	0	0.0	1	0.2	5	0.8	6	1.0	0	0.0
Nov	5	14	1.9	4	0.5	10	1.3	0	0.0	6	0.8	8	1.1	10	1.3	4	0.5
Dec	2	3	1.0	0	0.0	3	1.0	0	0.0	1	0.3	2	0.7	1	0.3	2	0.7
Jan–2023	5	4	0.5	2	0.3	2	0.3	0	0.0	1	0.1	3	0.4	0	0.0	4	0.5
Feb	3	24	5.3	8	1.8	16	3.6	1	0.2	6	1.3	17	3.8	17	3.8	7	1.6
Mar	3	27	6.0	8	1.8	19	4.2	0	0.0	8	1.8	19	4.2	13	2.9	14	3.1
Apr	5	53	7.1	15	2.0	38	5.1	0	0.0	9	1.2	44	5.9	19	2.5	34	4.5
Mean	4.2	52.4		24.5		27.9		2.7		19.4		30.3		42.4		10.0	
Total	50	629	100.0	294	46.8	335	53.2	32	5.1	233	36.9	364	58.0	509	80.8	120	19.2

In general, male RHs prevailed over female RHs throughout the year, except in late spring (June) and summer (July to September), the typical holiday season in the Algarve region, when females outnumbered males and youngsters (< 18 years) also participated in the family harvesting activity (94.1 % youngsters from June to September, with a peak of 35.3 % in August). Overall, 80.8 % RHs collected wedge clams with foot / hand and only 19.2 % also used a shrimp-net to retain the catch. Harvesting only with foot / hand clearly prevailed throughout the study period, except in December - January and March - April, when some RHs also used a shrimp-net (Table 1).

Regarding RHs spatial distribution, there were evident preferential harvesting areas (in both the easternmost and westernmost parts of the beach), apparently reflecting the location of higher densities of wedge clam beds (Fig. 2). In general, the distribution of male and female RHs was homogeneous along the beach, being absolutely gender-balanced in the westernmost part (214 M vs 215 F; $\chi^2 = 0.000$, $p > 0.05$) and slightly male-biased (99 M vs 70 F; $\chi^2 = 4.639$, $p < 0.05$) in the easternmost and least accessible part. Along the study area, RHs harvesting wedge clams using only their hands / feet clearly prevailed over RHs also using a shrimp-net to collect *D. trunculus* (Fig. 2).

3.2. Experimental vs recreational harvesting catches

During the experimental harvesting surveys (RH_{exp}), were caught 11,661 wedge clams ranging between 4 and 39 mm SL (corresponding to a total unsorted catch of 10.626 kg). On average, higher catches in both number and weight occurred from January to April, whereas lower catches in number were recorded in July and August and in weight in September.

Following the threshold based on the smallest *D. trunculus* caught and sorted by RHs (cutoff at 11 mm SL), the specimens excluded from subsequent analyses represented only 7.8 % and 0.9 % of total catches in number and weight, respectively. Among these, catches in both number and weight were negligible from May to July, being slightly higher in January, February and August. Overall, 1548 individuals (corresponding to 3.067 kg) were commercially-sized wedge clams (i.e. \geq MCRS = 25 mm SL), representing only 13.3 % and 28.9 % of total catches in number and weight, respectively.

The K-S test failed the normality S-W test to compare wedge clam's size frequency distributions between experimental and recreational harvesters. Alternatively, the K-W test did not detect statistically significant differences (K-W: $H = 2.431$, $p = 0.119$) in the mean size of *D. trunculus* caught by RHs (19.1 ± 4.8 mm SL) and by RH_{exp} (18.9 ± 4.8 mm SL), confirming that RH_{exp} catches are a suitable and reliable proxy of RHs catches.

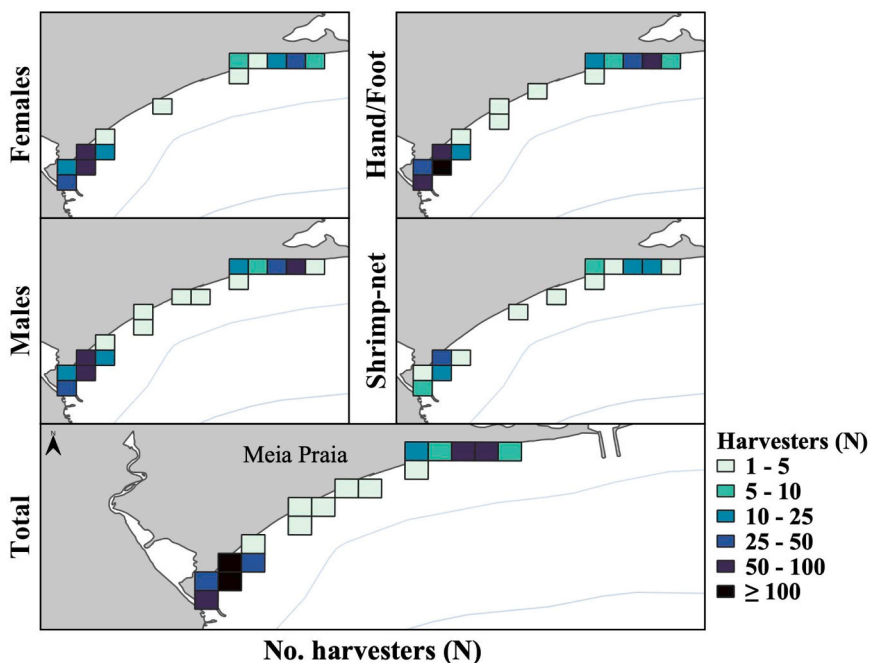


Fig. 2. Spatial distribution of wedge clams recreational harvesters along the Meia Praia beach in Lagos (Algarve coast - southern Portugal) during the study period (May 2022 – April 2023), subdivided by gender and harvesting method.

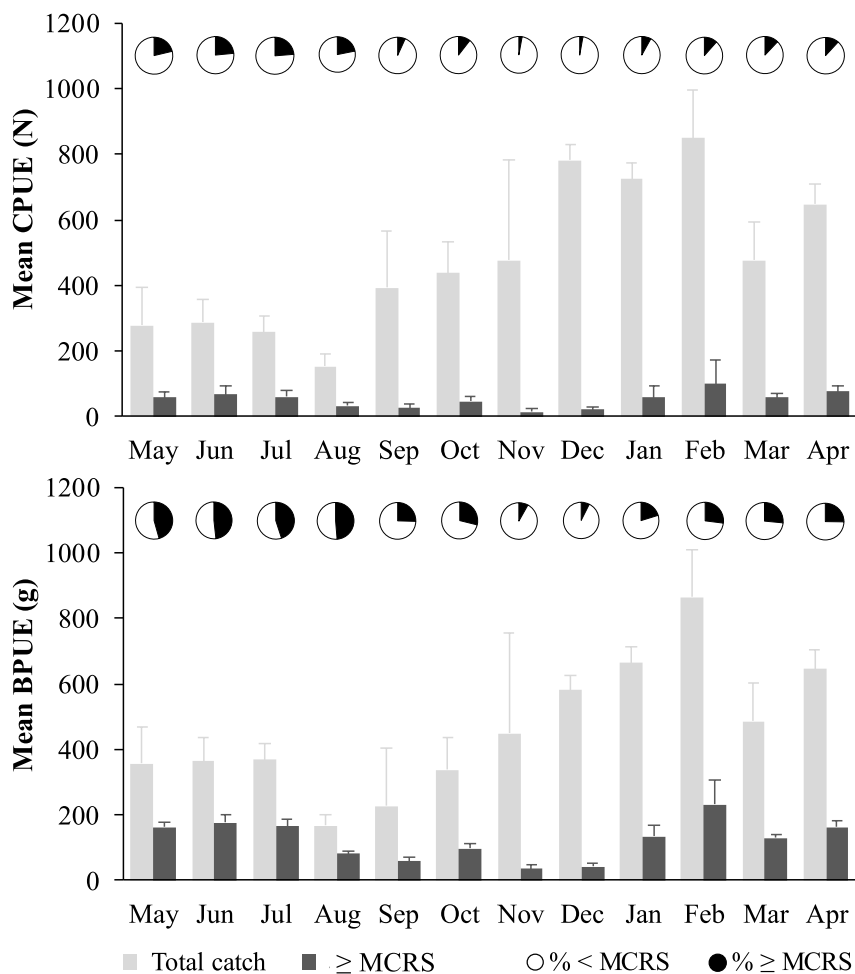


Fig. 3. Monthly mean CPUEs (in number) and BPUEs (in weight) based on the experimental recreational harvester (RH_{exp}) total catches and commercially-sized catches of wedge clams, together with the respective proportions of *D. trunculus* below and above the minimum conservation reference size (MCRS = 25 mm SL).

3.3. Recreational harvesting yield

After standardising all data for one hour of harvesting activity to estimate the effective catches in number (CPUE, inds. hour⁻¹) and weight (BPUE, g. hour⁻¹), were accounted 19,758 wedge clams totaling 19.435 kg, of which only 2430 individuals were commercially-sized (\geq MCRS) amounting 5.912 kg.

Highly significant statistical differences in both mean CPUE (481 inds.) (K-W: $H = 195.678$, $p < 0.001$) and mean BPUE (459.5 g) (K-W: $H = 198.019$, $p < 0.001$), were detected throughout the study (Fig. 3). The highest and lowest CPUE and BPUE were recorded in February (850 inds., 866.7 g) and August (154 inds., 167.0 g), respectively. In terms of pairwise monthly comparisons, statistically higher differences were detected between February and October in both number ($Q = 9.000$, $p < 0.001$) and weight ($Q = 8.960$, $p < 0.001$).

Regarding the commercially-sized wedge clams (\geq MCRS = 25 mm SL), mean CPUE was 52 inds. (range: 14 in November – 99 in February) and mean BPUE was 123.4 g (range: 36.2 g in November – 232.4 g in February), also with highly significant differences in both number (K-W: $H = 202.521$, $p < 0.001$) and weight ($H = 201.637$, $p < 0.001$) (Fig. 3). The proportions of *D. trunculus* \geq MCRS were lower in November and December in both number (3 inds.) and weight (8.0 and 7.4 g, respectively) and higher from May to August in both number (range = 21 – 24 inds.) and weight (range = 45.0 – 48.7 g) (Fig. 3). As such, statistically higher pairwise differences in number were detected between November and February ($Q = 8.470$, $p < 0.001$) and in weight between December and June ($Q = 8.600$, $p < 0.001$).

3.4. Wedge clams size frequency distributions

The monthly size frequency distributions of wedge clams caught by the RH_{exp} are presented in Fig. 4. A significant monthly variation in *D. trunculus* demographic structure throughout the study period was detected in shell length ($H = 40.631$, $p < 0.001$) but not in total weight ($H = 19.309$, $p = 0.056$). Statistically significant pairwise monthly differences in shell length were detected in December vs May ($Q = 4.130$, $p = 0.002$), December vs June ($Q = 3.630$, $p = 0.019$), December vs July ($Q = 4.060$, $p = 0.003$) and December vs August ($Q = 4.070$, $p = 0.003$). Such monthly variation was mostly because in December were not caught *D. trunculus* ≥ 29 mm SL, whereas in all other months were collected *D. trunculus* larger than 34 mm SL (especially between May and August, with some specimens ≥ 37 mm SL) (Fig. 4).

Overall, RH_{exp} catches comprised mostly individuals below the MCRS *D. trunculus* (25 mm SL) (Fig. 4). Commercially-sized wedge clams (≥ 25 mm SL) presented higher values in both number and weight from May to August, with peaks in July and August (23.9 % and 48.8 %, respectively). More specimens in the size fraction < 15 mm SL (> 20 % of total individuals) were caught between August and December, reaching a peak in September in both number (295 inds. = 50.4 %) and weight (85.9 g = 24.6 %). From September to December, the size fraction [15–20[was above 30 % in both number and weight, reaching higher values in November (533 inds. = 54.9 % and 348.2 g = 50.5 %). Finally, the size fraction [20–25[displayed invariably values above 35.0 % from January to April in both number and weight, with a peak in February (587 inds. = 40.1 % and 727.5 g = 49.5 %).

3.5. Recreational harvester's annual quantification and temporal variation

Based on RH_{exp} surveys, the extrapolation of the counted 629 RHs for all suitable tides with amplitudes ≤ 1.0 m during the study period, delivered an overall annual estimate of 2841 RHs (1533 M; 1308 F) collecting wedge clams between May 2022 and April 2023 at the Meia Praia in Lagos.

The monthly variation in the estimated number of RHs of *D. trunculus* throughout the study period is illustrated in Supplementary Fig. S1.

According to these estimates, more RHs occurred since late spring and especially during summer, namely in June (476 RHs), July (440 RHs), August (685 RHs) and September (356 RHs), corresponding to almost 69 % of the overall RHs. On the opposite, RHs never exceeded 100 individuals per month between October and January, reaching the minimum in January (17 RHs).

Regarding the seasonal variation in spatial distribution patterns, RHs were observed every month mainly in two distinct locations on opposite sides of the bay, coinciding with two easy accesses to Meia Praia beach.

3.6. Recreational harvester's annual catches

Based on the total number of RHs, overall suitable tides for performing this activity and standardised CPUEs or BPUEs, the wedge clams annual catches in the Meia Praia between May 2022 and April 2023 were estimated in 1180,576 *D. trunculus* corresponding to approximately 1221 kg (Fig. 5). However, among these total catches, only 16.8 % (197,897 individuals weighing 480.5 kg) were commercially-sized wedge clams (\geq MCRS = 25 mm SL).

Higher catches of wedge clams in both number and weight were estimated during February (191,538 inds. = 185.6 kg) and April (179,939 inds. = 181.8 kg), whereas lower catches were estimated to occur from October to January, especially in October (18,888 inds. = 14.7 kg) and December (34,290 inds. = 30.1 kg) (Fig. 5). The cumulative harvest along the one-year study period displayed two periods with higher increases in monthly catches (as revealed by the steepest slopes of the cumulative curves in both number and weight), particularly between May and September and between January and April. During summer, namely from June to September, the monthly cumulative harvest of *D. trunculus* was comparatively higher in weight than in number, especially in July and August (Fig. 5).

Regarding the spatial distribution of RHs estimated annual catches of wedge clams, the most intensively harvested area in the westernmost part of Meia Praia (illustrated in Fig. 2 and Supplementary Fig. S1) contributed with higher catches in both number (722,616 inds.) and weight (753.6 kg). Among these recreational catches, 122,887 specimens amounting 297.9 kg were commercially-sized *D. trunculus* (\geq MCRS = 25 mm SL) (Fig. 6).

The monthly spatial variation in this harvesting activity is illustrated in Supplementary Fig. S2. From October to January, RHs were concentrated in a few restricted areas of the beach, while in May, June, August and September, RHs were more spread along the beach, which is related to the higher number of people on the beach during these months. Regarding wedge clams catches, harvesting pressure was more concentrated on smaller individuals ($<$ MCRS), especially in number, whereas in weight such difference was slightly attenuated by the proportionally heavier weight of larger wedge clams (Fig. S2).

4. Discussion

The present study aimed to provide the first description of the recreational harvesting activity targeting wedge clams (*D. trunculus*) in the Algarve coast windward zone (“Barlavento”). The extent to which recreational harvest impacts wedge clam populations is still very poorly understood (McLachlan et al., 1996). In this context, in order to accomplish the main objectives of the present study, the recreational harvesting activity was characterised and the annual catches of wedge clams by RHs in Meia Praia beach were estimated. For this purpose, RH_{exp} catches were standardised and used to estimate RHs annual catches of *D. trunculus* (in both number and weight), by considering the total number of RHs and suitable tides for wedge clams recreational harvesting during the study period. Overall, RHs were gender-balanced and with predominance of older harvesters (≥ 65 years-old). RHs prevailed from late spring to summer (especially in August) and their catches comprised mostly *D. trunculus* below the MCRS legally stipulated for this species. In months with higher records of RHs (May, June,

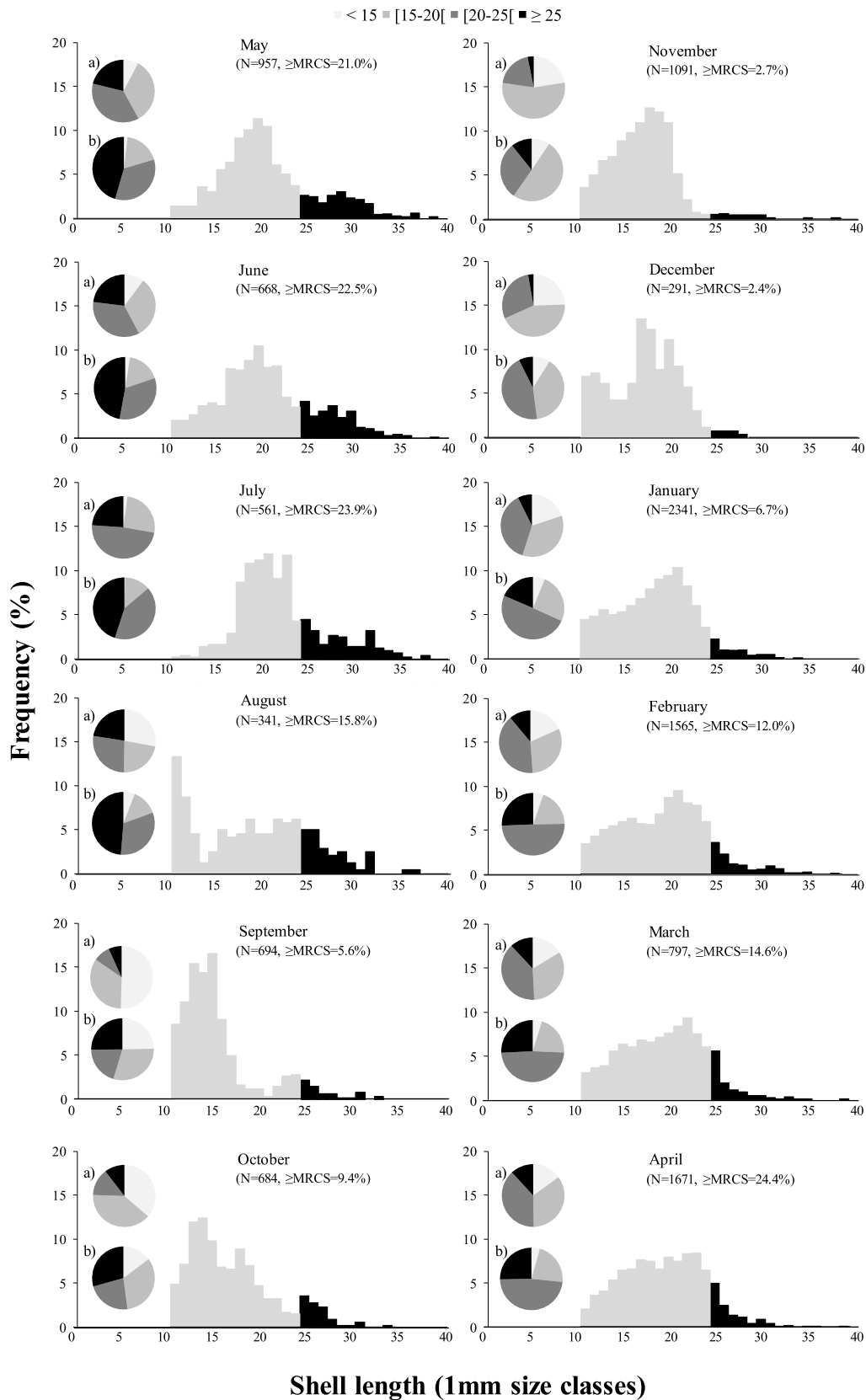


Fig. 4. Monthly size frequency distributions of wedge clams caught by the experimental recreational harvester (RH_{exp}). Pie graphs illustrate the catches proportions in a) number and b) weight within the size fractions. Commercially-sized *D. trunculus* (≥ MCRS = 25 mm SL) are denoted in black.

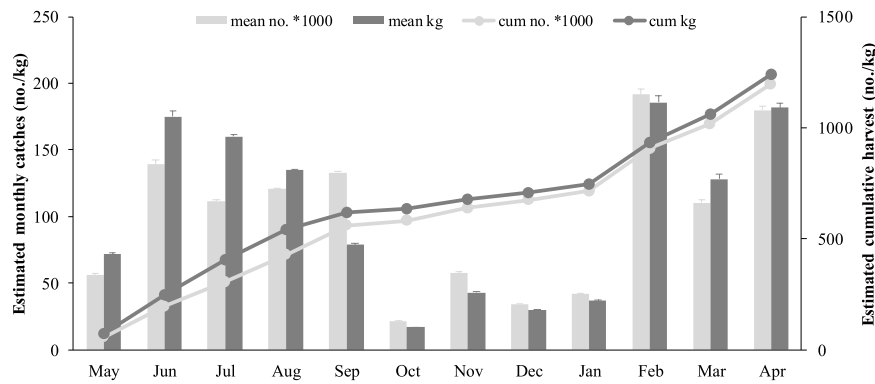


Fig. 5. Estimation of monthly catches and cumulative annual harvest of wedge clams by recreational harvesters in both number (light grey) and weight (dark grey).

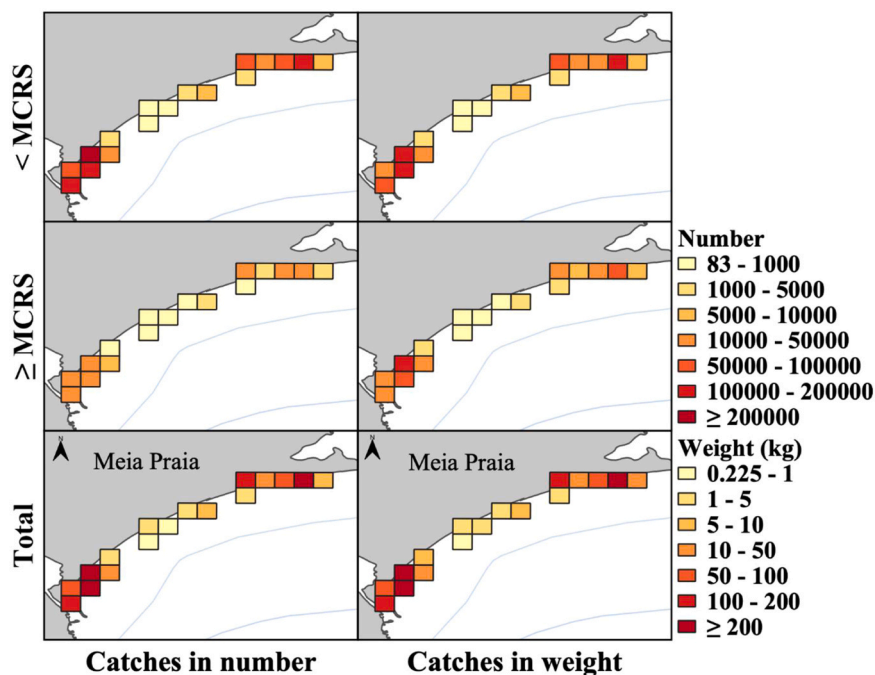


Fig. 6. Spatial distribution of recreational harvesters estimated annual catches of wedge clams in both number and weight (kg) throughout the study area, for total catches and for *D. trunculus* < MCRS (25 mm SL) and ≥ MCRS (25 mm SL).

August and September), they tended to disperse more along the beach, suggesting an eventual preference for further isolation and privacy when performing this leisure activity. On the opposite, RHs were only observed in the middle of the bay in five months, confirming that local wedge clam beds are the least exploited in Meia Praia beach. In the present case, limited information was previously available on the abundance, biomass or size composition of this species, whereas this study provided baseline information on the harvesting activity in this area by RHs that collect wedge clams along the beach mostly during summer holidays.

4.1. Recreational harvesting activity

RHs generally use their catches for family consumption or recreation, showing limited knowledge of the risks associated with their exploitation and consumption (Turra et al., 2016). Recreational harvesting is usually exerted in family and/or group (Schoeman, 1996; Murray-Jones and Steffe, 2000), but along the Algarve coast it is often a solitary activity, practiced by many RHs of highly diverse ages and frequently inexperienced (Sordo et al., 2023). On one hand, the catches are an appetizer for most people, while on the other hand, a small minority of

RHs practise this activity to obtain an extra income or even for subsistence.

Previous studies revealed that RHs are typically men (Turra et al., 2016; Anderson and Plummer, 2017), including the recent work focused on wedge clams recreational harvesting in the Algarve coast leeward zone (“Sotavento”) (Sordo et al., 2023). However, in the present study it was observed that women outnumbered men during summer, further confirming the seasonal nature of this activity, in a period when women are more available to join the family in this recreational task. In addition, most RHs were over 65 years old, indicating their full availability to regularly engage in wedge clams recreational harvesting, as already observed in the leeward zone (“Sotavento”) (Sordo et al., 2023).

Higher concentration of people on the beaches during summer causes problems related to overcrowding. An example of this issue was also reported for Isla Canela (southern Spain), a major touristic destination where tourists disturb intertidal areas by trampling and impact this shellfish resource through recreational hand-harvesting (Delgado and Silva, 2016). Corroborating the present findings, the urbanisation of coastal areas and the influence of human activities on the occurrence and abundance of bivalve populations have been reported elsewhere (Marcomini et al., 2002; Dadon, 2005). Just for instance, Herrmann

et al. (2009) considered intensive trampling as the main cause for the decreasing abundance of *D. hanleyanus* in Argentinean beaches. Consequently, the protection and conservation of these ecosystems and the sustainability of associated fishing resources require adequate control measures of tourism affluence and prevention of illegal harvesting. In fact, it is difficult to separate fishing effects from natural fluctuations in abundance (McLachlan et al., 1996).

In this study it was observed that hand / foot is the most common harvesting method (80.9 %), although some harvesters preferred to also use auxiliary shrimp-nets, essentially because most of them are > 65 years old and using those shrimp-nets avoids bending their backs for collecting the wedge clams. The greater presence of younger harvesters (<18 years old) during spring and summer is because they accompany their families during weekends and holidays, when the days are longer and the weather is pleasant. This was also the main reason why recreational harvesters in summer (304 RHs) clearly outnumbered those in autumn (23), closely following the seasonality in the Algarve tourism. The presence of RHs with highly varied ages during summer is another indicator of the family tradition of this recreational activity being passed from the older to the younger generations (Sordo et al., 2023).

This study also showed that RHs do not have much concern in sorting the catches and selecting larger individuals, frequently collecting wedge clams below the legally stipulated MCRS for *D. trunculus* (25 mm SL), sometimes just for competing for the highest number of wedge clams caught per person / group / family. Although some individuals up to 39 mm SL were collected, only 17 % of total catches were above the MCRS and individuals < 11 mm could reach 34 % of total catches, with maximum values in summer (17.4 %). Indeed, RHs can exert a heavy footprint and intentionally or accidentally target smaller individuals (in the absence of larger ones) during reproductive and/or recruitment periods (Cooke et al., 2002; Hartill et al., 2005), inducing harmful impacts on wedge clam populations, namely on biomass, size structure and maturity (Lewis et al., 2013). This negative scenario would be particularly problematic whenever recreational harvesting pressure occurs during periods of poor recruitment (Hartill et al., 2005). In the present study, during autumn and winter, when harvesting is performed essentially by local and more experienced harvesters, the collection of very small individuals (<11 mm SL) is more sporadic and the harvesting activity clearly targets specimens above that size.

According to Lewis et al. (2013), the establishment of minimum size limits for *Latona deltoidea* in Australia may effectively regulate recreational harvesting catches by protecting a fraction of population's reproductive capacity with 50 % sexually mature individuals, therefore preserving reproductive potential. Furthermore, diverse environmental factors and large temporal variations in both abundance and recruitment are also responsible for controlling larval production, settlement and survival, which can affect biomass supply (Murray-Jones and Steffe, 2000; Denadai et al., 2015; de Almeida et al., 2021). Additionally, the depth segregation between sizes of *D. trunculus*, with smaller individuals prevailing at 0.5–1 m depth where larval settlement occurs (Gaspar et al., 2002; Zeichen et al., 2002; Deval, 2009; Baeta et al., 2023), also explains the high proportion of individuals < 11 mm SL in recreational catches. Accordingly, while the bivalve dredging fleet targets larger individuals located at greater depths (up to 6 m), the harvesting activity (professional or recreational) is concentrated at very shallow depths in the intertidal zone, therefore exerting stronger pressure on juveniles with subsequent negative impact on the population structure and overall stock.

RHs sometimes do not react positively to intrusion in their harvesting activity, either because they suspect that control / surveillance might be involved and are afraid of committing any infraction, or simply because they do not want to respond to surveys about this activity performed during their holidays. Inquiries frequently touch on some personal issues that might create a climate of mistrust and tension, eventually leading to unreal and untruthful responses and subsequent biased results. Indeed, the information gathered through enquiries of RHs might not be the

most correct and fully reliable, because some false information can be given inadvertently or deliberately, without possibility of validation. Just for instance, such information might include aspects related to the wedge clams catches and respective selection criteria, i.e. sorting the catches, excluding the individuals below the MCRS and releasing them back to the sea.

In this context, the strategy adopted by the RH_{exp} in present work intended to be the least intrusive possible, without asking questions or interfering with RHs activity, maintaining some distance and discretion when counting the RHs along the shore, acting naturally while harvesting to simulate and estimate the fishing effort and catches by local RHs. This non-intrusive approach allowed spatializing the wedge clam recreational harvesting in a realistic and reliable manner, since the RHs behaved normally and remained in their harvesting locations, without moving away because they felt watched or bothered by an unknown external observer. Accordingly, it was demonstrated that the methodology for simulating the recreational harvesting validated in the present study, can be used in recreational harvesting activities targeting wedge clams (or other shellfish species), without significant differences between the catches of the RH_{exp} and RHs. Furthermore, the harvesting technique used by local RHs is quite easy to replicate, allowing to obtain high quality data on the harvesting activity, essential for estimating and mapping the spatial-temporal distribution of the fishing effort and catches throughout the year.

4.2. Wedge clams catches and size frequency distributions

Occasionally, catches exceeded 1 kg per person (but rarely surpassed the legal maximum daily catch per harvester = 2 kg), especially when more experienced RHs operated during extreme spring tides that allowed harvesting bivalve beds that are permanently immersed during most of the year. This fact could partially explain the large quantity of wedge clams caught in February, when the tidal regime reached the most harvestable low tide of the year. Actually, tidal migrations allow *D. trunculus* to maintain a favourable position on the beach that minimises predation risk while optimises feeding rate (Ansell, 1983).

A previous study in the Algarve coast showed that *D. trunculus* reaches maturity during the first year of life as a function of age and not size, since all individuals examined (13–21 mm SL) showed differentiated gonads (Gaspar et al., 1999). More recently, Delgado and Silva (2016) estimated a size at first sexual maturity (SL₅₀) of 10.8 mm for females and 10.9 mm for males of *D. trunculus* from Huelva (southern Spanish coast about 150 km east from Lagos). Accordingly, it is reasonable to assume that virtually all specimens analysed in the present study were potentially mature, since were not included individuals below 11 mm SL. Moreover, *D. trunculus* spawning usually occurs between late March and late August, being the main reproductive period very similar throughout the species distributional range (Gaspar et al., 1999 and references therein). Accordingly, in the present study, were caught more wedge clams > 20 mm SL from May to July, whereas smaller individuals appeared in August and reached a peak in September. The subsequent decrease in abundance of larger individuals (> 20 mm SL) is due to the higher harvest rate during late spring and summer, together with the ontogenetic migration of *D. trunculus* adults to deeper waters (Gaspar et al., 2002). It was also during this period when larger individuals became scarcer, that RHs collected more juveniles (< 15 mm SL), which is also influenced by the depth segregation of *D. trunculus* (Gaspar et al., 2002). Subsequently, juvenile growth was reflected in more slightly larger individuals within the fraction [15–20 mm] SL between September and December (peak in November). These results highlighted the potential impact of RH on the recruitment of *D. trunculus*, namely considering that harvesting effort is more pronounced during the species reproductive peak and exerted preferentially over larger individuals with higher fecundity and therefore with more potential to generate more recruits (Delgado and Silva, 2016).

4.3. Recreational harvesting estimated catches

Although the easternmost part of the Meia Praia beach is the least accessible and farthest from the city of Lagos, it was where a considerable number of RHs of both sexes were concentrated. The intermediate area of the beach is less harvested because of its deeper bottom, being the wedge clam local beds more distant from the shore and therefore more difficult or even impossible to access and harvest. The presence of more male RHs in this intermediate area might be due to particular tidal conditions that were more favourable for recreational harvesting in this less exploited zone, which require skilful and stronger RHs. Spatial patterns of distribution / concentration of clams' recreational harvesters are expected in adjacent areas to the beach access points (e.g. Schoeman, 1996). Geolocation data for mapping the spatial and temporal distribution of RHs and the harvesting effort exerted along the coast is essential to establish monitoring programs of recreational harvesting activities in the maritime space. Furthermore, in the near future, spatial and temporal data on recreational harvesting can be conjugated with geospatial data on the activities of the mechanized dredging fleet and professional hand-dredging, allowing to identify the most exploited areas and that might require further attention in terms of monitoring, assessment and management. In fact, high-resolution geospatial data is currently used in small-scale fisheries worldwide, with multiple applications in fisheries monitoring and management (e.g. Forero et al., 2017; Mendo et al., 2023; Rufino et al., 2023; Henriques, et al., 2024).

The first appraisal of RHs catches of wedge clams in the leeward zone ("Sotavento") of the Algarve coast was based on face-to-face interviews and estimated 13 tonnes of *D. trunculus* caught during summer along a sandy intertidal area of 19 km (Sordo et al., 2023), which corresponds to approximately 2.7 tonnes/summer for a 4 km beach (the extension of the Meia Praia in Lagos). In the present study, the estimated annual catches of wedge clams by RHs in all available tides with amplitudes ≤ 1.0 m along 4 km, corresponded to ≈ 1.2 tonnes of which 480.5 kg are individuals above the species MCRS (i.e. 740.5 kg of commercially undersized *D. trunculus* are collected annually in this relatively small beach). This value is much lower than those based on logbooks and catch statistics of *Latona deltoides* in SE Australia (46.5 tonnes/year along 32 km, i.e. roughly 5.8 tonnes/year in 4 km) (Murray-Jones and Steffe, 2000) or based on interviews of RHs collecting *Tivela mactroides* in Brazil (25 tonnes/year in 4 km) (Denadai et al., 2015), but still such biomass removal constitutes a relevant harvesting pressure on the local stock of wedge clams.

Until the beginning of the 21st century, a bivalve mechanised dredge fleet comprising nine vessels targeting wedge clams operated off the Meia Praia beach. Such fishing pressure, together with consecutive recruitment failures, led to the overexploitation of local beds of *D. trunculus*. Consequently, some dredge vessels were decommissioned, while others were relocated in other fishing areas along the Algarve coast where wedge clams are more abundant (M.B. Gaspar, pers. comm.). Meanwhile, the annual monitoring surveys performed by the Portuguese Institute for the Sea and Atmosphere (IPMA) revealed that the wedge clam population off Meia Praia has not recovered. This unsuccessful recovery might be due to the fact that wedge clam beds in this sandy area of the Algarve coast are very circumscribed by the predominant rocky bottoms around Meia Praia. Moreover, the nearest wedge clam bed is located more than 70 km to the east, hampering the transport of larvae from there to Meia Praia. Overall, this suggests that the potential recovery of the wedge clam bed along Meia Praia relies solely on the local population of *D. trunculus*.

During the present study period, only 120 kg of wedge clams were caught in this area by one dredge vessel during a single fishing day and sold in wholesale auction (amounting only 253 €). During the same period, catches of wedge clams in this area by 2 professional harvesters using hand dredges during 8 harvesting days reached 181 kg (totaling 1927 €). These quite low reported catches further confirm that the local wedge clam bed has not yet recovered and the fishing yield remains

unattractive for commercial exploitation.

However, relevant quantities of wedge clams (namely when compared to officially reported catches by the commercial dredge fleet and professional hand dredgers) are collected by RHs from local bivalve beds, with potential harmful impacts on wedge clam populations. Accordingly, it can be speculated that, despite its relatively low total catches, recreational harvesting also contributes for long-lasting unrecovered wedge clam beds. Indeed, the fact that RHs collect predominantly *D. trunculus* juveniles and individuals below the MCRS, certainly affects the species reproductive potential and subsequent population recruitment. Overall, the presence of more RHs in late spring and during summer, related to holiday season and longer days (Sordo et al., 2023), the species depth segregation between juveniles in shallower waters and adults in deeper waters, and the concentration of RHs along a narrow coastal strip, altogether lead to harvesting pressure exerted mostly on the smaller / younger fraction of the population.

The current national legislation and control rules applied to RHs include a maximum daily catch of 2 kg per harvester and a MCRS of 25 mm SL for the wedge clam, and RHs must also comply with the temporal closure applied to professional fishers and harvesters from 1 May to 15 June each year. However, given the extension of the crowded sandy beaches where recreational harvesting occurs and the insufficient logistic and human resources in the control authorities, most RHs do not comply with those mandatory regulations. Indeed, a study by Sordo et al. (2023) focused on *D. trunculus* recreational harvesting and based on face-to-face interviews, reported that most RHs were not even aware about the regulations in force for this activity. Therefore, besides effectively implementing those regulations, awareness-raising initiatives among RHs are needed, in order to elucidate them about the expectable impacts of this recreational activity on wedge clam populations.

5. Conclusions

In the present study, although the estimated catches of *D. trunculus* by RHs were not as high as in other studies, the fact that the recovery of wedge clam beds is intimately related to the species abundance in front of Meia Praia beach suggests that recreational harvesting is delaying the recovery of exploited bivalve beds. Most RHs are not size-selective, ignoring the species MCRS of 25 mm SL and directing their harvesting effort mainly towards commercially-undersized *D. trunculus*, further confirming that wedge clams recreational harvesting should not remain unmonitored and unmanaged. Indeed, monitoring recreational fisheries is the first step towards adequate management measures and proper decision-making. In this context, collecting geolocated data on this recreational harvesting activity, namely regarding the distribution of harvesting effort and catches in both time and space, is crucial for implementing alternative and adaptive management measures. Accordingly, an educational program should be developed and suitable management strategies should be implemented, in order to inform local inhabitants and tourists about the fragility of this shellfish resource and to promote sustainable recreational harvesting of wedge clams in the Algarve coast.

CRedit authorship contribution statement

Fábio Pereira: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **André N. Carvalho:** Writing – review & editing, Writing – original draft, Software, Investigation, Formal analysis, Data curation, Conceptualization. **David Piló:** Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Paulo Vasconcelos:** Writing – review & editing, Writing – original draft, Project administration, Investigation, Formal analysis. **Miguel B. Gaspar:** Supervision, Project administration, Investigation, Funding acquisition.

Declaration of Competing interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.risma.2025.104558](https://doi.org/10.1016/j.risma.2025.104558).

Data availability

Data will be made available on request.

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