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ABUNDANCE, DISTRIBUTION AND POPULATION STRUCTURE OF THE COMMON COCKLE *Cerastoderma edule* (Linnaeus, 1758) IN RIA DE AVEIRO

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ABUNDANCE, DISTRIBUTION AND POPULATION STRUCTURE OF THE COMMON COCKLE *Cerastoderma edule* (Linnaeus, 1758) IN RIA DE AVEIRO, PORTUGAL

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ABSTRACT

Title: Abundance, distribution and population structure of the common cockle *Cerastoderma edule* (Linnaeus, 1758) in Ria de Aveiro, Portugal. The common cockle (*Cerastoderma edule*) is currently the most important shellfish resource exploited in Ria de Aveiro. In recent years, surveys have been conducted by the Portuguese Institute of the Sea and Atmosphere to provide data on stock status for management purposes. The present work presents the results of the 2019 cockle survey, as well as the stock trends over the years. Results revealed that *Cerastoderma edule* is well established in all fishing areas of the Ria de Aveiro. The major cockle beds were found in Cale da Moacha (1951.0 g/m^2 at 2.5 m depth), Mira Channel (1519.4 g/m^2 at 3.4 m depth) and Ílhavo Channel (1192.8 g/m^2 at 2.0 m depth). These three production areas were responsible for about 60% of the total cockle biomass caught. However, the cockle fishing yields were still remarkably lower than those registered in the 2007 survey, which may compromise the sustainability of the stocks and seriously jeopardize future catches and incomes.

Keywords: Bivalves, common cockle, *Cerastoderma edule*, stock assessment, Ria de Aveiro

RESUMO

Sob o ponto de vista comercial, o berbigão (*Cerastoderma edule*) é o molusco bivalve mais importante da Ria de Aveiro. Nos últimos anos o Instituto Português do Mar e da Atmosfera tem realizado campanhas de investigação com o objetivo de recolher informação sobre o estado dos *stocks* para aconselhamento científico e implementação de medidas de gestão. Este relatório apresenta os resultados da campanha de pesca realizada em 2019, bem como a evolução dos *stocks* de berbigão ao longo dos anos. Os resultados mostram que esta espécie está presente em todas as zonas de pesca da Ria de Aveiro. Os principais bancos naturais de berbigão foram identificados na Cale da Moacha (1951,0 g/m^2 a 2,5 m de profundidade), no Canal de Mira (1519,4 g/m^2 a 3,4 m de profundidade) e no Canal de Ílhavo (1192,8 g/m^2 a 2,0 m de profundidade). Estas três zonas de produção foram responsáveis por cerca de 60% da biomassa total de berbigão capturada. No entanto, os rendimentos médios de pesca têm vindo a diminuir desde a campanha de 2007, o que pode pôr em risco a sustentabilidade dos *stocks* e comprometer a rentabilidade futura da atividade de apanha de bivalves na Ria de Aveiro.

Palavras chave: Bivalves, berbigão, *Cerastoderma edule*, avaliação do *stock*, Ria de Aveiro

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INTRODUCTION

The common cockle *Cerastoderma edule* (Linnaeus, 1758) is the most popular and profitable bivalve fishery resource in the estuarine coastal lagoon system of Ria de Aveiro and plays an important cultural and economic role in the local fisher communities. In 2018, the common cockle was the most exploited bivalve species in the north trade delegation of Aveiro, representing 91.7 % (~3456 tons) of the total global bivalve landings and 85.0 % (~4.0 million euros) of the total revenue.

Due to its abundance, ease of capture and strong market demand, *Cerastoderma edule* is collected year-round. This species is mainly harvested in the tidal flats and shallow waters (<1.5 m depth) of Ria de Aveiro by on-foot shellfishers equipped with rudimentary fishing tools, such as rakes or hand dredges. In the deeper subtidal areas (> 3 m depth) harvesting is less common and it is carried out with bullrakes operated from small fishing boats. Because this activity requires little investment in manpower and equipment, there has been an increase number of unauthorized harvesters and recreational users that intensified the fishing effort on the most accessible cockle beds. Uncontrolled exploitation of this living resource, coupled with adverse environmental conditions, can cause the depletion of the common cockle natural stocks and lead to the collapse of this fishery in Ria de Aveiro, with serious economic, environmental and social impacts.

To ensure the sustainability of this activity, the Portuguese Institute of the Sea and Atmosphere (IPMA, I.P) designed and implemented a bivalve monitoring program to determine the status of the main target bivalve commercial species in the Ria de Aveiro. Data on the population structure, spatial distribution and abundance of *Cerastoderma edule* were obtained during three research surveys carried out in the summer of 2007 (Maia & Pimenta, 2012) and 2013 (Maia *et al*., 2018), and in the spring/summer of 2019 on board of a small-scale artisanal fishing vessel. This report presents the results of the 2019 survey, as well as the temporal evolution of the common cockle abundance trough time (2007-2019).

METODOLOGY

The fishing survey took place between April and July 2019 and covered the main channels of Ria de Aveiro. Nine fishing areas were identified: the S. Jacinto and Ovar Channels, both running to the north for approximately 29 km; the Mira Channel, narrow and shallow, extends

20 km in the south-southwest direction; the Ílhavo Channel, orientated along the north-south axis, with 15 km long and 200 m at its widest point; the Espinheiro Channel, which spreads 17 km east towards the mouth of the Vouga river, the main input of fresh water of Ria de Aveiro; the Parrachil and Testada Channels; the Main Channel and Esteiro dos Frades; the Cale da Moacha; and the Cale do Ouro (Fig. 1).

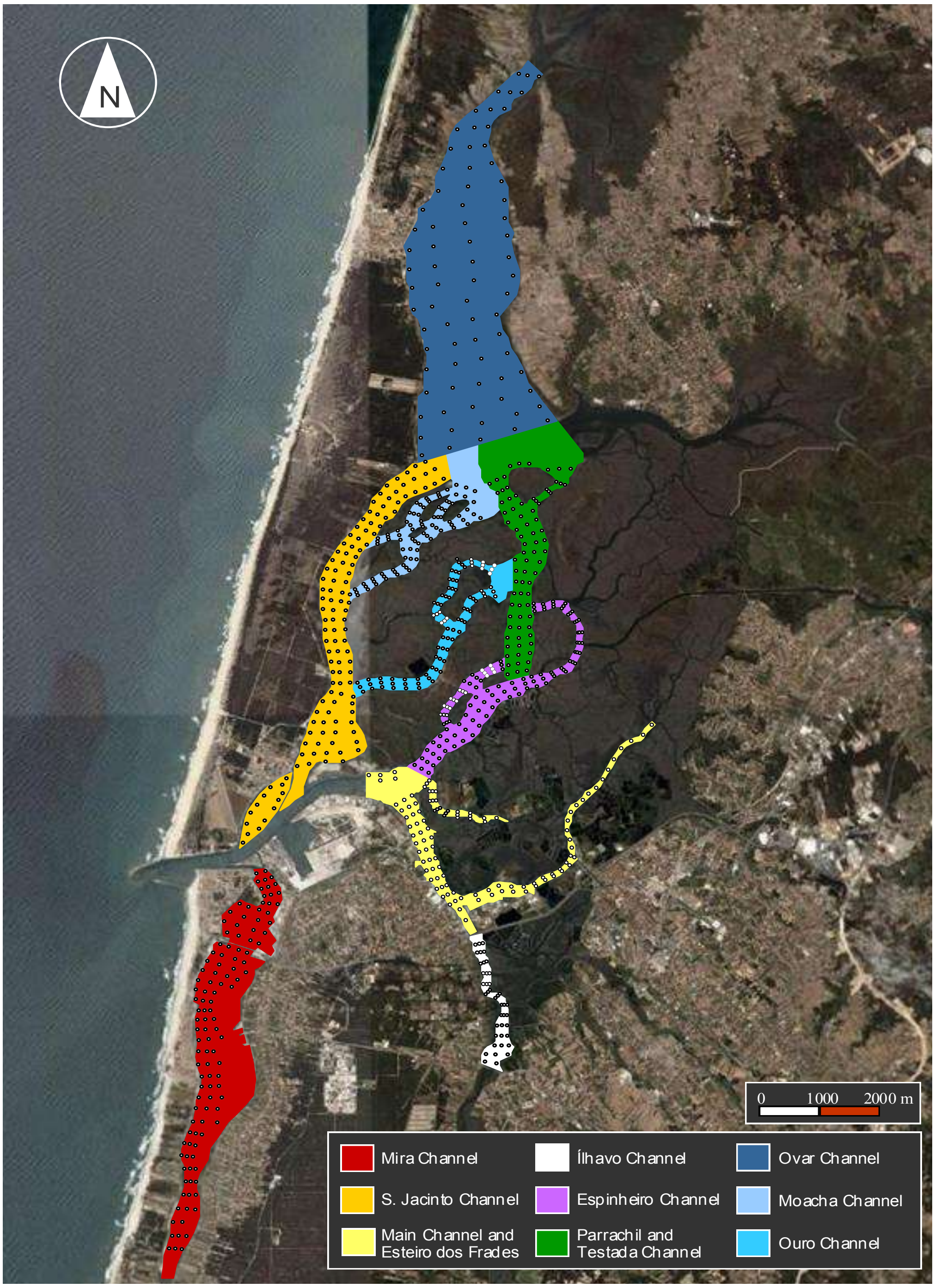

Figure 1. Map of the Ria de Aveiro highlighting the 9 fishing areas and the 2019 survey sampling stations (o). The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

Sampling was carried out along 290 cross-channel transects placed perpendicular to the stream flow and spaced 200 m from each other, except for the Ovar Channel where transects were 400 m apart (Fig. 1). A total of 827 fixed sampling stations were predefined, following the methodology adopted in the previous stock assessment campaigns (Maia *et al*., 2018).

The survey was carried out onboard of a traditional fishing boat and all samples were taken by a professional fisherman, in order to ensure that the fishing gear was properly operated. A bullrake similar to the ones used by bivalve harvesters was employed to obtain the samples. However, a 10 mm diameter-mesh net was used to retain small juvenile cockles (see appendix 1). In deep-water sampling stations (10-12 meters depth), and to guarantee permanent contact with the bottom, the bullrake was equipped with a heavy lead chain attached to the top of the basket frame.

During sampling, the position of the boat remained unchanged by using a two-anchor system with bow and stern anchoring. The area dredged was determined by multiplying the length of the mouth of the bullrake by the distance of the tow. To determine the tow distance (d), it was tied up a string at the dredge toothbar that passed through a weight on the bottom and that was held by a technician at the upper edge of the boat (gunwale). During the tow operation, the string was held in tension and pulled at the rhythm of bullraking. At the end of the tow operation, the distance towed (d) corresponded to the length of the string pulled (d') during sampling (Fig. 2).

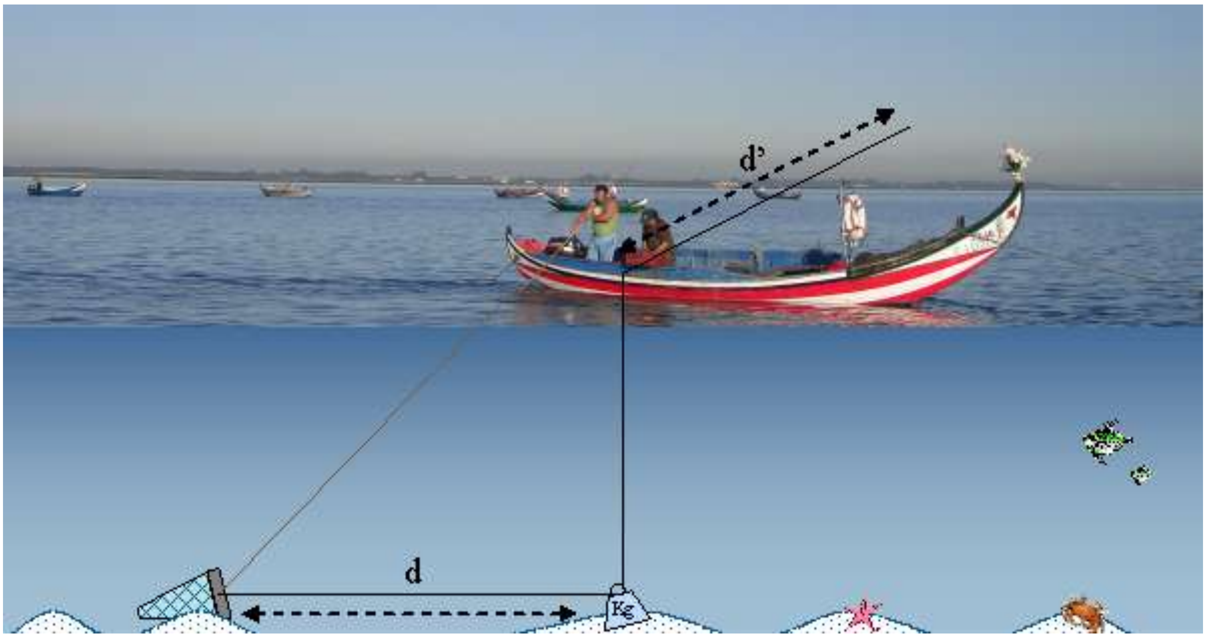

Figure 2. Schematic illustration showing how the distance towed was determined. Distance towed during bullraking (d); length of the string pulled during the fishing operation (d´).

Samples were washed *in situ* on a 1mm mesh sieve and all the retained cockles were placed in properly labelled plastic bags and carried to laboratory for further analysis. Shell length and weight were individually measured with a digital calliper (± 0.01 mm) and a digital balance (± 0.01 g), respectively.

RESULTS

Samples were only obtained from 800 stations of the 827 previewed. Samples from 27 sampling sites were impossible to obtain due to strong currents in the area and/or due to deep water local depths (> 12 m deep). These stations were located in the northern part of the Mira Channel (2) and Parrachil e Testada Channel (2), in the western margin of the S. Jacinto's Channel (12), in the Espinheiro Channel (8), in the Main Channel (2), and in the Ovar Channel (1).

Distribution, abundance and population structure of the common cockle *Cerastoderma edule*

The common cockle is quite adaptable and is widely distributed along the main channels of Ria de Aveiro. Nevertheless, is more abundant in Cale da Moacha, in Mira Channel and in the Ílhavo Channel, both in terms of density (ind./m^2) and biomass (g/m^2), (Fig. 3 and Fig. 4, respectively). This species was mostly found in shallow waters, on intertidal flats, from 0 to 3 m deep (Fig. 5 and Fig. 6).

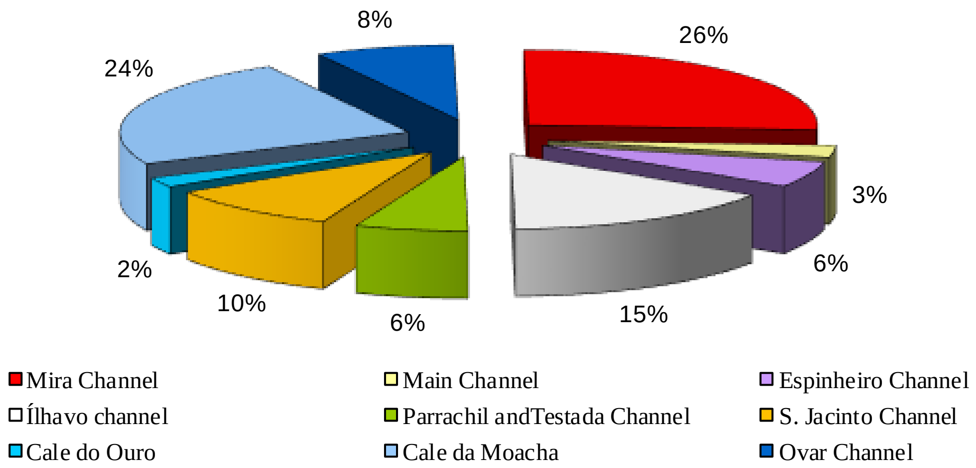

Figure 3. *Cerastoderma edule* density (ind./m^2) per fishing area, expressed in percentage.

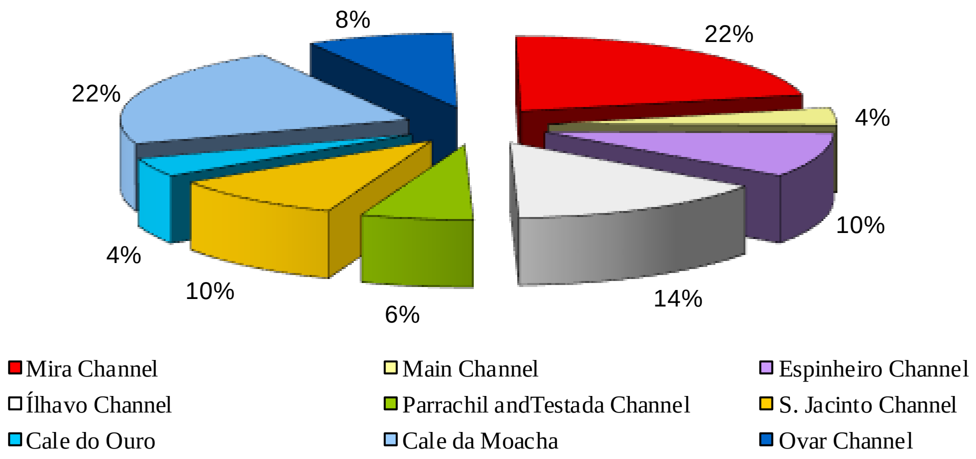

Figure 4. *Cerastoderma edule* biomass (g/m^2) per fishing area, expressed in percentage.

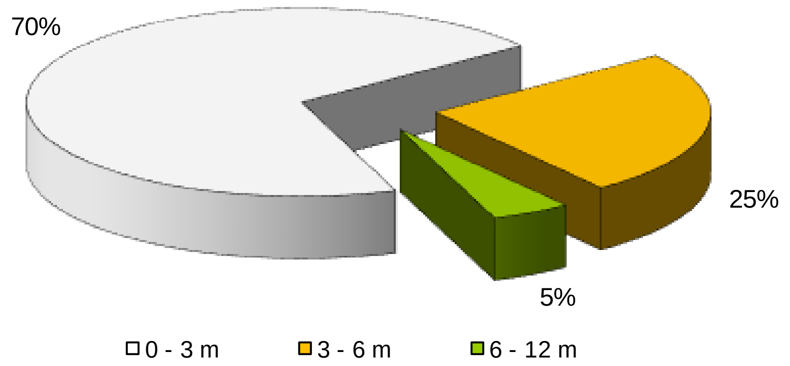

Figure 5. *Cerastoderma edule* density (ind./m^2) in three depth strata, expressed in percentage.

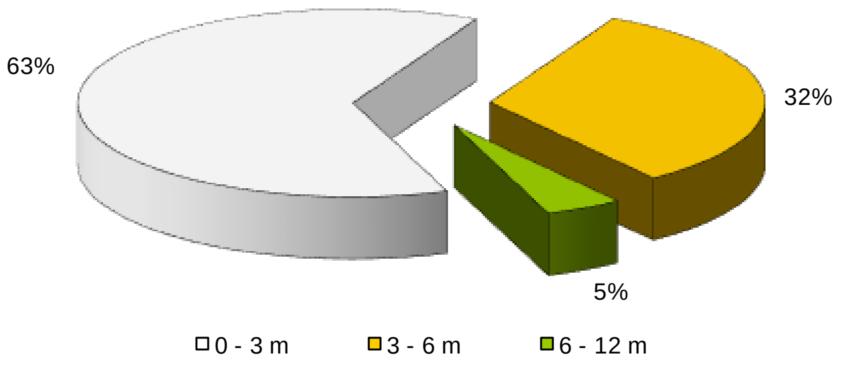

Figure 6. *Cerastoderma edule* biomass (g/m^2) in three depth strata, expressed in percentage.

Cockles were captured all along the Mira Channel with the highest biomass value (1519.4 g/m^2) being recorded in the central area of the channel, at 3.4 m depth. Two major production areas were identified: one located north of the Barra bridge and another in the intertidal flats, near to Biarritz beach front (Fig. 7).

Figure 7. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Mira Channel. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

In the S. Jacinto Channel cockles were more abundant in the intertidal flats located at the east margin of this channel. The area with the highest abundance value per m^2 (672.9 g) was found in S. Jacinto Bay, in a permanent submerged bed at 2m depth (Fig. 8).

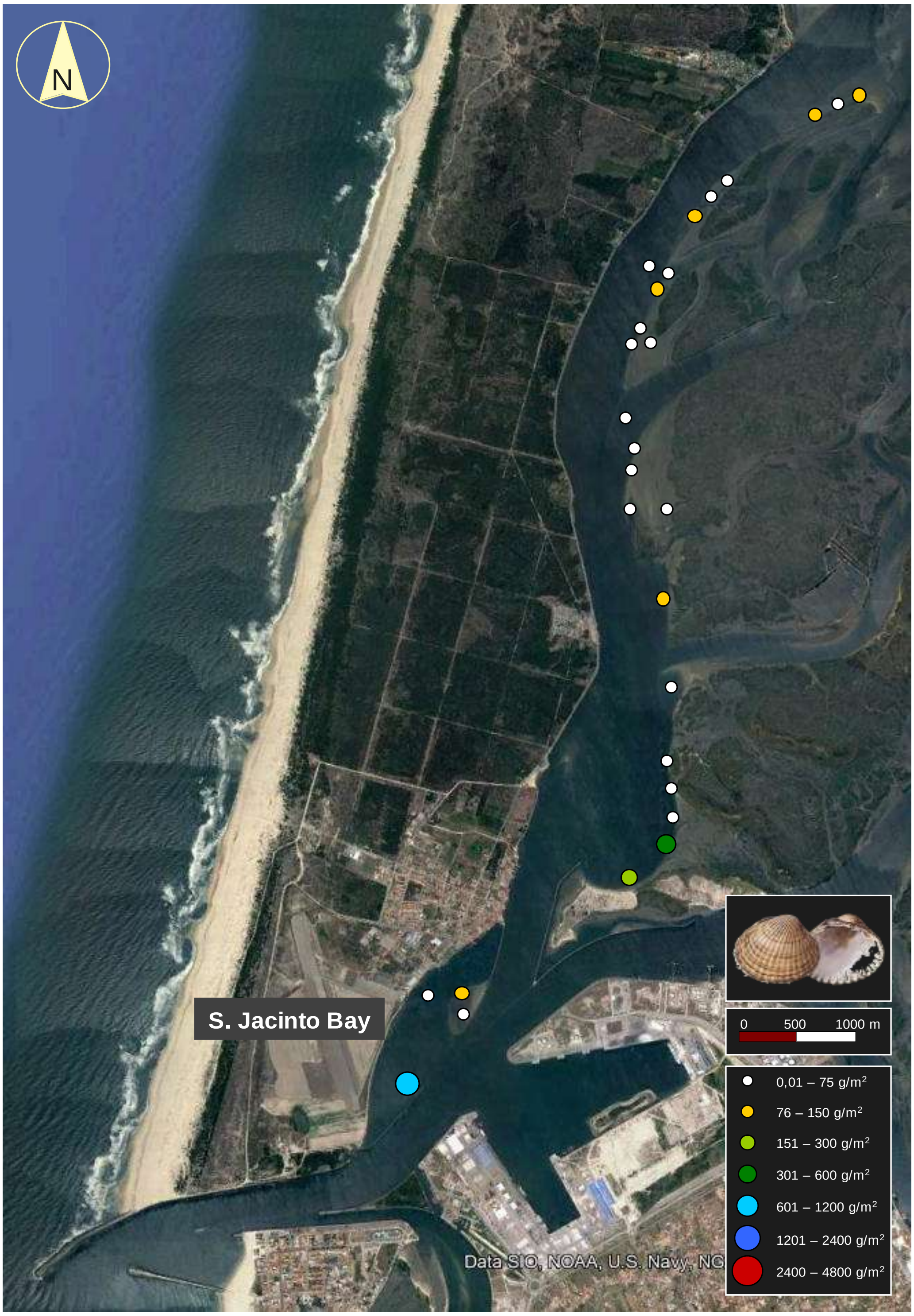

Figure 8. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the S. Jacinto Channel. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

The common cockle is widely distributed all over the Ovar Channel. However, the main beds were in the neighbouring areas of Bico do Muranzel, Murtosa Channel entrance and Torreira village. In these three locations, the highest biomass values were 130.9 g/m^2, 389.3 g/m^2 and 289.0 g/m^2 at the depth of 1.8m, 1.0 m and 2.0 m, respectively (Fig. 9).

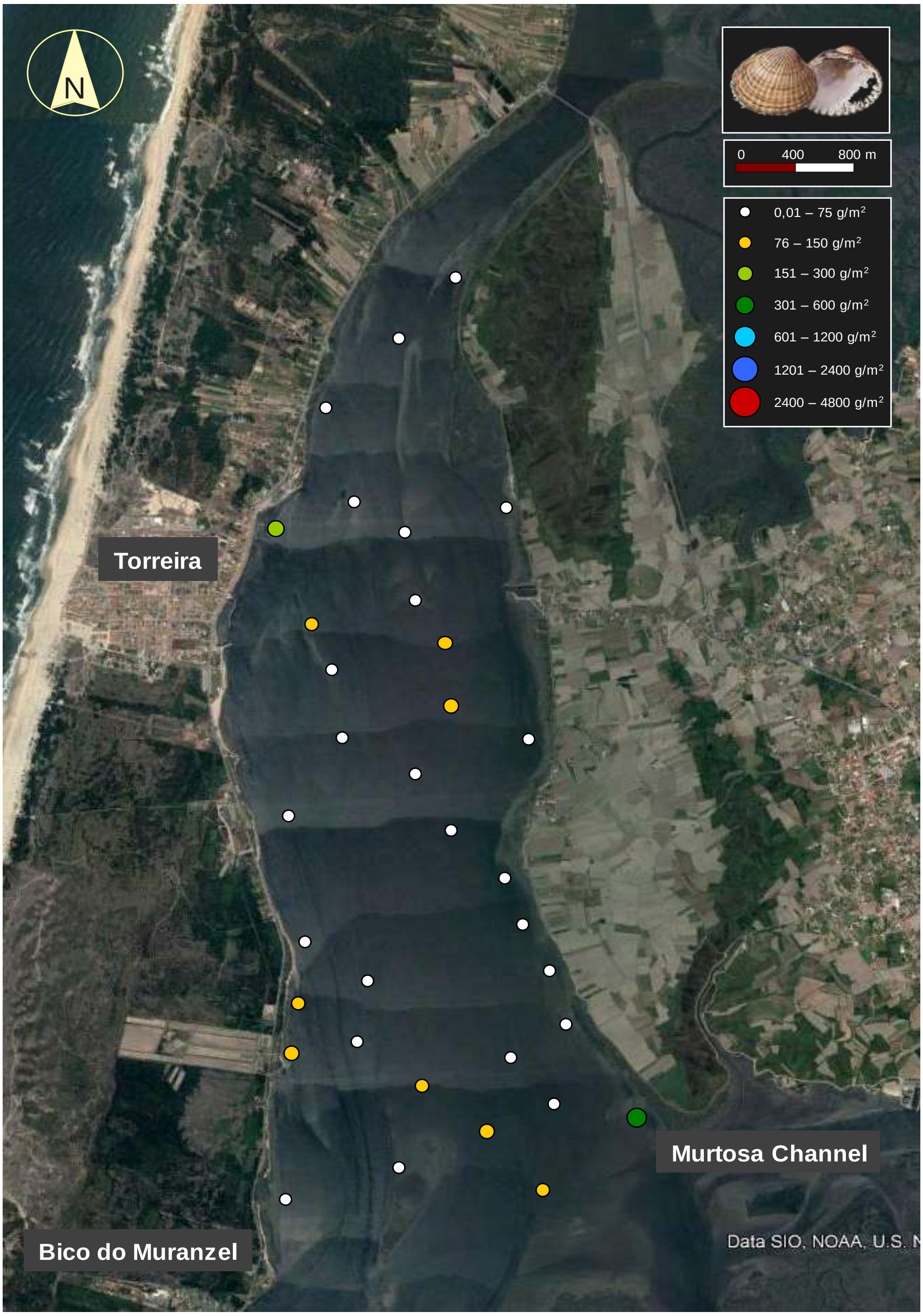

Figure 9. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Ovar Channel. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

Cockles were distributed throughout the Cale do Ouro, but occurred in greater density in the southern area of the channel (Fig. 10). The highest biomass value (181.3 g/m^2) was observed in shallow waters, at a depth of 0.5 meters.

Figure 10. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Cale do Ouro. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

In Cale da Moacha the common cockle was preferentially found in shallow waters, between 0.2 to 2.5 meters depth. The highest biomass value (1951.0 g/m^2) was recorded in the central area of this channel, at the depth of 2.5 m (Fig. 11).

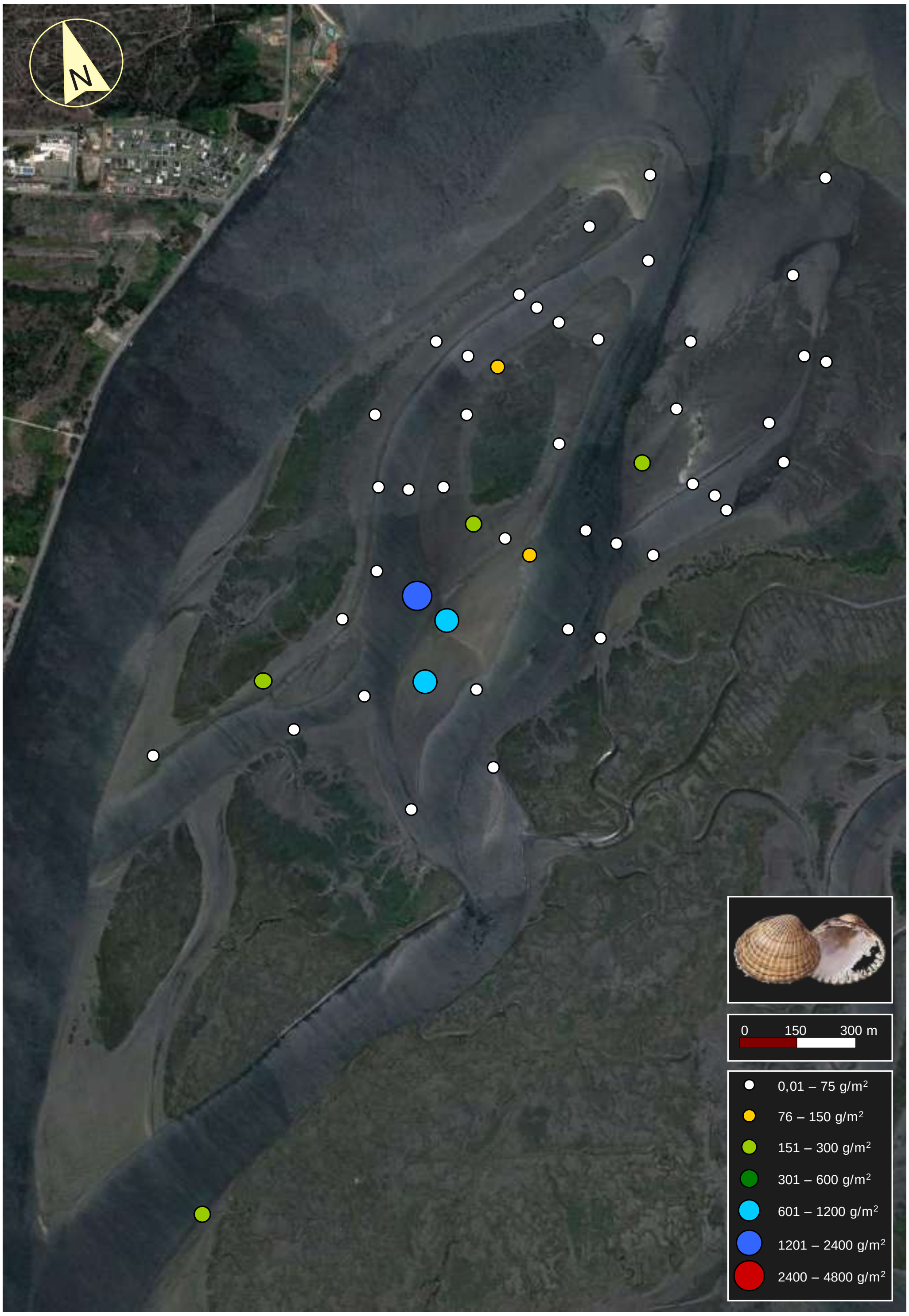

Figure 11. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Cale da Moacha. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

Cockle beds were predominantly distributed along the western and eastern margins of the Espinheiro Channel (Fig. 12). The highest biomass value (331.2 g/m^2) was recorded in the mid-section of the channel, at a depth of 4.0 meters.

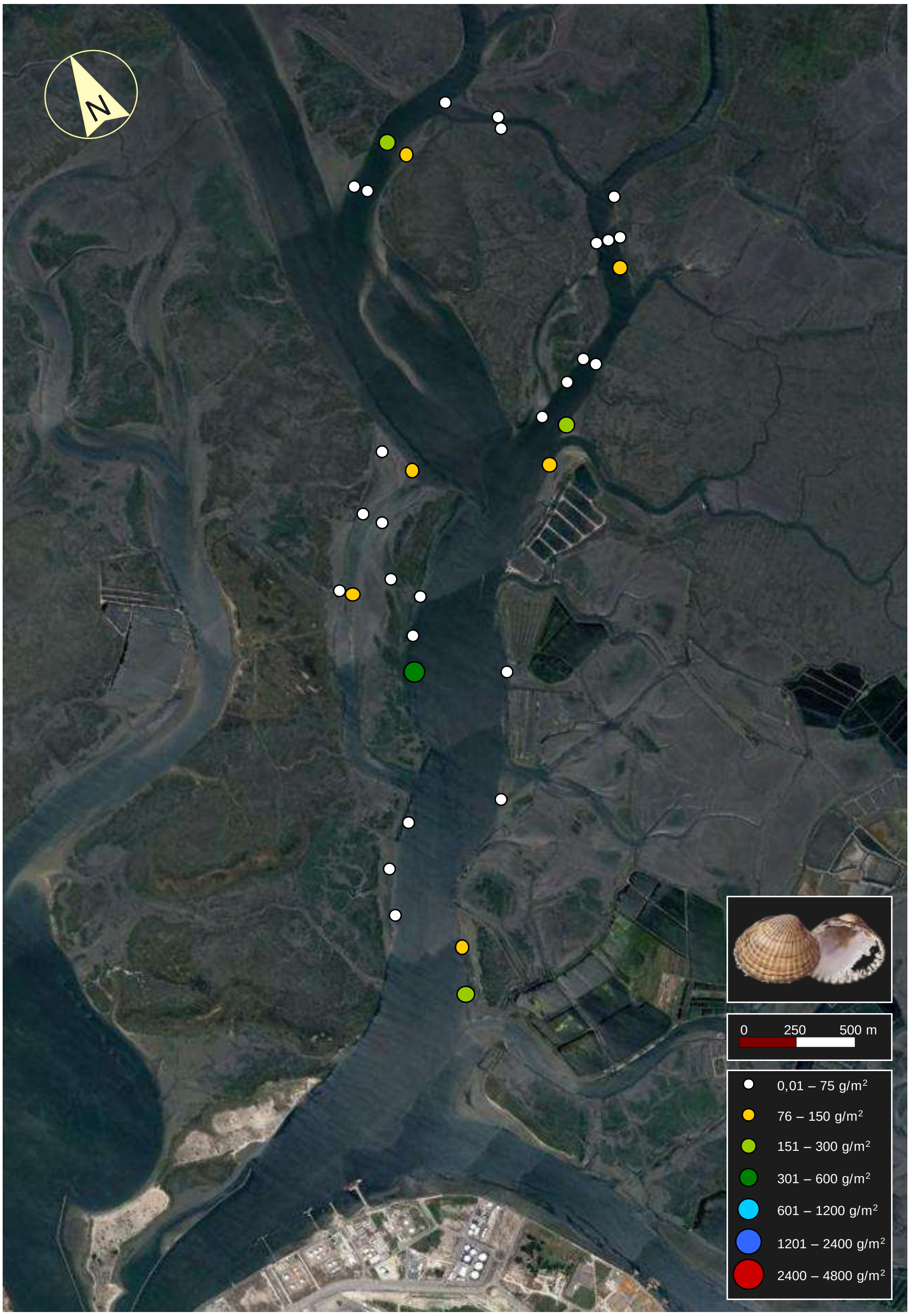

Figure 12. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Espinheiro Channel. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

Figure 13 shows that cockles were mostly distributed at the eastward margin of the Parrachil e Testada Channel. The highest biomass values (177.1 g/m^2; 163.6 g/m^2 and 152.3 g/m^2) were found in the north area of the channel, near Testada Island, at 1.0 m depth.

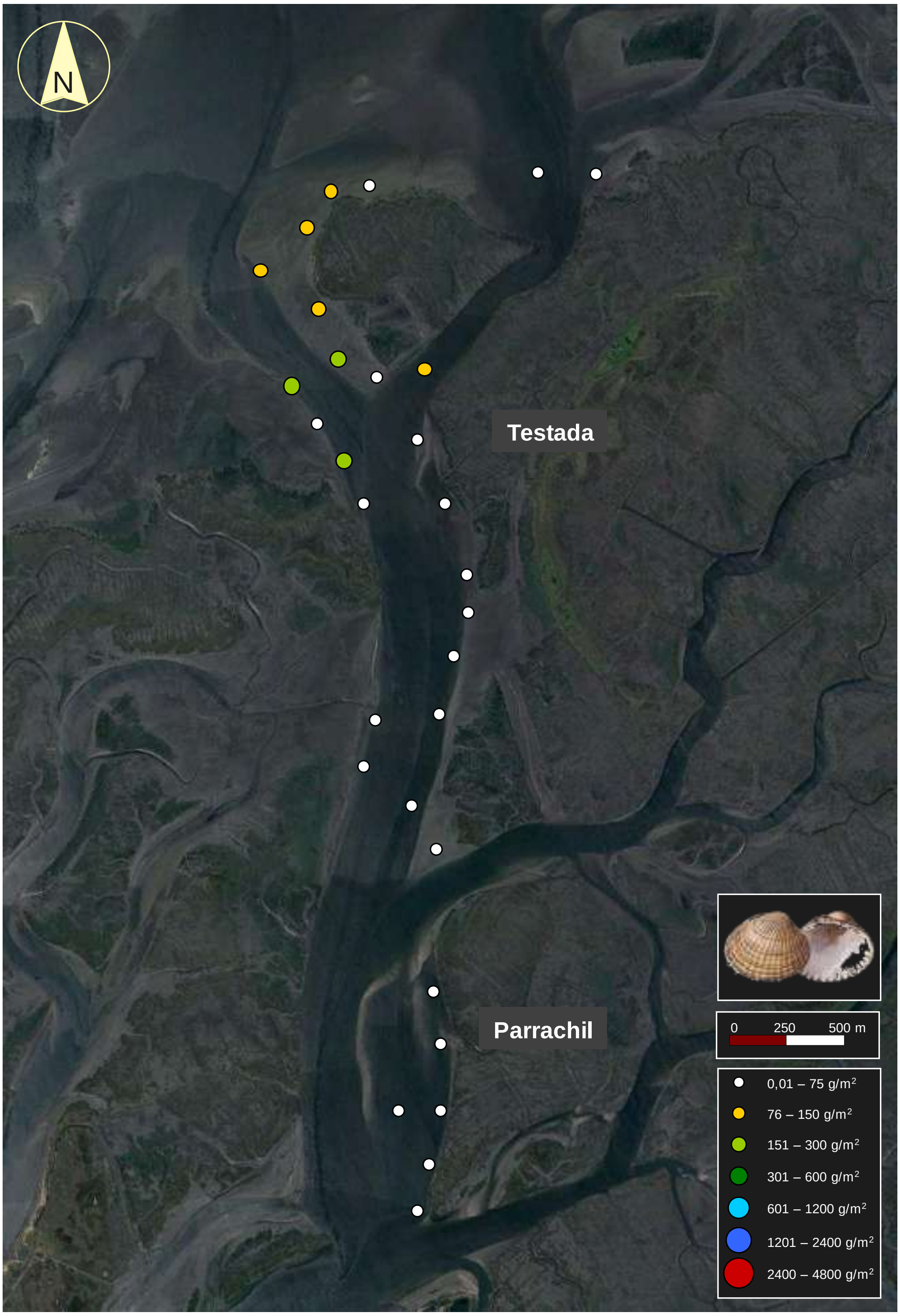

Figure 13. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Parrachil e Testada Channel. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

No major cockle beds were identified in the Main Channel. In this fishing area, the highest biomass value (58.4 g/m^2) was found on an intertidal flat located in the vicinity of Prio Energy facilities, at a depth of 0.5 meters. Cockles were more abundant in the shallow waters of Esteiro dos Frades and the highest biomass values (270.6 g/m^2 and 191.4 g/m^2) were registered at the depth of 1.2 and 2.1 m, respectively (Fig. 14).

Figure 14. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Main Channel and Esteiro dos Frades. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

Although cockles were caught all over the Mira Channel, the major bivalve beds were found in the north section of the channel (Fig. 15), where the highest biomass value (1192.8 g/m^2) was obtained, at a depth of 2.0 meters.

Figure 15. Distribution and biomass (g/m^2) of the common cockle *Cerastoderma edule* in the Ílhavo Channel. The figure was generated by using software Google Earth Pro (data was available from Data SIO, NOAA, U.S. NAVY, NGA, GEBCO, Image Landsat/Copernicus).

Figure 16 shows the size frequency histogram of the common cockle *Cerastoderma edule* grouped in 1 mm class intervals. Specimens ranged from 16 to 44 mm shell length (SL). The population length frequency had a well-defined mode at 25 mm SL and was strongly dominated (67.3 %) by individuals above the minimum landing size defined for this species (MLS=25 mm SL).

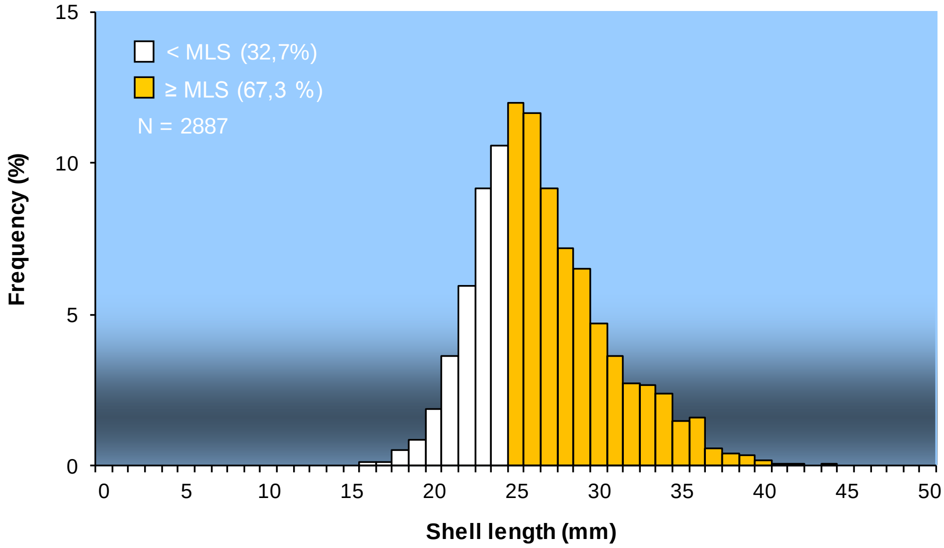

Figure 16. Shell length frequency distribution of the common cockle *Cerastoderma edule*. White bars represent non-commercial size classes, and the yellow bars indicate commercial size classes.

Figure 17 shows that *Cerastoderma edule* is well established in the Ria de Aveiro. The most important cockle fishing grounds were found in the intertidal beds of the Mira and Ílhavo Channels, and Cale da Moacha. These three production areas corresponded to nearly 60% of the total biomass caught. This species occurred in all fishing areas and biomass ranged from 4.0 to 1951.0 g/m^2.

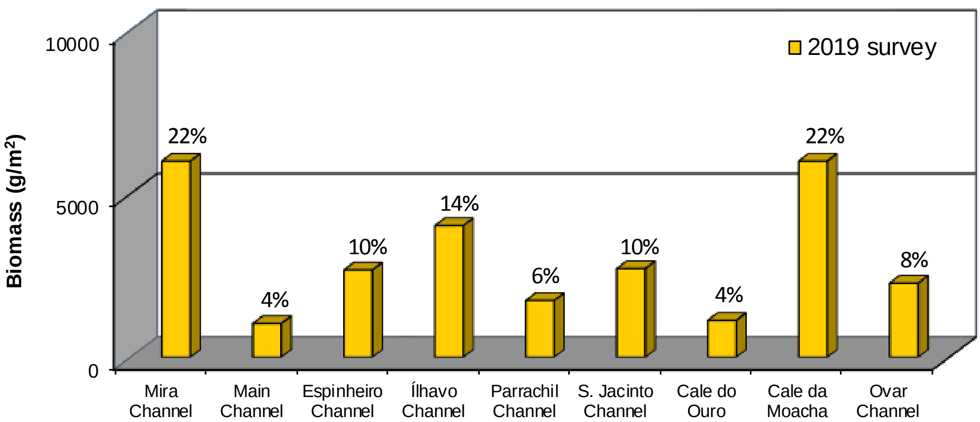

Figure 17. *Cerastoderma edule* biomass (g/m^2) in the Ria de Aveiro main fishing areas.

Evolution of the common cockle stocks between 2007, 2013 and 2019

Cockle total catches data from 2019 survey was compared with the results obtained in analogous monitoring surveys (2007 and 2013) in order to understand the effects of the current stock biomass in the upcoming cockle annual yields. 2013 survey results showed that *Cerastoderma edule* abundance decreased substantially when compared with the last stock assessment in 2007, both in terms of density (less 62.7 %) and biomass (less 57.2 %) (Figs. 18 and 19, respectively). Cockle density and biomass values declined slightly from 2013 to 2019 survey, persisting remarkably lower than those registered in 2007 campaign.

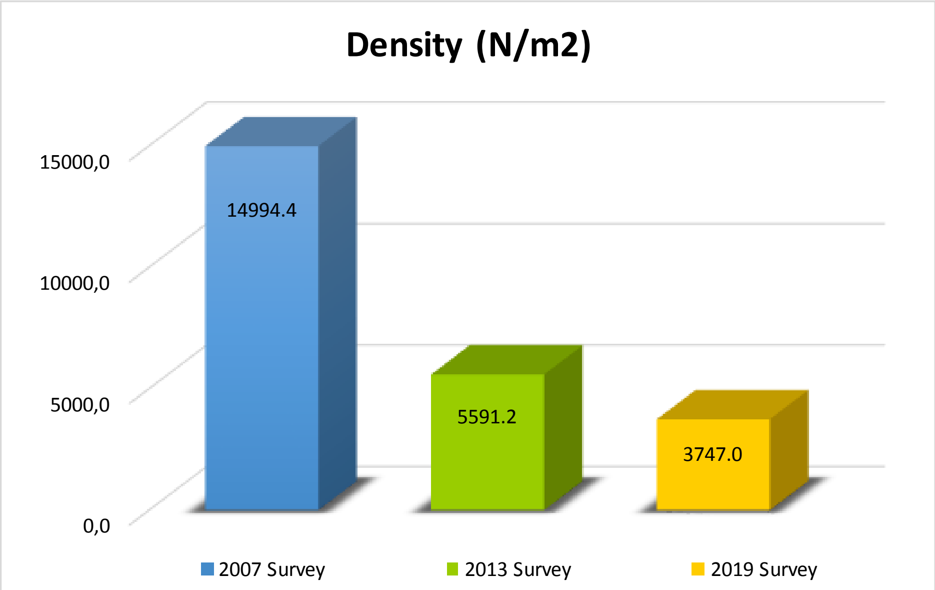

Figure 18. Evolution of the common cockle density between 2007 and 2019.

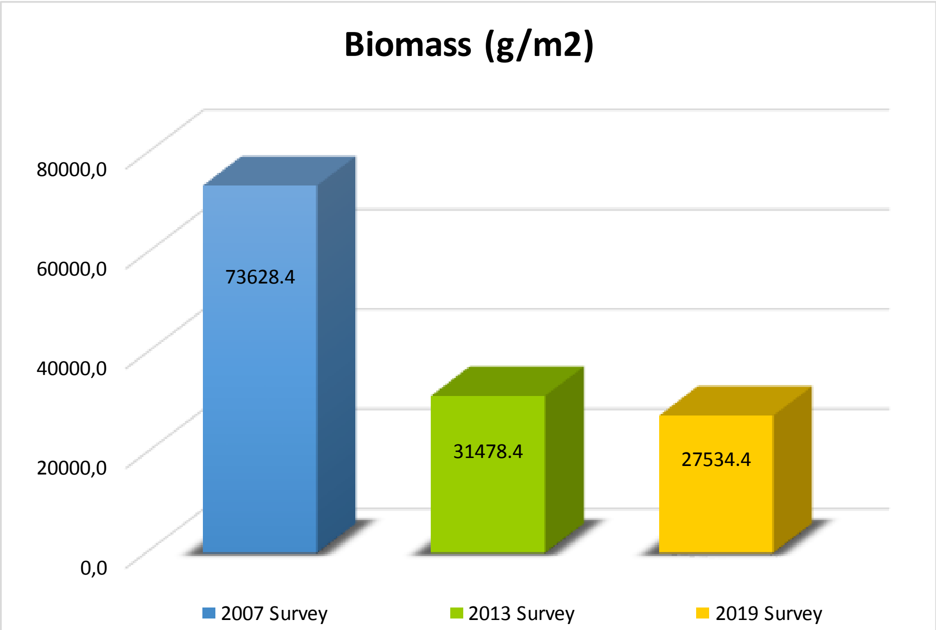

Figure 19. Evolution of the common cockle biomass between 2007 and 2019.

Historical trends in cockle first-sale landings and first-sale value, 2010-2020

Figures 20 and 21 shows the temporal evolution (2010-2020) of the major bivalve species total annual landings and commercial nominal values (i.e. uncorrected for inflation) registered in Aveiro first-sale fish auction market.

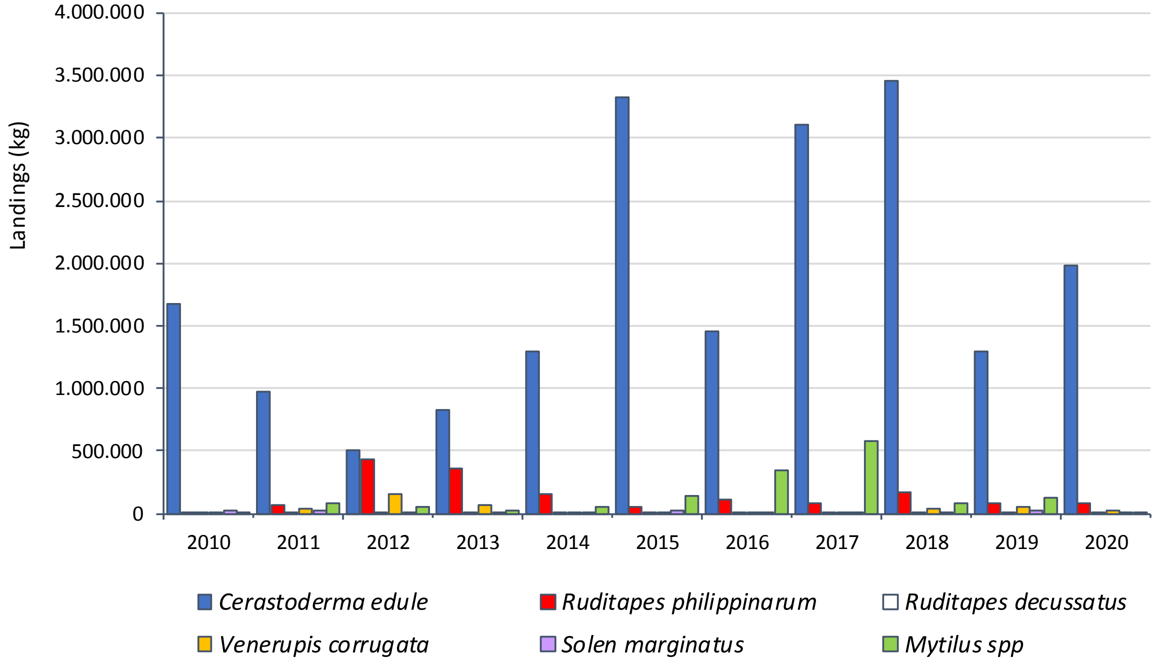

Figure 20. Total annual recorded bivalve landings in Aveiro first-sale fish auction market, 2010-2020.
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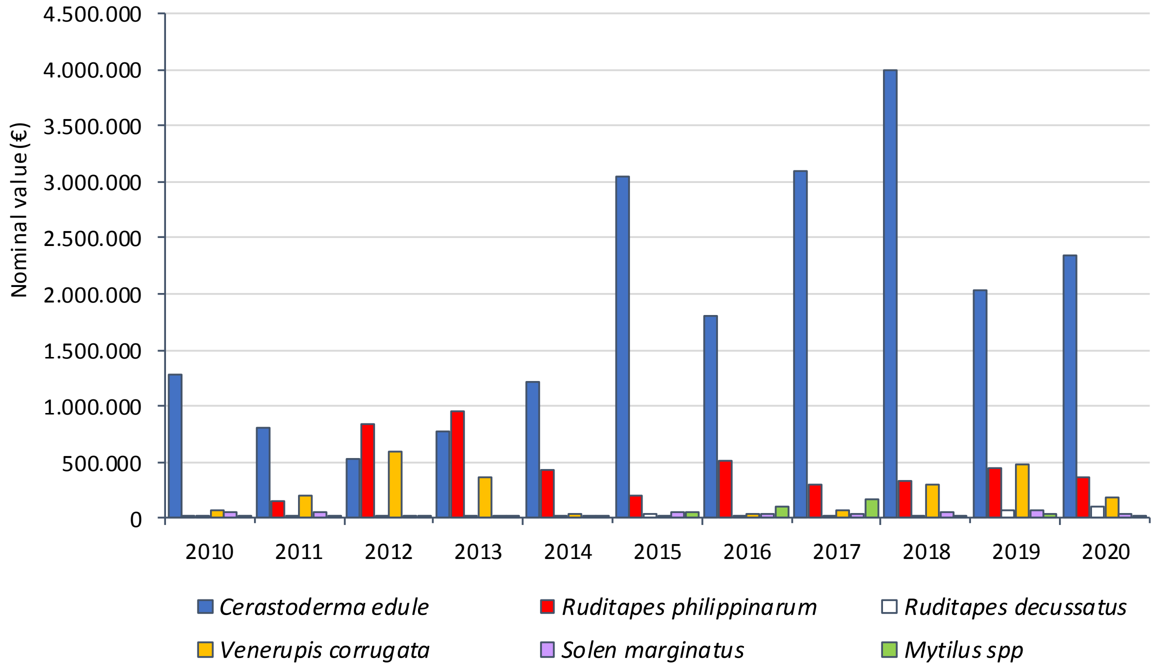

Figure 21. Nominal annual first-sale values of recorded bivalve landings in Aveiro first-sale fish auction market, 2010-2020.

Three exceptional years stand out from these long-term shellfisheries landing dataset. High cockle catches in 2015, 2017 and 2018 exceeded the 3000 tons per year, representing 93.7 %, 82.2 % and 91.7 % of the total global bivalve landings, respectively (Fig. 20). In those specific years, the annual cockle landings revenue surpassed the 3.0 million euros mark, reaching a peak in 2018 with 4.0 million euros (85 % of the total year bivalve revenue) (Fig. 21). This made cockles the most valuable mollusc fishery in the Ria de Aveiro, far exceeding the mussels, clams and razor shells production combined.

However, the 2019 survey low cockle abundance records, which were very similar to those observed in the 2013 stock assessment campaign (Figs. 18 and 19), forecast a decline in the forthcoming cockle annual yields. In fact, cockle annual landings dropped by 62.5% or 2161.5 tons in 2019, which caused a revenue loss of around 2.0 million euros compared to 2018 year, (Fig. 20 and Fig. 21). In 2020, the common cockle stocks seem to begin the process of recovery, but it may take some time to return to the 2015, 2017 and 2018 exploitation state (Fig. 20).

DISCUSSION AND FINAL CONSIDERATIONS

As previously referred, the 2019 survey results showed that *Cerastoderma edule* abundance levels were still remarkably lower than those recorded in the 2007 fishery survey. This scenario may compromise the integrity of the wild stocks, leading to fishery collapse if the negative trend maintains in the upcoming years. The history of this fishery followed a “boom and bust” pattern, with cycles of high catches and suddenly decline. Little is known about the underlying causes of these periodic fluctuations in cockle’s abundance, and the “boom and bust” cycles experienced by local shellfishermen.

Inter-annual cockle production is highly variable due to a range of interacting natural and anthropogenic factors. Overfishing, destructive fishing practices, predation, diseases and physical water quality changes (e.g. temperature, salinity) can induce recruitment failures with serious implications for Aveiro small-scale fishing communities.

Despite its economic importance and good underlying scientific knowledge, this fishery is still poorly managed. Therefore, there is an urgent need to reinforce and improve the management of cockle fishery that is carried out along the Ria de Aveiro, in order to reverse the current negative trend and to prevent the depletion of this resource. For this purpose, a variety of regulatory and technical measures could be applied, such as the implementation of harvesting calendars, trading plans, more selective and eco-friendly fishing gears, well-defined daily catching quotas, rotational and/or closed harvesting areas and stock enhancement actions (seedings and transplants).

In this regard, it could be employed a closed fishing season during the peak spawning and settlement periods of *C. edule* in Ria de Aveiro, i.e. from the beginning of August until the end of October (Maia *et al*., 2021). This management measure will ensure some degree of protection to the spawning biomass and spat settlement, enhancing the survival of new recruits and the overall population success. It could be also mandatory the use of an on-board sieving device that allow the discard of animals below the minimum landing size (MLS=25 mm shell length). For this purpose and taking into consideration *C. edule* shell width at MLS, a specific sieving tool with a series of rigid longitudinal bars with slot widths ≥ 18 mm should be developed (Maia *et al*., 2021).

It is also paramount to improve the efficiency of the fisheries law enforcement authorities, in order to reduce illegal, unreported and unregulated fishing, ensuring the sustainability of this fishery. Indeed, illegal fishing is an important issue that should be addressed and needs to be eradicated from Ria de Aveiro, otherwise management of cockle stocks will be very difficult or even impossible to put in practice.

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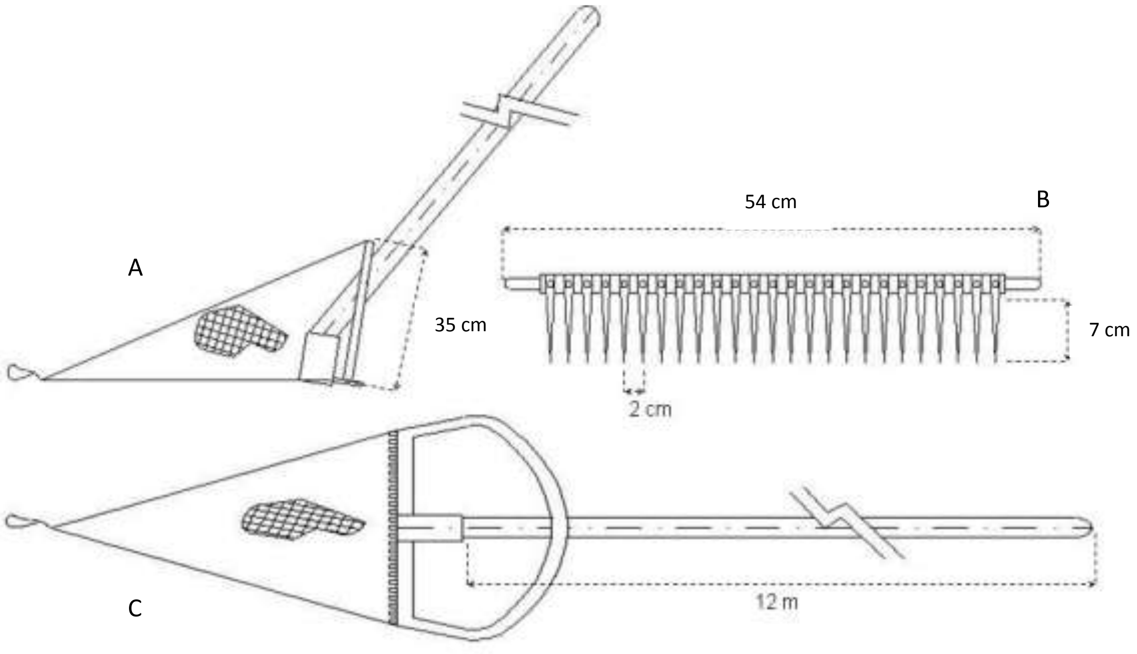
APPENDIX 1



2019 Survey bullrake technical specifications. (A) Lateral view; (B) Bullrake tooth bar; (C) Top view.

The bullrake is a simple fishing device designed for use by hand for the purpose of harvesting commercial bivalve molluscs. The bullrake used in this study had the following characteristics: rake mouth width - 54 cm; rake mouth height - 35 cm; tooth length - 7 cm; holding net - 10 mm mesh size; handle length - 12 m.

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