La pesquería artesanal de gasterópodos murícidos (Hexaplex trunculus y Bolinus Brandaris) en la laguna de Ría Formosa (costa del Algarbe, sur de Portugal)

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The artisanal fishery for muricid gastropods (banded murex and purple dye murex) in the Ria Formosa lagoon (Algarve coast, southern Portugal)

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SUMMARY: The artisanal fishery for muricid gastropods in the Ria Formosa lagoon (Algarve coast, southern Portugal) is a locally important fishing activity because the banded murex (*Hexaplex trunculus*) and the purple dye murex (*Bolinus brandaris*) are greatly appreciated seafoods with high commercial value in the Portuguese seafood market. An integrated study was implemented to monitor the muricid gastropod fishery with the artisanal fishing gear ("wallet-line") through monthly experimental fishing operations carried out during one year. The aim was to describe the fishing operations and fishing gear, to estimate the fishing yield, to characterise the target species catch composition, and to identify by-catch species and discards. The "wallet-line" is neither a species-specific nor a size-selective fishing gear, because the catches comprised a variety of by-catch species and a high proportion of commercially under-sized target species. The vast majority of the by-catch is discarded immediately on board, so mortality is presumably negligible. The CPUE of both target species and by-catch species decreased during consecutive fishing days, mainly due to declining bait attraction. Considering the overall information gathered on this fishing activity, some management measures are proposed for this artisanal fishery, which might ultimately contribute to the long-term sustainable exploitation of the fishing resource.

Keywords: *Hexaplex trunculus*, *Bolinus brandaris*, Ria Formosa, artisanal fishery, fishing gear, catches, by-catch, management measures.

RESUMEN: LA PESQUERÍA ARTESANAL DE GASTERÓPODOS MURÍCIDOS (*HEXAPLEX TRUNCULUS* Y *BOLINUS BRANDARIS*) EN LA LAGUNA DE RÍA FORMOSA (COSTA DEL ALGARBE, SUR DE PORTUGAL). – La pesquería artesanal de gasterópodos murícidos en la laguna Ría Formosa (costa del Algarbe, sur de Portugal) constituye una actividad pesquera importante porque la corneta (*Hexaplex trunculus*) y la cañaílla (*Bolinus brandaris*) son mariscos muy apreciados con alto valor comercial en el mercado Portugués. Se aplicó un estudio integrado para controlar la pesquería de gasterópodos murícidos con el arte de pesca artesanal "wallet-line" a través de pescas experimentales mensuales desarrollados durante un año. El objetivo fue describir las operaciones de pesca y el arte de pesca, para estimar el rendimiento pesquero, caracterizar la composición de las capturas de las especies objetivo, identificar las especies procedentes de las capturas no dirigidas y descartadas. El arte de pesca "wallet-line" no es ni específica para cada especie ni selectiva por tallas, ya que las capturas incluyen una variedad de especies procedentes de capturas no dirigidas y una alta proporción de especies objetivo de talla inferior a la permitida. La amplia mayoría de capturas no dirigidas son descartadas a bordo inmediatamente, y por tanto la mortalidad es presumiblemente insignificante. La CPUE tanto de las especies objetivos como de las no dirigidas disminuyó durante días de pesca consecutivos debido principalmente a la disminución de la atracción de los cebos. Teniendo en cuenta la información global recopilada en esta actividad pesquera, se proponen algunas medidas de gestión para esta pesquería artesanal, que podrían finalmente contribuir a la explotación sostenible del recurso pesquero a largo plazo.

Palabras clave: *Hexaplex trunculus, Bolinus brandaris*, Ria Formosa, pesquería artesanal, arte de pesca, capturas, capturas no dirigidas, medidas de gestión.

INTRODUCTION

Gastropods represent around 2% of the marine molluscs fished worldwide, but some species play significant social roles in small-scale artisanal fisheries. In Europe, France, the United Kingdom and Ireland account for over 90% of the European gastropod catches, mainly composed of the common periwinkle (*Littorina littorea*) and the whelk (*Buccinum undatum*) (Leiva and Castilla, 2002).

The banded murex, *Hexaplex trunculus* (Linnaeus, 1758), is mainly distributed in the Mediterranean Sea, but also occurs in the adjacent Atlantic Ocean, from the Portuguese coast southward to Morocco and to the Madeira and Canary Archipelagos (Poppe and Goto, 1991; Houart, 2001). The purple dye murex, *Bolinus brandaris* (Linnaeus, 1758), is very common throughout the Mediterranean Sea, whereas its distributional range in the Atlantic Sea is restricted to Portugal and Morocco (Poppe and Goto, 1991; Houart, 2001).

Historical sources, such as Aristotle and Pliny, described a method of catching muricid gastropods (namely *H. trunculus* and *B. brandaris*) using baited wicker baskets for subsequent extraction of the purple dye (Spanier and Karmon, 1987). Presently, both *H. trunculus* and *B. brandaris* are commercially valuable species in several Mediterranean countries (Poppe and Goto, 1991; Houart, 2001), traditionally fished for human consumption by using diverse types of artisanal fishing gears (e.g. pots, basket traps, dredges, scoop nets, trawl nets, gill nets and trammel nets) (Gaillard, 1987; Martín *et al.*, 1995). The banded murex is regularly or occasionally fished/harvested in Italy, Cyprus, Turkey (Gaillard, 1987), Croatia (Peharda and Morton, 2006) and Tunisia (Gharsallah *et al.*, 2004), while the purple dye murex is fished for seafood in France (Bartolome, 1985), Italy (Ramón and Amor, 2001) and occasionally Tunisia and Turkey (Ramón and Flos, 2001). In Iberian waters, *H. trunculus* and *B. brandaris* are commercially exploited by artisanal fisheries both in Spain, essentially along the Mediterranean and Atlantic coasts of Andalucía (Martín *et al.*, 1995; Anon., 2001; Ramón and Amor, 2001; Tirado *et al.*, 2002), and in Portugal, along the Algarve coast, mainly in the Ria Formosa lagoon (Marques and Oliveira, 1995; Muzavor and Morenito, 1999; Carneiro *et al.*, 2006).

In the Ria Formosa, the artisanal fishery targeting these muricid gastropods is a locally important activity, because the banded murex and the purple dye murex are greatly appreciated seafoods with high commercial value on the market (reaching values of around 10-15 €/kg and 20 €/kg for first sale, respectively). In addition to hand harvesting in inter-tidal areas, they are traditionally caught with an artisanal fishing gear, locally known as the "wallet-line", an illegal fishing gear according to the regulations for the fishery in the lagoon (D.R., 1990). Due to their easy capture and high fishing yield, the massive aggregations of *H. trunculus* and/or *B. brandaris* females during collective spawning are also subjected to hand harvesting by recreational users and professional fishermen during low tide (Vasconcelos *et al.*, 2004), hand harvesting by scuba divers operating illegally in the lagoon, and fishing by professional fishermen using prohibited entangling nets (Muzavor and Morenito, 1999), amounting to a considerable total catch of these species.

Probably due to over-fishing, detrimental harvesting practices and a disregard for the minimum landing size (MLS) stipulated for these species, the abundances of *H. trunculus* and *B. brandaris* in the Ria Formosa have been decreasing for more than a decade, possibly indicating over-exploitation of the fishing resource (Marques and Oliveira, 1995). Unfortunately, no reliable official statistics are available on the local catches of these species and their appraisal is almost impossible because much of the trade is conducted through a "black economy", in which sales are not officially declared. Despite these declining abundances of *H. trunculus* and *B. brandaris*, in the last five years there has been some pressure from local fishermen to legalise the fishery with the "wallet-line".

Since the information available on this fishing activity is essentially based on empirical knowledge (Marques and Oliveira, 1995; Muzavor and Morenito, 1999) or generic descriptions (Carneiro *et al.*, 2006), an integrated study was implemented to monitor the fishery for muricid gastropods using the "wallet-line", including monthly experimental fishing operations carried out during one year in the Ria Formosa. This study aimed primarily to describe the fishing operations and fishing gear, to estimate the fishing yield, to characterise the target species catch composition, and to identify by-catch species and discards. If this fishing activity is legalised in the near future, the information gathered in this study (complemented by relevant aspects of the target species biology, namely growth and reproduction), will allow suitable management measures for this artisanal fishery to be proposed to the fisheries administration, which could ultimately contribute to the long-term sustainable exploitation of this locally important fishing resource.

MATERIAL AND METHODS

Before starting the study, a confidential inquiry was made to professional fishermen from the Culatra Island involved in the fishery for muricid gastropods in the Ria Formosa, who voluntarily accepted to participate in these experimental fishing surveys. These interviews aimed basically to pre-characterise the fishing activity (location and type of bottom, frequency and duration of the fishing operations, number and size of fishing gears, etc.) and set up an experimental design that would realistically reflect the fishing operations usually carried out by the local fishing community. Additionally, five fishing gears that had been previously apprehended by the fishery authorities were measured in order to identify their main characteristics and specifications (materials and dimensions) and prepare a technical plan of a "wallet-line" containing the most relevant features of the fishing gear (adapted from Carneiro *et al.*, 2006).

Following the information gathered during the enquiries made to local fishermen, each monthly fishing survey comprised three consecutive fishing days (day 0 - setting the fishing gears; days 1 and 2 - retrieving the catches; day 3 - hauling the fishing gear and retrieving the catches). The time required for setting the fishing gear (day 0), retrieving the catches (days 1 and 2), hauling the fishing gear and retrieving the catches (day 3) was registered in each fishing operation. In each fishing survey, six "wallet-lines", each one comprising 100 "wallets" baited with live cockles (*Cerastoderma edule*) were used. This gear is similar to the ones used by local fishermen.

At the end of each fishing day, all individuals caught were removed from the "wallet-lines" and studied in the laboratory. Specimens of the target species (*H. trunculus* and *B. brandaris*) were counted, measured for shell length (SL - mm) with a digital calliper (precision of 0.01 mm), weighed for total weight (TW - g) on a top-loading digital balance (precision of 0.01 g) and the catches per unit effort (CPUE - number or total weight) were standardised for 100 "wallets"/24 hours. All specimens of the by-catch species were also counted and identified to the lowest possible taxonomic level. Finally, at the end of

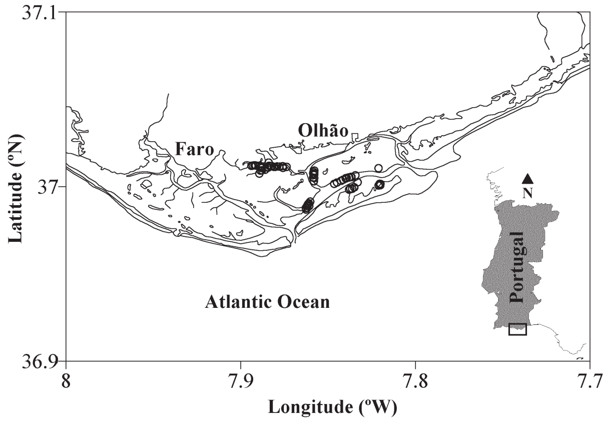

Fig. 1. – Geographical location of the experimental fishing surveys with the "wallet-lines" (circles) carried out in the Ria Formosa lagoon (Algarve coast, southern Portugal).

each fishing survey, when the fishing gear was hauled the bait was removed from 20 randomly selected "wallets" and the live cockles and empty shells were counted to estimate the bait mortality at the end of three fishing days. During the fishing operations, data on the surface seawater temperature registered by the Faro Oceanographic buoy (offshore of the study area) was downloaded from the web page of the Portuguese Hydrographical Institute (I.H., 2005-2006) to assess potential relationships between this environmental parameter, the bait mortality and the fishing yield.

The experimental fishing operations were carried out using the fishing boats of the professional fishermen from Culatra Island involved in this study (each month, a fisherman was randomly selected to perform the fishing surveys, accompanied by the scientific staff of the IPIMAR). The experimental fisheries were undertaken at locations chosen by the fishermen, usually on muddy-bottoms with seagrasses (namely *Zostera* spp.) in the vicinities of Culatra Island (the geographical coordinates of the fishing grounds were recorded using a portable GPS) (Fig. 1). During a one-year study period, a total of 12 monthly fishing surveys were carried out between July 2005 and June 2006. Overall, 36 fishing days (12 months x 3 fishing-days) and 216 fishing operations (36 fishing-days x 6 fishing-gears) were performed.

RESULTS

Fishing gear and fishing operations

The artisanal fishing gear locally known as the "wallet-line" is basically composed of a long main

TABLE 1. – Main characteristics and technical specifications (dimensions and materials) of the “wallet-line” used in the fishery for muricid gastropods in the Ria Formosa.

	Main lines		Gangions		“Wallets”			“Wallet” fastening cables		“Wallet” mesh sizes		
	length* (m)	width (mm)	length (cm)	width (mm)	number	length (cm)	width (cm)	length (cm)	width (mm)	length (mm)	width (mm)	diagonal (mm)
Mean±S.D.	≈ 1.8	4.0±0.7	63.8±19.4	1.5±0.2	85±14	13.5±1.1	11.8±0.7	27.4±5.2	1.4±0.3	9.1±0.3	9.1±0.5	11.0±0.4
(min-max)	(≈1 fathom)	(2.1-5.0)	(26.5-124.0)	(1.1-2.6)	(76-109)	(11.5-16.5)	(9.0-14.0)	(11.0-44.0)	(1.0-2.6)	(8.4-10.3)	(8.2-10.4)	(10.3-12.1)
Material	Polyamide (interlaced PA)		Polyethylene (twisted PE)		Rigid plastic (square mesh)			Polyethylene (twisted PE)		-		

* - Approximate distance (spacing) between consecutive gangions (and “wallets”) on the main lines.

line with many gangions, to which small square bags made of rigid plastic mesh are attached. The main characteristics and technical specifications (dimensions and materials) of the five “wallet-lines” that were apprehended by the fishery authorities are compiled in Table 1 and a technical drawing showing the most relevant characteristics of the fishing gear is presented in Figure 2.

The inspection and measurement of the “wallet-lines” revealed that some fishing gears were slightly variable in terms of materials and dimensions (Table 1). With the exception of a “wallet-line” partially built with natural materials (gangions of sisal), the remaining fishing gears were constructed with synthetic materials (main lines of interlaced polyamide and gangions of twisted polyethylene). The gangions measured an average of 63.8±19.4 cm in length. In the main line, the gangions were separated between each other by approximately 1.8 m (around one roughly measured fathom) to avoid entanglements among adjacent “wallets”. Each “wallet-line” comprised an average of 85±14 “wallets” and this variability in the number of “wallets” per fishing gear (range: 76-109) is mainly due to the loss of some gangions or “wallets” during the fishing operations (detected through the atypical and excessive spacing on the main line between consecutive gangions). The measurement of half of the “wallets” in each fishing gear (in a total of 215 “wallets”) showed that these roughly square bags measured an average of 13.5±1.1 cm in length and 11.8±0.7 cm in width (with a square mesh size of around 1 cm in diagonal) (Table 1). The “wallet-line” is set on the bottom of relatively shallow (2-3 m depth) channels of the lagoon, with a weight (usually a stone of around 1 kg) and a floating device (generally a small buoy made of cork or plastic) at each end of the fishing gear.

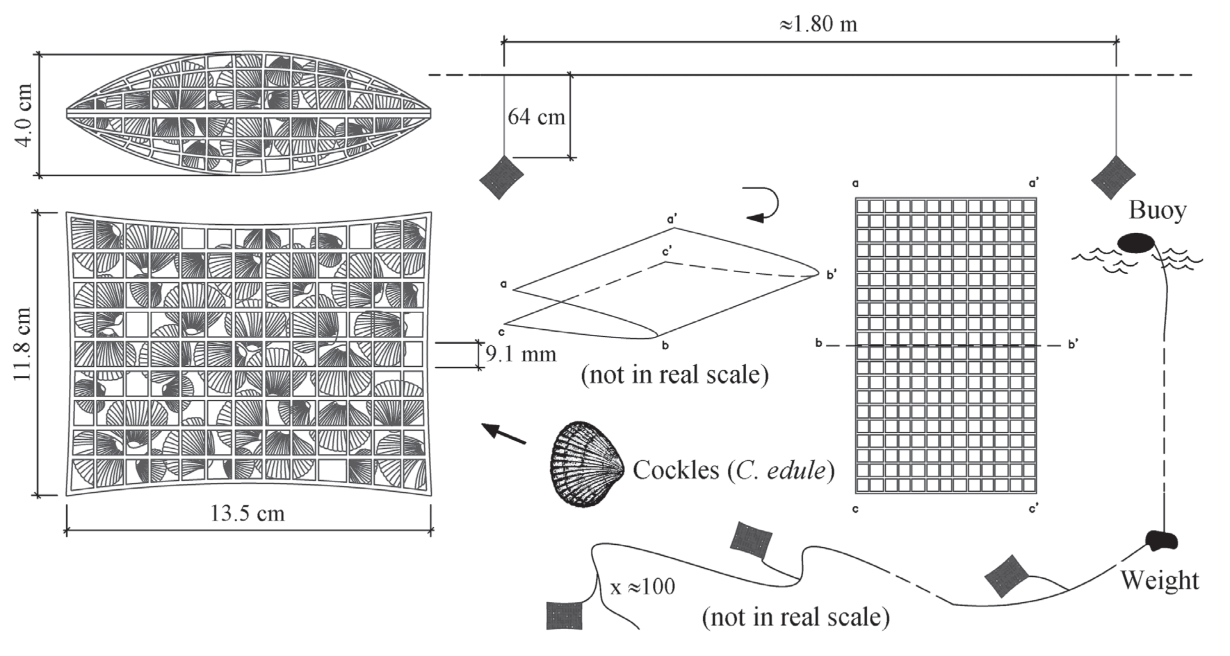

FIG. 2. – Technical drawing with the most relevant characteristics of a standard “wallet-line” used in the fishery for muricid gastropods [design modified from Carneiro *et al.* (2006) with the measurements made in the present study)].

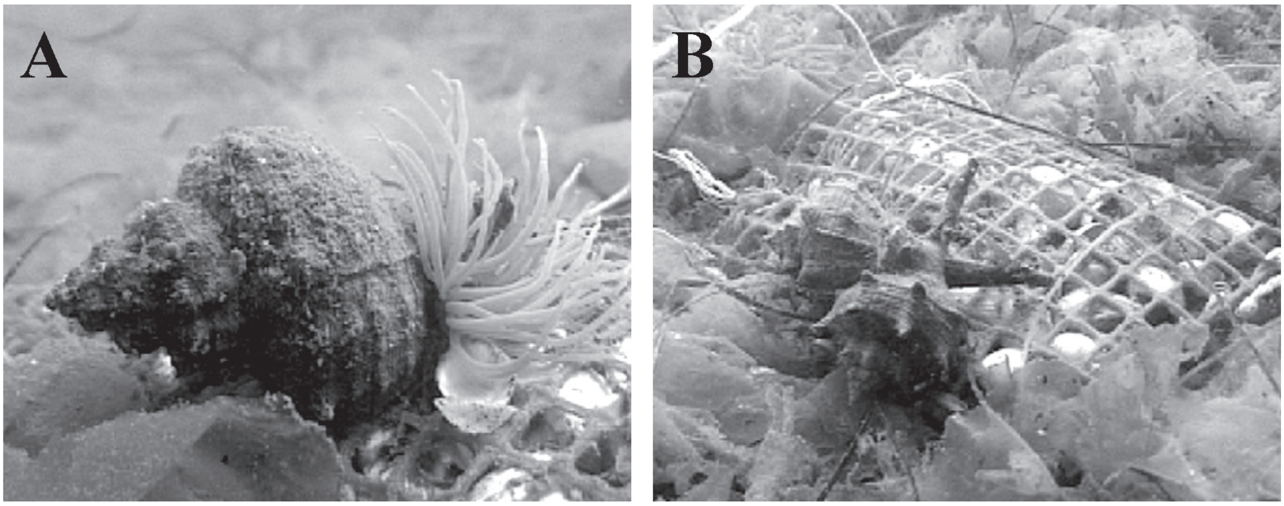

FIG. 3. – Under-water photographs of the target species attached to the external surfaces of the "wallets" baited with cockles: A) *Hexaplex trunculus*; B) *Bolinus brandaris*.

At the beginning of each fishing survey, these "wallets" are filled with live cockles (*C. edule*), generally commercially under-sized individuals caught by the fishermen. The "wallet-lines" are normally set early in the morning and hauled the next morning. On the three consecutive fishing days, the average soaking time of the gear was 23:35±01:10 hours (ranging from 20:24 to 26:36 hours of daily immersion of the fishing gear, data used for the calculation of standardised CPUE). Several predator and scavenger species, including the target species of this fishery, the banded murex (*H. trunculus*) and the purple dye murex (*B. brandaris*), are attracted to the bait and become attached to the external surfaces of the "wallets" while handling, attacking or ingesting the bait (Fig. 3). Subsequently, fishermen periodically haul the gears, retrieve the target species, discard the by-catch species and simultaneously redeploy the "wallet-lines" on the fishing ground.

The main feature of this kind of fishing operation is the rapid handling of the artisanal fishing gear (the time needed for setting the gear, retrieving the catches, hauling the gear and retrieving the catches of a "wallet-line" with 100 "wallets"). Actually, fishermen took an average of 3±1 minutes to set the gear (day 0) and 6±2 minutes for both retrieving the catches (days 1 and 2) and retrieving the catches and hauling the "wallet-line" (day 3). Nevertheless, a high variability was observed in the duration of these fishing operations (between 2 and 20 minutes), because the handling depends on the amount of target-species caught and by-catch species discarded. Furthermore, under adverse weather conditions (particularly strong winds that make it difficult to manoeuvre the boat), fishermen took as much as 20 minutes both for setting and hauling the "wallet-line".

The relationship between bait mortality (the percentage of dead cockles at the end of the third fishing day) and surface seawater temperature during the experimental fishing surveys with the "wallet-lines" is illustrated in Figure 4. With few exceptions, bait mortality was lower in autumn and winter (namely between October 2005 and March 2006), and increased markedly in spring and summer (reaching

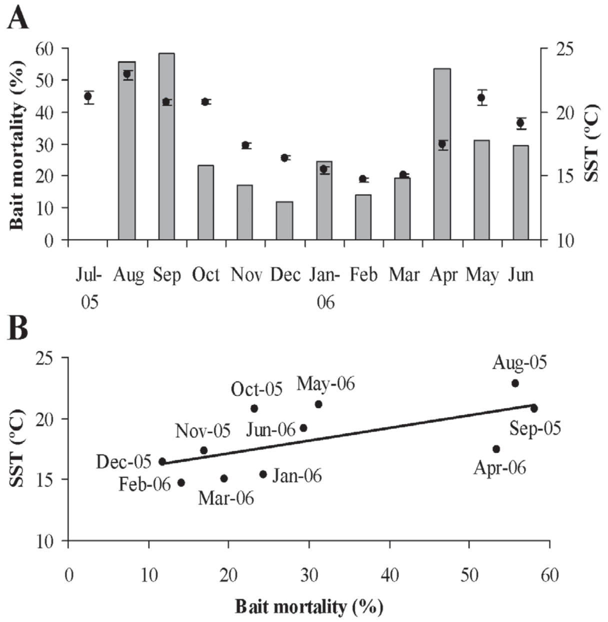

FIG. 4. – Relationship between bait mortality (percentage of dead cockles in the "wallet-line" at the end of three fishing days) and the surface seawater temperature (SST) during the experimental fishing surveys: A) Monthly variation during the study period; B) Linear regression established between bait mortality and surface seawater temperature.

Table 2. – Taxonomic identification and number of individuals of by-catch species caught in the experimental fishing surveys using the "wallet-line".

Taxa	No.	Taxa	No.
Phylum Cnidaria		Class Polyplacophora	
Class Anthozoa		Family Ischnochitonidae	
Anthozoa n.d.	10	*Acanthochitona* sp.	4
Phylum Mollusca		*Chaetopleura angulata* (Spengler, 1797)	7
Class Gastropoda		Phylum Sipuncula	
Family Cerithiidae		Class Sipunculidae	
Bittium reticulatum (Linnaeus, 1778)	322	Sipunculida n.d.	1
Cerithium vulgatum Bruguière, 1792	7	Phylum Arthropoda	
Family Columbellidae		Class Thecostraca	
Columbella rustica (Linnaeus, 1758)	4	Superorder Eucarida	
Family Hydrobiidae		Order Decapoda	
Hydrobia ulvae Pennant, 1777	8	Family Diogenidae	
Family Muricidae		*Clibanarius erythropus* (Latreille, 1818)	3
Nassarius (Telasco) cuvieri (Payraudeau, 1826)	249	*Diogenes pugilator* (Roux, 1829)	9
Nassarius (Gussonea) pfeifferi (Philippi, 1844)	1	Family Paguridae	
Nassarius (Gussonea) corniculus (Olivi, 1792)	2	*Pagurus* sp.	2
Nassarius (Hima) incrassatus (Stroem,1768)	88	Family Leucosiidae	
Nassarius (Hinia) reticulatus (Linnaeus, 1758)	391	*Ebalia edwardsii* (Costa, 1838)	1
Nassarius spp.	60	Family Pilumnidae	
Ocenebra erinaceus (Linnaeus, 1758)	3	*Pilumnus hirtellus* (Linnaeus, 1761)	1
Ocinebrina aciculata (Lamarck, 1822)	32	Family Porcellanidae	
Cyclope (Cyclope) neritea (Linnaeus, 1758)	17	*Pisidia longicornis* (Linnaeus, 1767)	1
Family Naticidae		Family Portunidae	
Naticidae n.d.	63	*Carcinus maenas* (Linnaeus, 1758)	3
Family Rissoidae		*Liocarcinus arcuatus* (Leach, 1814)	6
Rissoidae n.d.	48	Family Xanthidae	
Family Trochidae		*Xantho incisus* (Leach, 1814)	1
Gibbula spp.	6	Superclass Pycnogonida	
Gibbula pennanti (Philippi, 1846)	8	Pycnogonida n.d.	1
Gibbula umbilicalis (da Costa, 1778)	9	Phylum Echinodermata	
Gibbula umbilicaris (Linnaeus, 1758)	268	Order Asteroidea	
Jujubinus striatus (Linnaeus, 1758)	183	Family Asteriidae	
Family Turritellidae		*Coscinasterias tenuispina* (Lamarck, 1816)	23
Mesalia brevialis (Lamarck, 1822)	3	Family Asterinidae	
Subclass Opistobranchia		*Asterina gibbosa* (Pennant, 1777)	120
Order Nudibranchia		Order Echinoidea	
Nudibranchia n.d.	10	Family Echinidae	
		Paracentrotus lividus (Lamarck, 1816)	3
	Total	1978	

the highest values in August and September 2005) (Fig. 4A). A significant correlation between seawater temperature and bait mortality was detected, with increasing temperature leading to higher cockle mortality inside the "wallets", as confirmed by the linear regression established between these parameters ($r = 0.639$; $p = 0.034$) (Fig. 4B).

Catches of target and by-catch species

In the whole experimental fishing surveys carried out with the "wallet-lines" 1620 specimens of banded murex and 3306 specimens of purple dye murex were caught, corresponding to total catches of 19.74 kg and 31.24 kg, respectively. Both target species presented broad size (*H. trunculus*: 9.10-77.14 mm SL; *B. brandaris*: 15.73-88.96 mm SL) and weight ranges (*H. trunculus*: 0.06-40.41 g TW; *B. brandaris*: 0.17-36.09 g TW). The average size and weight were 49.94±10.15 mm SL and 12.19±6.67 g TW for *H. trunculus*, and 53.82±11.47 mm SL and 9.45±6.10 g TW for *B. brandaris*.

The taxonomic identification and abundance of the by-catch species caught by the "wallet-lines" are compiled in Table 2. Overall, 1978 by-catch specimens belonging to 39 taxa were caught, with gastropods being clearly dominant (89.6% of the by-catch), particularly due to *Nassarius (Hinia) reticulatus* (n = 391), *Bittium reticulatum* (n = 322), *Gibbula umbilicaris* (n = 268), *Nassarius (Telasco) cuvieri* (n = 249) and *Jujubinus striatus* (n = 183). Several specimens from other taxonomic groups (Phyla Cnidaria, Sipuncula, Arthropoda and Echinodermata) were also caught, with echinoderms being the most abundant group (7.4% of the by-catch), mainly due to the sea stars *Asterina gibbosa*

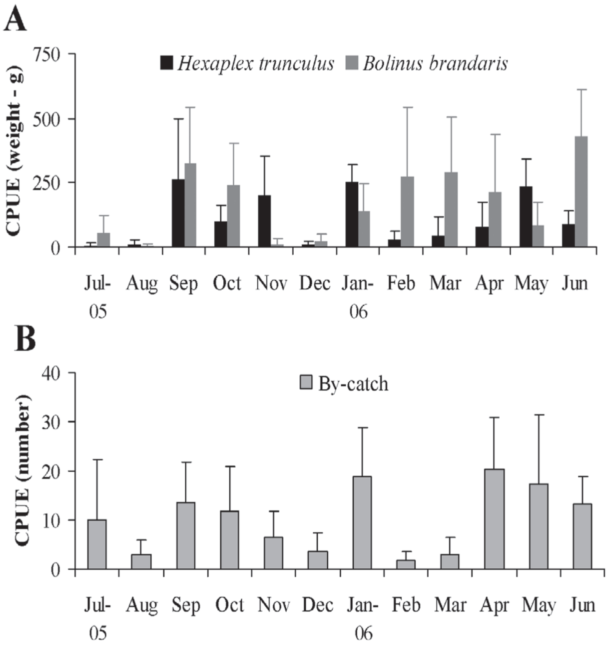

FIG. 5. – Monthly variation of the catch per unit effort (CPUE - weight or number/100 "wallets"/24 hours) with the "wallet-lines": A) Target species - *Hexaplex trunculus* and *Bolinus brandaris*; B) By-catch species.

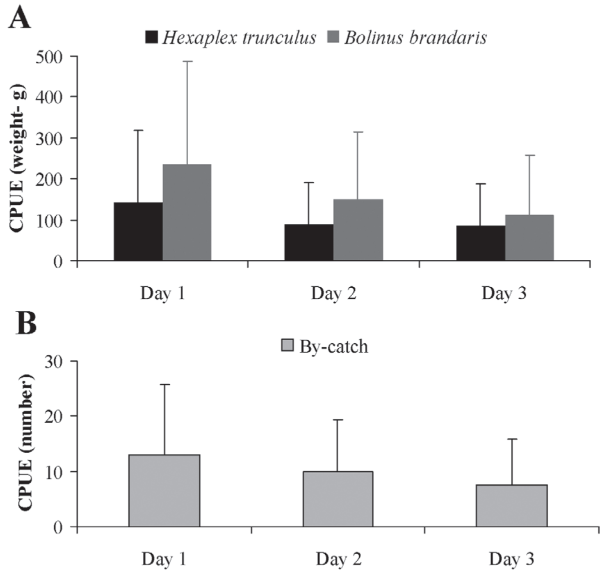

FIG. 6. – Variation of the average catches per unit effort (CPUE - weight or number/100 "wallets"/24 hours) during three consecutive fishing days with the "wallet-lines": A) Target species - *Hexaplex trunculus* and *Bolinus brandaris*; B) By-catch species.

(n = 120) and *Coscinasterias tenuispina* (n = 23) (Table 2).

The comparison between the overall number of target specimens (*H. trunculus* and *B. brandaris*) and by-catch specimens caught by the "wallet-lines" during the experimental fishing surveys revealed that the target species corresponded to 71.3% of the total catches in number, unequally distributed between *H. trunculus* (23.4%) and *B. brandaris* (47.9%), with by-catch species accounting for only 28.7% of the total catches in number.

The monthly variation of the target species CPUE (total weight/100 "wallets"/24 hours) and by-catch species CPUE (total number/100 "wallets"/24 hours) during the experimental fishing surveys is presented in Figure 5. The highest CPUEs in weight of *H. trunculus* occurred in September and November 2005 and January and May 2006, whereas the highest CPUEs in weight of *B. brandaris* occurred in September and October 2005, between February and April 2006, and in June 2006. The average CPUE of *H. trunculus* was 105.70±134.85 g (maximum of 821.10 g) and that of *B. brandaris* was 166.71±200.18 (maximum of 836.44 g). Except in November 2005 and January and May 2006, the CPUEs in weight of *B. brandaris* were larger than those for *H. trunculus* (Fig. 5A). The most significant CPUEs in number of by-catch specimens were observed in January, April and May 2006. Overall, the average CPUEs of both target and by-catch species were highly variable during the study period (even between consecutive monthly fishing surveys), without a discernible seasonal pattern (Fig. 5B).

The variation in the average CPUE of target species (total weight/100 "wallets"/24 hours) and by-catch species (total number/100 "wallets"/24 hours) during three consecutive fishing days is illustrated in Figure 6. Independently of the fishing day, the CPUE in weight of *H. trunculus* was invariably lower than that of *B. brandaris*. Between consecutive fishing days, a marked decreasing trend was observed in the CPUE of *H. trunculus* and *B. brandaris* (CPUE in weight) (Fig. 6A), as well as in that of the by-catch species (CPUE in number) (Fig. 6B).

The size-frequency distribution of the catches of the target species (*H. trunculus* and *B. brandaris*) and the proportion of individuals below and above the MLS stipulated for these species (*H. trunculus* = 50 mm SL and *B. brandaris* = 65 mm SL) is illustrated in Figure 7. During the overall fishing surveys, the "wallet-lines" caught specimens of both target species with a broad size range and with significant proportions of under-sized individuals relatively to the MLS, namely 47.2% of *H. trunculus* smaller than 50 mm SL (Fig. 7A) and 81.9% of *B. brandaris* smaller than 65 mm SL (Fig. 7B).

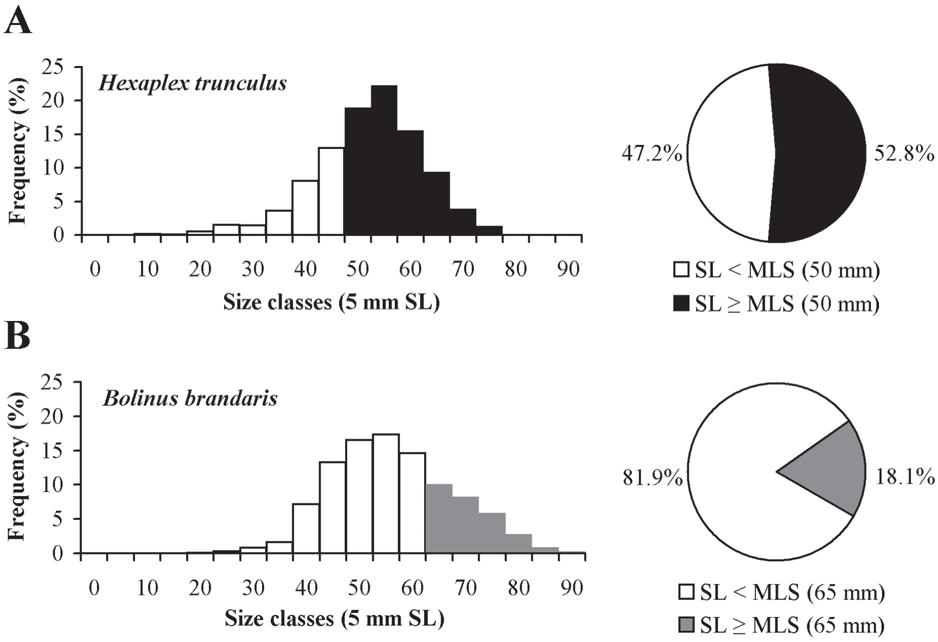

FIG. 7. – Size-frequency distribution of the catches of target species and respective proportion of individuals below and above the minimum landing size (MLS): A) *Hexaplex trunculus*; B) *Bolinus brandaris*.

DISCUSSION

Fishing gear and fishing operations

"Wallet-lines" are typical artisanal fishing gears characterised by a high variability in their dimensions, in the size of specific components (main lines, gangions and "wallets"), and in the materials used in their construction. In fact, "wallet-lines" are sometimes constructed with remains of other fishing gear, such as cables for assembling main lines and gangions, and rigid plastic mesh for constructing "wallets". Each "wallet-line" is originally constructed to accommodate approximately 100 "wallets", which is considered a reasonable number to facilitate handling on board and to minimise the economic losses when a fishing gear is destroyed, apprehended or stolen (requiring repair or manufacture of new fishing gears).

Local fishermen generally use three or four "wallet-lines" simultaneously (Carneiro *et al.*, 2006), but some professional fishermen can operate up to ten fishing gears (Marques and Oliveira, 1995) in an almost permanent fishery (except during the period necessary for baiting the "wallets" with cockles). This illegal fishing activity is usually a complement to various legal fisheries (e.g. nets, long-lines, traps, etc.), and therefore the rapid handling of the "wallet-lines" is highly advantageous, making it possible to set the gear, retrieve the catches and/or haul the gear in the intervals available between other fishing activities.

Professional fishermen generally operate the "wallet-lines" during three consecutive days (with a soaking time of approximately 24 hours), exceptionally reaching five consecutive fishing days when the bait survival and attraction allows for an extraordinarily high and stable fishing yield. The "wallets" are usually baited with commercially under-sized cockles (*C. edule*) caught by the fishermen themselves, because they are easier to introduce and accommodate inside the "wallets", and have a low commercial value (Marques and Oliveira, 1995). In the present study, the fishing surveys with highest bait mortality generally occurred in spring and summer, coinciding with periods of warmer seawater temperature. The few exceptions to this general trend could be eventually related to longer aerial exposure of the cockles (in the period between harvesting the bivalves, baiting the "wallets" and setting the fishing gear), excessive crowding of the bait inside the "wallets", and/or lower condition of the cockles, which altogether might have reduced their resistance to higher seawater temperatures.

Catches of target and by-catch species

The disproportion in the catches of the two target species in the whole experimental fishing surveys (less than half the number of *H. trunculus* compared to *B. brandaris*) was rather unexpected and might possibly reflect the intense fishing effort directed towards the banded murex, which has been gradually driven to lower abundances and catches of this species (Marques and Oliveira, 1995). The information gathered during enquiries made to professional fishermen involved in this activity drew attention to the potential occurrence of high inter-annual variability in the local abundance of banded murex and purple dye murex. However, since no reliable official statistics are available on the catches of the two species, it is virtually impossible to ascertain whether during the study period abnormally low catches of *H. trunculus* (or unusually high catches of *B. brandaris*) occurred in the Ria Formosa.

Although the target species represented the vast majority of total catches (71.3% of the catches in number: 23.4% of *H. trunculus* and 47.9% of *B. brandaris*), by-catch species accounted for 28.7% of total catches in number. Just for comparison, in hauls made with dredging gear ("rastell") specifically designed to target purple dye murex off the Catalan coast (Spain), *B. brandaris* constituted 21% of the total catch and 73% of the commercial catch (Martín *et al.*, 1995). In the present fishing surveys, among the high variety of organisms caught (39 taxa), the by-catch was largely dominated by gastropods, followed by echinoderms, revealing that the "wallet-line" is not a species-specific fishing gear, since besides *H. trunculus* and *B. brandaris*, the bait has a broad spectrum of attraction to many other predator and scavenger species. Fortunately, in the commercial fishery the vast majority of by-catch species are discarded on-board (alive and frequently undamaged) during the retrieving of the catches and hauling of the fishing-gear, so the mortality of these discards is presumably negligible. The only exception occurs with very small specimens that penetrate the "wallet" mesh (mainly gastropods), whenever after hauling of the gear on the last fishing day the remaining bait in the "wallets" is not removed on board and discarded into the lagoon. Nevertheless, compared with the amount of by-catch specimens discarded on board, the proportion of by-catch specimens enclosed inside the "wallets" at the end of the fishing operations is insignificant (<1% of the overall by-catch, as detected in the "wallets" examined to estimate bait mortality).

During the whole fishing surveys with the "wallet-lines", the average CPUE of both target species and by-catch species showed a high monthly variation, without any evident seasonal pattern and apparently lacking any discernible relationship with the seawater temperature or particular features of the biological cycle of the species (e.g. reproduction and spawning). Firstly, the normal activity and behaviour of banded murex are apparently affected by the seawater temperature, since field and laboratory studies indicate that *H. trunculus* burrows shallowly into soft sediments, trying to avoid both unfavourable low water temperatures (hibernation) and high water temperatures (aestivation) (Spanier, 1981, 1986), and often being observed partially buried in the sand (Spanier, 1986; Rilov *et al.*, 2004). However, in the present fishing surveys, although some of the lowest CPUEs of *H. trunculus* occurred in both winter (e.g. December 2005 and February 2006) and summer (e.g. July and August 2005), it was impossible to identify a clear trend of decreasing catches during the coldest and warmest seasons. Similarly, the lowest CPUEs of *B. brandaris* obtained in the present fishing surveys were recorded in July, August, November and December 2005, but also without any evident relationship between the catches and seawater temperature. By contrast, in the fishery off the Catalan coast (Spain), *B. brandaris* catches showed a pronounced seasonality, being lowest in summer (June-July) and highest in late autumn and winter, which was attributed to changes in the species abundance throughout the year (Martín *et al.*, 1995).

Additionally, under both natural and laboratory conditions, the banded murex reduces its normal activity during the reproductive season and *H. trunculus* females interrupt feeding during the spawning period (Dulzetto, 1946, 1950; Vasconcelos *et al.*, 2004), therefore minimising their attraction to baited fishing gears (such as the "wallet-line") and contributing to the occurrence of male-biased sex-ratios in the catches (Vasconcelos *et al.*, 2008). However, during the present fishing surveys, unpredictably no evident trend of decreasing catches during spawning of both target species was detected. Actually, in the Ria Formosa *H. trunculus* has a spawning peak between May and June, in agreement with the spawning season reported for Mediterranean populations of this species, which generally occurs in late spring-early summer (more frequently between May and July) (Vasconcelos *et al.*, 2008). Moreover, field observations detected the simultaneous deposition of collective spawns of *H. trunculus* and *B. brandaris*, sometimes with females of both species depositing egg capsules in the same spawn (P. Vasconcelos, personal observation). At several locations in the Mediterranean Sea, *B. brandaris* has a lengthy spawning season (Martín *et al.*, 1995), with the main spawning periods occurring mainly in spring (Bartolome, 1985) and summer, namely in May-June (Anon., 2001; Ramón and Flos, 2001), May-July (Barash and Zenziper, 1980; Tirado *et al.*, 2002), June-July (Ramón and Amor, 2002) or August (Martín *et al.,* 1995).

It is worth emphasising that the variability in the catches of both target species might be hypothetically due to an apparent patchy distribution in the lagoon (evidenced by the frequent occurrence of very dissimilar fishing yields between adjacent "wallet-lines"). Similarly, in the purple dye murex fishery off the Catalan coast (Spain), the lack of significant correlations between the duration of the hauls and the hourly fishing yields suggested that the distribution of *B. brandaris* is not homogeneous (Martín *et al.*, 1995). Furthermore, both field and laboratory observations detected the frequent occurrence of group foraging in *H. trunculus* (Peharda and Morton, 2006).

An evident decreasing tendency was detected in the CPUE of both target species and by-catch species during the three consecutive fishing days. Since *H. trunculus* and *B. brandaris* are relatively slow-moving gastropods, decreasing CPUE might indicate a temporary local depletion of these species in the vicinities of the fishing gear, worsened by the declining bait attraction due to the progressive cockle deterioration and mortality during the three fishing days. Furthermore, the decreasing fishing yield of both target species in the fishing surveys explains why local professional fishermen generally operate the "wallet-lines" for three consecutive fishing days (only exceptionally reaching a maximum of five consecutive fishing days in winter, because of the lower seawater temperature) and then they haul the fishing gears, remove the previous bait and refill the "wallets" with recently caught cockles for further fishing operations.

The size-frequency distribution of the catches of both target species revealed that the "wallet-lines" caught significant proportions of commercially under-sized individuals relative to the MLS (*H. trunculus*: 47.2% <50 mm SL and *B. brandaris*: 81.9% <65 mm SL). This information reveals that the "wallet-line" is not a size-selective fishing-gear and therefore the size composition of the catches depends exclusively on the attainment of the MLS by the fishermen (through sorting the catches and discarding the target species below the MLS). Fortunately, during the fishing operations, professional fishermen generally sort the catches by size on board and roughly discard the majority of commercially under-sized target species, which are immediately returned to the lagoon. Nevertheless, usually the MLS is not strictly adhered to (particularly in the case of *B. brandaris*, the species with the highest MLS) and sometimes fishermen also retain some smaller individuals of both target species for their own consumption. Just for comparison, in almost 2500 *H. trunculus* specimens bought at the local seafood market for routine biological sampling, 37.8% were below 50 mm SL, but less than 5% were smaller than 40 mm SL and less than 0.5% were smaller than 30 mm SL (P. Vasconcelos, unpublished data). In the whole catches of *B. brandaris* with the "wallet-lines", specimen size ranged between 15.73 and 88.96 mm SL and the size-frequency distribution revealed that 39.8% of the individuals were smaller than 50 mm SL and 10.0% were smaller than 40 mm SL. Similarly, in the total catches of the fishery for the purple dye murex off the Catalan coast (Spain), specimen size was between 16 and 90 mm SL, with 38.7% of the individuals ranging between 46 and 54 mm SL. In the culled catch (the marketed fraction of the whole catch) specimen size ranged between 28 and 90 mm SL, 60.3% of the individuals were in the interval 46-54 mm SL and small-sized *B. brandaris* (<42 mm SL) were practically absent (Martín *et al.*, 1995). Accordingly, commercial sizes of *B. brandaris* from the Catalan coast (Spain) ranging from 50 to 90 mm SL were reported by Ramón and Flos (2001).

Fishery management measures

The baseline information gathered in this study (complemented by relevant aspects on the target species biology, namely growth and reproductive cycle), allows several management measures to be proposed to the fisheries administration for implementation in this traditional fishing activity, which could support legalisation in the near future.

Fishing activity with the "wallet-lines" targeting muricid gastropods is a complementary fishery, since fishermen hold other fishing licenses and generally only use this illegal fishing gear during particular periods of the year as an alternative and secondary source of income. Therefore, the fishing licenses for operating the "wallet-lines" (provisional and renewable every year) should only be given to boats already licensed to operate other fishing gears in the Ria Formosa and preferentially to fishermen who can attest to previous sales of banded murex or purple dye murex in the past. Their annual renewal should be conditional on meeting a minimum number of yearly sales or minimum amounts sold per year of *H. trunculus* and/or *B. brandaris* by wholesale auction. Fishermen should report relevant data (e.g. areas, effort, lost fishing gears, catches, value, etc.) for at least five years using confidential log-books created for this purpose, allowing for the development of a data base on this gastropod fishery. It should also be stipulated that failure to regularly deliver log-book information or reporting incorrect data would involve the loss of the fishing license.

Because this fishery is carried out inside the lagoon, and frequently in inner and sheltered channels, it is not greatly affected by adverse weather conditions, therefore allowing for many fishing days per year. Therefore, to control fishing effort and to prevent over-development of the fishery before sufficient knowledge is gathered to permit effective conservation, the number of fishing licenses should be restricted, and the fishing gears per boat should be limited to a maximum of 10 "wallet-lines" (the highest number operated by some fishermen), each one limited to a maximum of 100 "wallets". This limitation in the number of "wallets" per fishing gear could be also beneficial for reducing the environmental impact due to lost fishing gears. Actually, mostly due to conflicts between fishing gears (some of them also illegal, such as the beam trawl) for the exploitation of the same fishing grounds, destruction and partial or total loss of "wallet-lines" is relatively common. Nevertheless, as they are a static/passive, closed and baited fishing gear, ghost fishing does not occur in lost "wallet-lines", so they do not represent a major ecological concern.

Since the "wallet-line" is not size-selective, the degree of compliance with the MLS by fishermen should be assessed by regularly monitoring the landings and analysing the length-frequency distribution of both target species. In addition, since the "wallet-line" is not species-specific, by-catch species should be discarded immediately on-board and the bait should be removed from the "wallets" in the fishing areas (releasing the surviving cockles and minimising the mortality of by-catch specimens that might have penetrated the "wallet" mesh).

In the present fishing surveys, the fishing yield of both target species was extremely variable and the average CPUE (standardised for 100 "wallets"/24 hours) was roughly 100 g of *H. trunculus* and slightly higher than 150 g of *B. brandaris*. These yields imply that operating with 1000 "wallets" corresponds to an average daily catch of around 1 kg of banded murex and approximately 1.5 kg of purple dye murex. However, these numbers refer to total catches, i.e. including target species below the MLS (*H. trunculus*: 47.2% <MLS; *B. brandaris*: 81.9% <MLS). By discarding the commercially under-sized specimens, the culled catches in number (commercial fraction of the catches) are reduced to 52.8% individuals of banded murex and 18.1% individuals of purple dye murex, implying a consequent reduction in weight to 73.6% and 37.7% of the original, unsorted total catches of *H. trunculus* and *B. brandaris*, respectively. Considering the prices of these species in the local seafood market, these catches correspond to an income of around 20 Euros per fishing day, which is an acceptable earning for a complementary fishing activity that can be undertaken almost year-round.

Finally, due to the apparently patchy distribution of *H. trunculus* and *B. brandaris*, further studies should be conducted to identify preferential distribution areas and to ascertain the influence of depth, type of bottom and seagrass coverage (*Zostera* spp.) in the distribution of these species in the lagoon. To sustain local gastropod populations, exploitation in these areas should be restricted, through the establishment of permanent closed areas or conservation zones (which also help to control fishing effort). Additionally, limiting the fishing season through the implementation of seasonal closures coincident with the reproductive and spawning periods of the target species (Vasconcelos *et al.*, 2008) may prove highly beneficial for successful recruitment.

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