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Sustainability of bait fishing harvesting in estuarine ecosystems – Case study in the Local Natural Reserve of Douro Estuary, Portugal *

Sustentabilidade da apanha de isco para pesca nos ecossistemas estuarinos – Caso de estudo na Reserva Natural Local do Estuário do Douro, Portugal

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ABSTRACT

A narrow relationship between marine resources and local populations always existed in fishing communities of coastal areas. In the Portuguese estuaries bait fishing is a common practice in which gatherers collect intertidal species such as seaworms, shrimps, crabs or clams. In recent Local Natural Reserve of Douro Estuary (RNLED) this activity is fairly entrenched due to the proximity of a great fishing zone, the Afurada, and the abundance of recreational fishermen operating in the area. This study aimed to quantify the impact of bait fishing gathering on the ecology of this estuary benthic community, in order to propose management measures for this activity, ensuring its sustainability, and to verify the influence this activity may have on the conservation of intertidal resources in a protected area. Between June 2010 and May 2011 monthly samples were collected in the intertidal zone, in order to quantify the density of populations of *Hediste diversicolor* and *Scrobicularia plana* at two locations in the estuary. During the same time period, weekly interviews were performed to bait fishing gatherers operating in RNLED area. In this area of Douro estuary, *H. diversicolor* (239.7ind/m^2) was the most abundant species compared to the clam *S. plana* (0.3ind/m^2). In the area of RNLED the species most collected by bait fishing gatherers was the polychaete *H. diversicolor*, and it is estimated that each year 9.9tons are captured, representing an annual mean catch per bait fishing gatherer of 0.3tons. However, the total annual biomass collected was substantially less than the productivity estimated for the entire intertidal area of RNLED (78.7 to 141.3tons). The number of bait fishing gatherers varied between 0 on December 2010 and 12 in July 2010, showing a decrease in activity in the RNLED, especially during the times when surveillance occurs. The area prospected by each gatherer was estimated to be 10m^2/day. Considering both tides and all the effort done by an average of 8 men/day, the prospected area was 80m^2/day, corresponding to 0.3% of the intertidal area. This effort was mainly concentrated in about 1/3 of the available intertidal area. Results indicated the sustainable management of bait fishing activity in the referred protected area is possible. However, other aspects must be taken into account, such as the possible conflict of this activity with biodiversity conservation in the reserve. Therefore, we suggest some possible solutions for the sustainability of this activity, along with less disturbance to birds that may feed in the reserve, such as: delimitation of a marginal area within the reserve, smaller than the current one, where the collection of organisms is allowed, as well as the oversight and control of licenses and educational procedures. Moreover, these measures would have a positive impact in the integrated management of the reserve, while enabling an activity with positive economic consequences in an underprivileged population. Also, they will contribute to lower the impact of human presence on the avifauna and on the structure of the sediments.

Keywords: Douro Estuary, Protected Area Sustainable, Estuary Management, *Hediste diversicolor*, Bait Fishing Harvesting

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RESUMO

Nas comunidades piscatórias das zonas costeiras sempre existiu uma estreita ligação entre os recursos marinhos e as populações locais. Nos estuários portugueses é comum a presença de mariscadores na apanha de algumas espécies intertidais como as minhocas, os camarões, os caranguejos ou as ameijoas. Na recente criada Reserva Natural Local do Estuário do Douro (RNLED) esta actividade está bastante enraizada pela proximidade de uma forte zona piscatória, a Afurada, e pela abundância de pescadores lúdicos que actuam na zona. Os objectivos deste estudo são quantificar o impacto que esta actividade tem na ecologia desta comunidade bentónica estuarina, propor medidas de gestão para assegurar a sua sustentabilidade, e verificar a influência que esta actividade poderá ter na conservação dos recursos intertidais numa área protegida. Entre Junho de 2010 e Maio de 2011 foram efectuadas amostragens mensais na zona intertidal para quantificação da densidade das populações de Hediste diversicolor e Scrobicularia plana em dois locais do estuário. Durante o mesmo período de tempo foram realizados inquéritos semanais aos apanhadores que efectuavam esta actividade na área da RNLED. Nesta zona do estuário do Douro, a espécie H. diversicolor é mais abundante (239.7ind/m^2) em relação à ameijoa S. plana (0.3ind/m^2). Na área da RNLED a espécie apanhada em maior abundância pelos mariscadores é o poliqueta H. diversicolor e estima-se que por ano sejam capturadas 9.9 toneladas, o que representa uma média anual de captura por mariscador de 0.3 toneladas. No entanto a biomassa anual total colectada é bastante inferior à produtividade anual estimada para a totalidade da área intertidal da RNLED (78.7 a 141.3 toneladas). O número de mariscadores por dia variou entre 0 em Dezembro 2010 e 12 em Julho 2010, tendo-se verificando uma diminuição da actividade dentro da RNLED, especialmente nas horas em que existe vigilância. A área revolvida por cada apanhador estima-se em 10m^2/dia. Considerando as duas marés por dia e todo o esforço feito por uma média de oito apanhadores/dia, a área prospectada foi de 80m^2/dia, correspondendo a 0,3% da área intertidal. Este esforço foi concentrado principalmente em aproximadamente 1/3 da área disponível intertidal. Os resultados indicam que é possível a gestão sustentável da apanha da minhoca na área protegida. No entanto, outros aspectos devem ser tidos em conta para que esta actividade não provoque conflitos com os objectivos de conservação da biodiversidade na reserva. Assim, sugerimos algumas possíveis soluções para a sustentabilidade da actividade, juntamente com menor perturbação para as aves que se alimentam na reserva tais como: delimitação de uma área marginal dentro da reserva, menor que a actual, onde a apanhar é permitida, bem como a fiscalização no controle das licenças e acções de educação ambiental. Por outro lado estas medidas teriam um impacto positivo na gestão integrada da reserva, permitindo simultaneamente uma actividade com reflexos económicos positivos numa população desfavorecida. Também vão contribuir para diminuir o impacte da presença humana na avifauna e sobre a estrutura dos sedimentos.

Palavras-chave: *Estuário do Douro, Área Protegida Sustentável, Gestão de Estuários, Hediste diversicolor, Colheita de Isco da Pesca*

1. INTRODUCTION

The collection of bait for recreational or professional fishing purposes is a widespread activity and has achieved commercial importance in many parts of the world (Olive, 1993; Cunha *et al*., 2005; Costa *et al*., 2006). Polychaetes are harvested from intertidal mud or sand flats for their value as saltwater fishing bait (Cunha *et al*., 2005; Sypitkowski *et al*., 2010). Several families of polychaetes are exploited, due to their high abundance and to being an efficient fishing bait, most notably: Arenicolidae, Glyceridae, Nereididae, Nephtyidae and Eunicidae (Fonseca & Costa, 2008). Bait gathering, along with clam digging, can degrade ecosystems' health and reduce biodiversity in estuaries around the world (Milius, 1999; Logan, 2005; Rossi *et al*., 2007). Several studies reported bait gathering activities in Portugal, where both worm and clam harvesting is performed from north to south of the country's coast, contributing to local economies. *Diopatra neapolitana* is the target worm species in Ria Formosa, Sado estuary and Ria de Aveiro (Cunha *et al*., 2005; Pires *et al*., 2012). The clam *Scrobicularia plana* is the target species on Tagus estuary, although the worm *Hediste diversicolor* is also often collected (Moreira, 1999; Dias *et al*., 2008).

Estuaries are important ecosystems for fish and birds. They provide nursery grounds for several commercial fish and crustacean species (McLusky, 1999; Meire *et al*., 2005; Cabral *et al*., 2007) and also resting and feeding areas for birds, especially for waders and shorebirds (Ambrose, 1986; Moreira, 1999). Benthic macroinvertebrates are the key prey in estuarine food webs supporting a wide range of predators, such as crabs, shrimps, fishes and birds (McLusky, 1999; Little, 2000; Rosa *et al*., 2008). Harvesting activity of these benthic invertebrates may affect the prey availability of target and non-target species, causing direct and indirect impacts on predators (Milius, 1999; Shepherd & Boates, 1999). Birds and fish, along with other organisms that frequent these habitats, are forced to compete not only with bait harvesters but also with other shellfish (Fonseca & Costa, 2008). The disturbance and harvesting of these organisms result in decreased densities and shifts in the population size structure of the target species, resulting in changes in community composition (Logan, 2005; Smith & Murray, 2005; Sypitkowski *et al*., 2010). Several studies report a density decrease in communities of mud shrimp *Corophium volutator,* due to the disturbance caused by commercial bait digging in intertidal mudflats, reducing the availability of this invertebrate for its main predator, semipalmated sandpipers (Milius, 1999; Shepherd & Boates, 1999). When mud is turned over by hand rake and trampling, habitat destruction and direct mortality occurs (Logan, 2005; Sypitkowski *et al*., 2010). Infauna is exposed on the mud surface, thereby increasing the chance of either predation or desiccation (Ambrose 1986; Griffiths *et al*., 2006; Rossi *et al*., 2007). Morevoer, infauna biophysical structures, such as worm tubes, are often destroyed (Rossi *et al*., 2007; Sypitkowski *et al*., 2010).

Trampling is an inherent disturbance of bait gathering that can cause substantial changes in flora and fauna assemblages on intertidal habitats (Rossi *et al*., 2007; Hardiman & Burgin, 2010). In addition to these disturbances, harvesting and digging can have significant impacts on the sediment composition and dynamics, affecting the physical, chemical, and biological characteristics of the intertidal mudflats (Moreira, 1999; Shepherd & Boates, 1999; Logan, 2005; Dias *et al.*, 2008; Sypitkowski *et al.*, 2010). Consequently, these disturb non-target invertebrates and birds that prey upon them (Shepherd & Boates, 1999; Logan, 2005; Dias *et al.*, 2008; Sypitkowski *et al.*, 2010). Moreover, digging may release heavy metals from the sediment (Sypitkowski *et al.*, 2010).

Bait harvesting, as well as shellfisheries, represent a very important economic activity in many estuaries worldwide, but these activities may conflict with the conservation of these habitats of great natural value (Dias *et al.*, 2008). Even though the negative effects of bait harvesting are well known, this activity is often poorly managed, only accounting for the sustainable management of target species, thus neglecting non-target species (Kraan *et al.*, 2007; Fonseca & Costa, 2008). Consequently, a more comprehensive ecosystem approach is necessary (Kraan *et al.*, 2007). The analysis of the ecological structure of invertebrates should be a tool to support management measures and conservation of marine habitats (Shokri *et al.*, 2009).

According to Portuguese legislation (Portaria nº 1228/2010) bait gatherers can only operate with a personal license and are only allowed to work using hand gathering or with restricted gear. This legislation provides a list of species of mollusks and annelids allowed to be captured, but not all species have a minimum quantity capture rate. In addition, harvesting supervision, policies and concerns on sustainable control of intertidal resources do not act properly. This undefined exploitation contributes to a parallel economy and directly conflicts with a sustainable and controlled activity (Costa *et al.*, 2006). Some degree of protection in marine areas can help in biodiversity conservation and potentially be useful as a management tool of exploitation of marine resources, removing or reducing relevant negative anthropogenic impacts (Griffiths *et al.*, 2006; Hardiman & Burgin, 2010). Intertidal soft-sediment habitats can often support robust recreational and commercial harvests, however there is limited research on the effects of reserves in these habitats (Griffiths *et al.*, 2006).

The Local Natural Reserve of Douro Estuary (RNLED) is a new protected area located on the left margin of the estuary mouth. Founded in 2008 and occupying a total area of 54ha, this reserve is composed by several important biotopes including a marine sandy shore, sand dunes, small salt marsh and mud/sand area that is covered and uncovered by the tide. This estuarine intertidal area of mud/sand, covering about 27ha of the total reserve area, is one of the most important biotopes of the RNLED and is listed under the EU Habitats Directive (92/43/EEC) as an important habitat type to protect (habitat 1130). This location is used by many birds for shelter and feeding, particularly migratory wintering shorebirds, many with priority conservation status under the EU Birds Directive (79/409/EEC). Along the migration route, suitable habitat is restricted and large numbers of birds are forced to concentrate at a few key coastal areas, estuaries, salt marshes or marine wetlands, where food is abundant (Shepherd & Boates, 1999). For birds migrating from the north of Europe, RNLED is one of the main areas in Portugal that offers good conditions of shelter and feeding for wintering birds. Therefore, RNLED has a great importance for biodiversity conservation on a regional scale. However, this protected area, especially the intertidal mud/sand flats, is used for bait harvesting and for several other activities such as dog walking, recreational angling and aquatic sports like windsurf, which cause disturbance in most of the feeding area available. The aims of this study were to quantify the impact of bait fishing gathering on the abundance of *Hediste diversicolor* (Polychaeta) and *Scrobicularia plana* (Bivalvia) in the RNLED, and analyse the consequences of this activity on the ecology of the community, as well to propose management measures for this activity to ensure its sustainability.

2. MATERIAL AND METHODS

2.1. Study area

The Douro River originates in Spain on Sierra de Urbión and flows into the Atlantic Ocean in Portugal, between the cities of Porto and Vila Nova de Gaia. Its basin covers an area of approximately 98000km^2, corresponding to about 17% of the Iberian Peninsula. Douro forms a temperate mesotidal salt wedge estuary in its last 22km (Vieira & Bordalo, 2000; Azevedo *et al.*, 2008). The lower estuary extends 3km from the mouth and the tides are semi-diurnal with average tidal range of 2.8m at the mouth (Vieira & Bordalo, 2000). This estuary is classified as stratified when river flow is lower than 300m^{3}s^{-1} (Azevedo *et al.*, 2008). The Douro estuary plays an important role in the regional economy, being the mouth of the navigable channel for many commercial, fishing and tourism ships, which serve the population of northern Portugal. The creation of RNLED has raised the importance of the estuary for biodiversity conservation and regional sustainability. The study area has been limited to 27ha of total protected area, the same intertidal zone used for harvesting the bait fishing species.

2.2. Sampling and laboratory analysis

Twelve monthly samples were collected between June 2010 and May 2011 from two stations (Q1 and Q2) located on the intertidal area (Figure 1). Both sites are located in two areas frequently visited by bait fishing gatherers. In each sampling session, the relevant biota for bait was quantified in a total area of 1.53m^2 divided into two squares (Q1 and Q2) 100 m apart of each other. In each square, four 0.19m^2 replicates were sampled, allowing an adequate representation. The superficial sediment layer, 25cm in depth, was removed with a shovel and immediately passed on sieves of 2mm mesh. Biological samples collected were fixed in 4% formalin. The polychaetes collected were measured putting each one over a V-bended ruler (1mm) and divided in three classes of body lengths, 0 to 50mm, 51 to 80mm and over 81mm in order to identify the period of recruitment. In each square, approximately 1.5kg of superficial sediment was collected with a 10cm diameter corer for subsequent granulometric analysis.

In the laboratory, the biological samples were incubated at 70°C for 12 hours and then placed in a muffle, VulcanTM A-550, at 550°C for 4 hours, in order to determine the ash-free dry weight value (AFDW). The sediment collected for granulometric analysis was dried in an oven at 60°C. The samples were sieved using the sequence of 2mm, 1mm, 0.5mm, 0.25mm, 0.125mm, 0.063mm sieves for one cycle of 10 minutes with amplitude of 0.80mm, in an electrical battery of sieves, Retsch AS 200 Basic. The sediment present in each sieve was weighed on a semi-analytical scale AND GF-300 (d = 0.001g).

During the same time period, interviews were performed weekly to bait fishing gatherers operating in the RNLED area, only in daytime, in order to estimate the harvester activity. The interview (Appendix 1) consisted in 3 groups of questions related to the social integration of the harvester, to the harvesting methods and amounts and to the sustainability of this activity. Similar interviews were used in Ria de Aveiro (Cunha *et al*., 2005; Freitas *et al*., 2011).

2.3. Data analysis

Comparing the four replicates in each square we did not find significant differences. The results of replicates were then pooled for subsequent data analysis. To calculate the annual productivity of polychaetes, the methodology applied by Abrantes et al., (1999) in a study of the population dynamics in Ria de Aveiro was adopted. This methodology is based on the equation: ratio = P / B, where P is the productivity and B the annual mean biomass. In the present work the ratio value of (4.4 - 7.9) of Ria de Aveiro was used, since this is the known value in the north estuaries of Portugal nearest to Douro. The relationship between sediment grain size and density (ind./m^2) of polychaetes was established by the Pearson's correlation coefficient and comparisons between stations and months were conducted using analysis of Two-tailed *T* test assuming unequal variances (heteroscedastic) with *t* critical value (5 %). The *T* test was also used to compare the values of density and biomass among different body size classes of polychaetes.

3. RESULTS

3.1. Biological descriptor of bait fishing species

From all the possible species harvested for bait, only two species were found, the polychaeta of phylum Annelida, *Hediste diversicolor* and the bivalve of phylum Mollusca, *Scrobicularia plana*. For *H. diversicolor* there were no significant differences between density values (ind./m^2) found at sampling stations Q1 and Q2 (t=2.120; p=0.118, n=12) and between biomass values (g/m^2) (t=2.080; p=0.709, n=12). The records of *S. plana* were very limited and disperse over the sampling period, making it impossible to perform a valid statistical analysis. Only two individuals in September (2.690g), two in October (7.017g) and one in March (0.108g) were found. However, the abundance of empty shells of *S. Plana*, as well as from other bivalves like *Cerastoderma sp*., was indicative of the presence of clams in adjacent areas. Considering these results, all data was pooled to obtain global values for the studied area.

The species *H. diversicolor* was the most abundant, with an annual mean density of 239.7ind./m^2 and annual mean biomass of 66.244g/m^2. *S. plana* had an annual mean density and an annual mean biomass of 0.3ind./m^2 and 0.534g/m^2, respectively. Both species have commercial interest for local fishing communities. The density and biomass of *H. diversicolor* was higher in spring and summer and lower in autumn and winter (Figure 2). The highest value of density was recorded in May 2011 (494.4ind./m^2) and the lowest in January 2011 (48.3ind./m^2). The highest value of biomass was recorded in June 2010 (172.296g/m^2) and lowest in

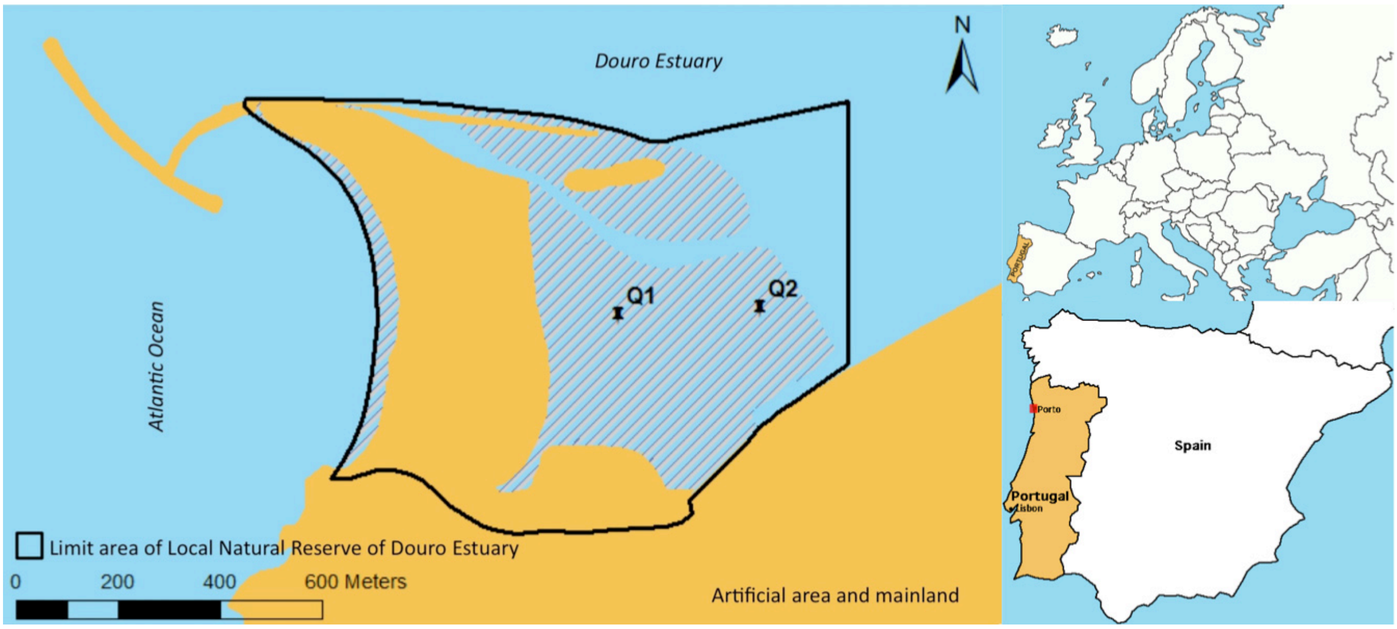

Figure 1. Location of samples squares (Q1 and Q2) in Local Natural Reserve of Douro Estuary (RNLED).
Figura 1. *Localização dos quadrados de amostragem (Q1 e Q2) na Reserva Natural Local do Estuário do Douro (RNLED).*

December 2010 (14.686g/m^2). The body lengths analyses of *H. diversicolor* showed that the length class of 0-50mm was the most present along the sampling period, with the higher values of density being recorded in August 2010 and May 2011 (Figure 3). The density values of individuals with body length of 51-80mm and >81mm were lower than those recorded for the length class of 0-50mm. There was an absence of individuals of the length class 51-80mm in November 2010 and >81mm in September 2010. Also, there were no significant differences in density values between the length classes of 51-80mm and >81mm (the values of T test are available in Table 1). However, density values between classes of lengths between 0-50mm and 51-80mm and 0-50mm and >81m) are significantly different. For biomass, the values were not significantly different among the different body length classes considered. The density of *H. diversicolor* was positively correlated with medium grain sediment of 0.25 mm (R=0.458; p=0.024) and 0.5mm (R=0.627; p=0.001), and negatively correlated with coarse grain sediment, 2mm (R=-0.500; p=0.013).

The conversion rate of fresh weight in ash-free dry weight determined in this work was 7.8%. Thus, the mean value of biomass per unit area of 66.244g/m^2 of fresh weight (FW) corresponds to the value of 5.166g/m^2 of ash-free dry weight (AFDW), this being the annual average monthly values, pooling both squares. The total biomass of *H. diversicolor* in the area considered productive, the intertidal area, which corresponds to about 27ha of RNLED, achieved a mean value of 17.9 tons (FW). In the intertidal area of RNLED, the *H. diversicolor* estimated annual productivity, according to methodology applied by Abrantes *et al*. (1999) ranges between 78.7 and 141.3 tons (FW).

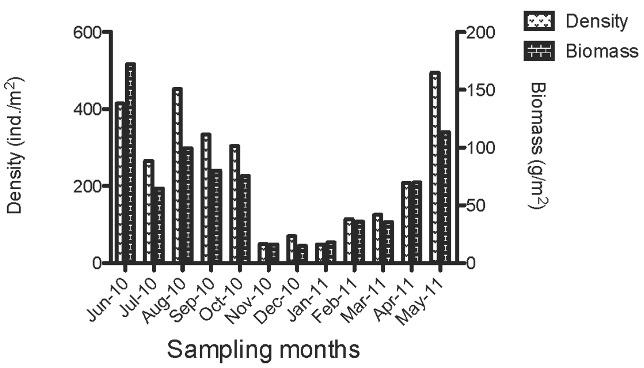

Figure 2. Density (ind./m^2) and biomass (g/m^2) of *Hediste diversicolor* per sampling months, considering all the sampled area.

Figura 2. *Densidade (ind./m^2) e biomassa (g/m^2) de Hediste diversicolor por meses de amostragem, considerando a totalidade da área amostrada.*

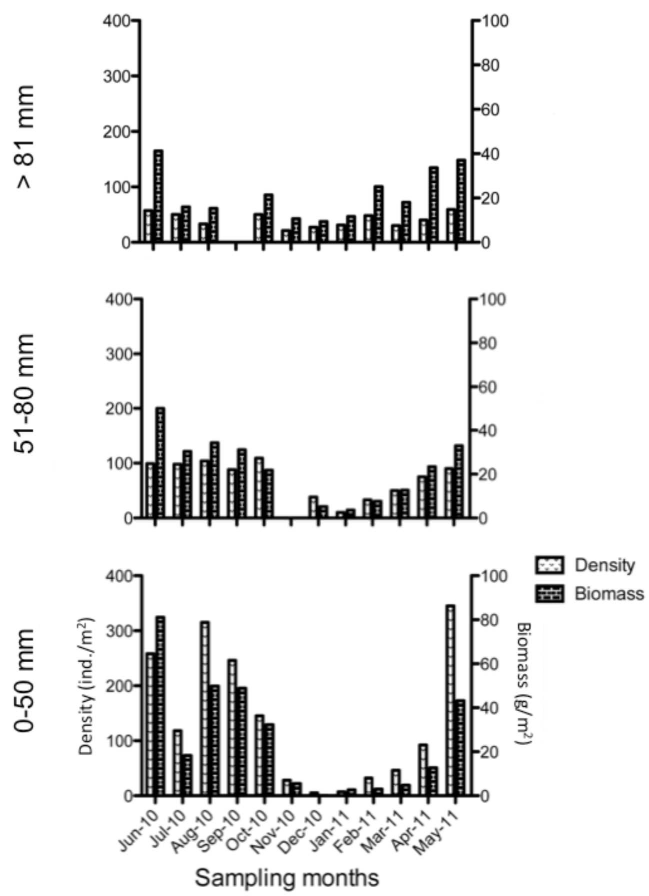

Figure 3. Density (ind./m^2) and biomass (g/m^2) of *Hediste diversicolor* per sampling months and by body length (0-50mm; 51-80mm and >81mm), considering all the sampled area.

Figura 3. *Densidade (ind./m^2) e biomassa (g/m^2) de Hediste diversicolor por meses de amostragem e por classe de comprimento (0-50mm; 51-80mm and >81mm), considerando a totalidade da área amostrada.*

3.2. Quantification of bait fishing gatherer activity

During the study 54 bait fishing gatherers were registered operating in the RNLED and 33 (61%) of these, responded to the inquiry performed. June and July 2010 were the months that registered the greater number of gatherers per visit, 8 and 12 respectively. This number decreased in the remaining months and a null value was recorded in December 2010. The gatherers that operated in the reserve area presented an age distribution of 51% of middle age (between 40 and 60 years old) and 39% of advanced age (>60 years old), only 9% were under 40 years old. Most of these individuals were residents from nearby towns of the RNLED, 63% of Vila Nova de Gaia and the remainder of Porto. Of the total gatherers interviewed, 40% were unemployed, 40% were pensioners and 20% were employed. The unemployed gatherers use this activity as their main economic income and sell bait fishing to recreational fishermen. Pensioners and employed ones use the bait they gather for their own recreational fishery. The target species exploited as bait fishing on Douro estuary is the worm *Hediste diversicolor* (O.F. Müller, 1776),

Table 1. T-test (two tailed) comparing annual density (ind./m^2) and annual biomass (g /m^2) of *Hediste diversicolor* by body length (0-50mm and 51-80mm; 51-81mm and >81mm and 0-50mm and >81mm), considering all the sampled area. The sign * denotes significative differences.
Tabela 1. *Teste t (bi-caudal) comparando a densidade anual (ind./m^2) e a biomassa anual (g /m^2) de Hediste diversicolor entre classes de comprimento (0-50mm e 51-80mm; 51-81mm e >81mm e 0-50mm e >81mm), considerando a totalidade da área amostrada. O sinal * indica diferenças significativas.*

	body length	n	freedom degrees	t value	p value
density (ind./m^2)	0-50mm – 51-80mm	24:24	32	2.037	0.047 *
	51-80mm – >81mm	24:24	32	2.037	0.064
	0-50mm – >81mm	24:24	25	2.059	0.004 *
biomass (g/m^2)	0-50mm – 51-80mm	24:24	44	2.015	0.599
	51-80mm – >81mm	24:24	39	2.023	0.844
	0-50mm – >81mm	24:24	34	2.032	0.445

all the interviewees harvested this species. The most widely instrument used in its capture was a hand rake with 40cm wide (94% of interviewees). Other instruments, although less used were the shovel (3%) or hoe (3%). Only 12% of the gatherers collected other species besides *H. diversicolor*, such as the green crab (*Carcinus maenas*), clam (*Scrobicularia plana*) or shrimps (*Crangon crangon* or *Palaemon serratus*), also used as fishing bait. Most of the harvesters (62%) use the reserve area between 4 to 7 times a week. The highest exploitation occurs during the summer months, in addition to 35% of harvesters that use the RNLED throughout the year, 41% perform this activity only in the summer season. Also, only 24% harvest sporadically. These data are consistent with the number of harvesters per visit directly observed during the fieldwork. The weighted mean of harvesting days by each harvester was 260 days/year, considering the several types of harvesters interviewed. The maximum time spent per day in the reserve ranged between 2 to 4 hours (89% of the answers). Only 11% remained up to a maximum of 1 hour. When accounting for the amount of *H. diversicolor* collected per day, 14% of gatherers indicated that they collected on average 250g, 52% collected 500g, 14% collected 2500g, 10% collected 3500g and 10% collected 5000g. Most gatherers (78%) have been performing this activity over many years and many of them started as a child to help their parents, this being an economic activity supporting many families in the surrounding villages of the RNLED. These gatherers said that in past years, the bait worm was more abundant in the reserve. Also, only 30% think that the harvesting should be controlled using a system of fish bait activity licensing. All the other gatherers have an unfavourable opinion, saying that the bait worm has always existed and was always plentiful for all gatherers and they think that the licensing system will not control the bait abundance.

Table 2. Mean annual density (ind./m^2), mean annual biomass (g AFDW/m^2) and productivity (g AFDW/m^2) of *Hediste diversicolor* in relation to the geographical distribution.
Tabela 2. *Densidade anual média (ind./m^2), biomassa anual média (g AFDW/m^2) e productividade (g AFDW/m^2) de Hediste diversicolor em relação à distribuição geográfica.*

Local	Mean annual density (N/m^2)	Mean annual biomass (g/m^2)	Range of mean annual productivity (g/m^2)	Author
Douro estuary (Portugal)	48 – 494	1.1 – 13.4	22.7 – 40.8	**Present work**
Ria Formosa (Portugal)	---	3.7 – 9.7	19.2 – 31.7	Sprung (1993)
Ria de Aveiro (Portugal)	190 – 718	3.6 – 10.2	15.9 – 74.2	Abrantes (1999)
Gernika estuary (Spain)	173 – 3051	1.08 – 17.36	16.9	García-Arberas and Rallo (2002)
Loire estuary (France)	300 – 2600	4.6 – 9.6	5.1 – 34.4	Gillet and Torresani (2003)
Norsminde Fjord (Denmark)	1305	10.46	27.17	Kristensen (1984)

According to information obtained from interviews, there was an average of 15 harvesters per day. Each gripper collects an average of 1.190kg per day, i.e. a total of 17.857kg was extracted per day. The annual biomass gathered is 4642.8kg, taking into account the total number of harvesting days estimated (260 days). This data indicates that harvesting bait in the RNLED leads to a depletion in annual productivity between 3.3% and 5.9%.

Our observations in the field indicate that the area prospected by each gatherer was 10m^2/day. Considering all the effort done by an average of 8 men/day, the area prospected was 80m^2/day, corresponding to 0.3% of the intertidal area. This effort was mainly concentrated in about 1/3 of the available intertidal area. Each gripper collects an average of 0.662kg/day, i.e. a total of 5.300kg/day was extracted per day, considering a digging area of 10m^2 per harvester/day and a mean biomass of *H. diversicolor* of 0,066kg (see 3.1). Annual biomass gathered is 1.378 tons, considering 260 days as a total number of days of harvesting. According to these data, there is depletion in annual productivity between 0.97% and 1.7%.

4. DISCUSSION AND CONCLUSIONS

This study presents, for the first time, data of the state of the harvesting bait activity on the Douro estuary and its protected area, and the potential impacts on the ecosystem. Two possible bait digging target species were recorded in the RNLED, the worm *Hediste diversicolor* and the clam *Scrobiculaira plana*. *H. diversicolor* was the target species harvested by bait gatherers in the reserve area. *S. plana* was rarely collected to human consumption or bait fishing probably due to the low density recorded in the RNLED. However, shellfishing of *S. plana* is an intensive activity in the Tagus estuary (Dias *et al.*, 2008) and in Canal de Mira (Cunha *et al.*, 2005). The presence of contaminants, pesticides and heavy metals recorded in sediments from the Douro estuary *(Mucha et al., 2003; Carvalho et al.*, 2009b; Carvalho *et al.*, 2009a) may have effects on clam recruitment. In fact, the effects of TBT levels in the recruitment of juvenile clams were observed in Arcachon Bay, France (Ruiz *et al.*, 1997). Changes in the deposition of sediments in the area of the reserve occurred recently due to the requalification works of Douro's breakwater (from 2005 to 2009) and nearby dredging of the reserve made for the construction of a new leisure harbor (from 2011). These changes may be an explanation for the low density of clams and cockles, since changes in sediment composition influence the feeding performance of deposit feeding bivalves (Kraan *et al.*, 2007) and can also contribute to contaminants' resuspension. The intense activity of bait-worm harvesting in the RNLED is one more factor adding pressure on the population density of bivalvs and decreasing their abundance. In addition, worm harvesting could reduce the density of non-target species like clams, by direct mortality, shell damage and increased exposure to predators (Ambrose, 1986; Griffiths et al., 2006; Sypitkowski et al., 2010). In Ria de Aveiro, worm harvesting negatively affected the survival of *M. arenaria* by directly damaging shells and by exposing clams to increased risk of predation (Cunha *et al.*, 2005).

The values of abundance and biomass of *H. diversicolor* registered in the Douro estuary were highest in spring and summer and lowest in autumn and winter. This seasonal variation in the density was also observed in Canal de Mira (Abrantes *et al.*, 1999) and in Denmark (Kristensen, 1984). Density decrease in autumn and winter may be due to increased predation by migratory birds. *H. diversicolor* of small body sizes (0-50mm) were recorded throughout the year in RNLED, with a higher abundance in the spring and summer months. These data suggests a recruitment period throughout the year for *H. diversicolor* with these two peaks, however, further studies should be performed to confirm it. Along the Southwestern coast of Portugal the reproducing period was also reported throughout the year, although with important peaks in spring/summer, as shown in Sado estuary (Costa, 2003). In Ria de Aveiro, in the central west coast of Portugal, *H. diversicolor* also showed two important reproductive periods, in spring and early autumn (Abrantes *et al.*, 1999). In Bay of Biscay, North Iberian Peninsula, *H. diversicolor* had a continuous but not uniform recruitment period during the year, with two peaks, spring/summer and autumn/winter (García-Arberas & Rallo, 2002). In Norsminde Fjord, Denmark, size-frequency distributions of *H. diversicolor* suggested one age class during most of the year, with recruits appearing in two displaced groups, one in spring and another in summer (Kristensen, 1984). Mean annual density values of *H. diversicolor* in RNLED were lower than those observed in other Portuguese and European estuaries (Table 2). Mean annual biomass values were higher than those recorded in Portuguese estuaries (Sprung 1993; Abrantes et al., 1999) and lower than those registered in the Gernika estuary, Spain (García-Arberas & Rallo, 2002). The range of the estimated annual productivity for this species was higher than that registered in Ria Formosa but lower than those obtained in Ria de Aveiro (Sprung, 1993; Abrantes *et al.*, 1999). These differences were not only verified for the range interval, but also for the maximum values comparison. The range of annual productivity values was highest than that registered in Spain and lower than that recorded in France and Denmark (Kristensen, 1984; García-Arberas & Rallo, 2002; Gillet & Torresani, 2003).

According to the information of the interviews, *Hediste diversicolor* is the harvest target species on the RNLED and the most commonly fresh bait used by sport and professional fishers in the Douro estuary and in beaches around its mouth. *H. diversicolor* is a cosmopolitan intertidal Nereid in Europe (Ambrose, 1986). In Portugal, this species is gathered as live bait in Canal de Mira, Ria de Aveiro (Cunha *et al.*, 2005) and in the Tagus estuary (Rosa *et al.*, 2008). The hand rake used in RNLED is the commonly used tool on bait worm harvesting all around the world (Shepherd & Boates, 1999; Dias *et al.*, 2008; Sypitkowski *et al.*, 2010). Worm bait is gathered mainly by pensioners, who use it in their own angling, and unemployed gatherers, who sell bait boxes to anglers and professional fishers in a parallel commercial activity. Both classes of gatherers were observed by Cunha *et al.* (2005) in Canal de Mira. However, these authors reported a third class that was not found in the Douro, the full time professional bait diggers that distribute the gatherings to retailers, often to the Spanish market. The bait worm harvesting has an impact on the economy of the neighbouring population of the RNLED. It is estimated that each gatherer per year harvests in average 300kg of *H. diversicolor*, valued at €3000. The total annual biomass of 99000kg collected has been evaluated in €990000. In Ria de Aveiro, Cunha *et al*. (2005) indicated for the most gathered species, *Diopatra neapolitana*, an annual harvest of 45 tons, valued at over €325000. The harvesting of *H. diversicolor* in the RNLED is held throughout the year, although more intensively in spring and summer, when the number of anglers is also higher. In Portugal the exploitation of polychaetes occurs throughout the year, being more intense in warm months (Cunha *et al*., 2005; Pires *et al*., 2012). Sypitkowski *et al*. (2009) reports a seasonal variation of worm digging in Maine, USA, exhibiting a peak in early spring and another smaller peak in summer. In Whitley Bay, UK, the harvest was also higher in summer (Retraubun *et al*., 1996). Even in visits where no individuals were recorded harvesting these living resources, marks of stirred mud/ sand sediment, made by hand rake, were always observed. According to Sypitkowski *et al*. (2010), digging stripes can remain visible on the mud flats for several months but it is difficult to determine which strips represent new digging activity or features of old harvest efforts. The same was noticed here and these evidences indicate the presence of an undetermined number of bait operators on the reserve area in the tides preceding our observation. As such, the real number of gatherers each day could be of a higher value than our observations. The present study has taken into account harvesting bait on nocturnal tides, which had so much affluence of catchers as diurnal tides. This differs from the study of Cunha *et al*. (2005) in the Canal de Mira, where they concluded that the activity of harvesting at night was sufficiently negligible to be discounted from the sampling program. In the RNLED, the mud flats are exposed and accessible for approximately 4.5 hours at low tide. The gatherers remain mostly between 2 to 4 hours in the reserve. Despite being a temporary disturbance and variable depending on the amount of harvesters, it overlaps with the most favorable period for shorebirds feeding, causing an impact by shortening the feeding period. According to Cunha *et al*. (2005) in Canal de Mira, bait digging occurs over a period of 3.5 hours and, as also seen in the Douro, the bait diggers start the activity when the sediment is still flooded.

The difference between the data of the interviews and the data of our field observations in impact on annual productivity is a result of the methodology used, comparing the harvester's perception of the daily catch and the biomass evaluated in this work, as a function of the density and the area used by each gatherer, which could have been under-estimated. Moreover, the evaluation of the number of harvesters/day is different, as a result of the inquiries or the observed harvesters in the field. One additional source of differences could be the number of harvesting days declared in the interviews, as it seems overstatement. This could also lead to an overestimation of the annual harvest and the annual sold bait.

Even with the impact of the extraction of worm fresh bait, more intense in the summer, and with shorebirds predation, higher in the winter with the arrival of migratory birds, the estimated biomass of *H. diversicolor* in total area of reserve is much higher than the estimated biomass harvested. Likewise, a qualitative assessment of the total catch of each category indicated that occasional diggers have a negligible impact on the population in Canal de Mira (Cunha *et al*., 2005). Our results suggest that bait harvesting has a low impact on reduction of density of *H. diversicolor*, reflecting on a low impact on the food availability for shorebirds. Avifauna will be more disturbed by the presence of gatherers and not by food reducing. For some species, access to feeding resources result from induced mortality of target species for whom harvesting is higher. The induced mortality on small crustaceans such as *Corophium volutator* or *Cyathura carinata* by the use of the hand rake in sediment digging was not quantified in this study. However, studies in other estuaries indicated that the induced mortality may reduce the recruitment of these benthic species, and thus may derail the successful reproduction and consequently lead to a decrease in density (Shepherd & Boates 1999; Logan 2005). Studies in the Tagus estuary suggested that predation is a key factor on the population dynamics of *H. diversicolor* and that this polychaete can be a limited resource, having major ecological consequences for its predators (Rosa *et al*., 2008). *H. diversicolor* is a major link in food webs, as it is available at the sediment surface and is one of the most important prey items for waders and fish in European estuaries (Ambrose, 1986; Gillet & Torresani, 2003; Rosa *et al*., 2008). The increased density of bait collectors had much more negative impact on the habitat affected than in the percentage of worms removed, especially for species with greater flight distances like the Grey Heron (*Ardea cinerea*), Little Egret (*Egretta garzetta*) or Great Cormorant (*Phalacrocorax carbo*), wintering species of the RNLED. Dias *et al*. (2008) have also verified this type of disturbance by human presence on shorebirds with clams digging in the Tagus estuary. Besides its importance for feeding, it is acknowledged that *H. diversicolor* has an ecological importance in coastal ecosystems due their U or Y shaped burrow constructions. Sediment reworking by feeding and burrow construction influence particle transport, being important for sediment biogeochemistry and element cycling (Retraubun *et al*., 1996; Scaps, 2002). Oxygen is heterogeneously distributed in the lumen and wall of *H. diversicolor* burrow (Pischedda *et al*., 2012), increasing the verticalize oxic zones into the black sediment (Scaps, 2002; Contessa & Bird, 2004). Oxygen availability in burrow environments may affect growth and population sizes of associated organisms, like *Corophium volutator* (Retraubun *et al*., 1996; Scaps, 2002; Contessa & Bird, 2004).

Globally, protected areas in marine ecosystems are receiving increasing attention as management tools for protecting marine populations from human activities (Casu *et al*., 2006). A considerable part of the polychaetes harvested for bait fishing come from estuarine protected areas or nature reserves. Species conservation and maintenance of ecosystem functioning should be reconciled with the human interests and economic development. Mindful of the need and importance of maintaining this activity in a protected area, management proposals for the RNLED further presented will make bait fishing a more sustainable activity at an environmental, social and economical level. All gatherers must have their personal license to catch bait worms and the supervision of this activity should be more efficient. Although the law prescribes the license, most harvesters who currently use the RNLED do not have it, mainly due to the insufficient supervision. The ineffectiveness of control of bait licenses was also reported in Ria de Aveiro by Cunha *et al.* (2005). The ill-defined exploration creates conflicts with the proper regulation of the activity and its development in a sustainable way (Fonseca & Costa, 2008). It would be necessary to define an area within the protected area where gatherers would be allowed to perform the activity of harvesting worm bait. By reducing the area available for harvesting, it should reduce the impact on shorebirds and waders by decreasing the sediment excavation, tramping, and also the disturbance caused by the presence of gatherers. This measure results in an improvement of the well-being for birds, as it increases the reserve area available for feeding and resting, and may enhance the occurrence of birds most susceptible to human presence. Thus, we can avoid changing of feeding behaviors by shorebirds and compensate by moving elsewhere or by feeding at a greater rate during periods of the day when less disturbances occur, as observed in the Exe estuary, UK (Goss-Custard & Verboven, 1993). In the RNLED, the area now proposed is limited to a track of 10m width between the street wall and the narrow channel, comprised between the small harbor and the upstream official limit of protected area. This area would be properly signaled with informational signboards of limit area for worm bait harvesting and the obligation of personal license. Furthermore, there are other adjacent areas, upstream of RNLED that may continue to be used in bait harvesting. Additionally, it is also suggested the holding of forums to improve civic education and environmental awareness of the local population, framing the importance of protected areas and sustainable harvesting of bait. The absence of environmental education in this field has also been reported in Mondego estuary (Cardoso *et al.*, 2007). As a complementary measure for sustainable management of RNLED, the prohibition of digging of clam *Scrobicularia plana* would be necessary. Despite its reduced exploitation, its density is very low. This prohibition, together with area delimitation, will decrease the trampling and excavating sediment and may benefit the recovery of this species in the protected area, which is also important in the bird's diet. The integration of all these management measures could thus have positive effects, not only in birds, but also on the target and non-target species, with an expected increase in density and species richness of the benthic invertebrate community of the RNLED. The fact that the collection of *H. diversicolor* in Douro estuary is allowed is very positive, since it encourages the use of a native species as bait fishing, reducing the risk of use of non-native species. The use of imported species can lead to the introduction and establishment of non-indigenous species being a threat to coastal ecosystems and to the local economy (Costa, 2003; Costa *et al.*, 2006; Pernet *et al.*, 2008; Haska *et al.*, 2012).

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Appendix 1. Questions presented in the oral interview conducted to the bait fishing harvesters in the intertidal of Local Natural Reserve of Douro Estuary.
Anexo 1. *Questões presentes na entrevista oral realizada aos mariscadores de isco da pesca no intertidal da Reserva Natural Local do Estuário do Douro.*

Interviewer Data
Name: Date:
Low tide at: Height (m):
Weather conditions:
Number of harvesters in RNLED:
Time of Arrival: Time of Departure:
Notes:

1. Socio-economic Data

1.1. Age:
1.2. Gender: Male ☐ Female ☐
1.3. Education Level:
1.4. Professional Activity:
1.5. The Municipality of residence:

2. Harvesting Activity
2.1. Today, what time did you started the harvesting?
2.2. What did you caught?

Species	Weight (~ g)	Number of individuals (~)	Harvesting Tool

2.3. Do you always harvest the same species? Yes ☐ No ☐ Other:
2.4. How many hours per day do you harvest?
2.5. How many days per week do you harvest in RNLED?
2.6. How many months per year do you harvest in RNLED?
2.7. What is the purpose of the harvest? Sale ☐ Own recreational fishing ☐ Other:
2.7. If the answer is selling, who is the buyer? Recreational fishermen ☐ Fishing shops ☐ Other:

3. Conservation Opinions
3.1. Do you already performed harvesting activity in last years? Yes ☐ No ☐
3.2. How many years?
3.3. What kind of species?
3.4. Did you caught more, less or equal than the present year? More ☐ Less ☐ Equal ☐
3.5. How are the abundance of bait fishing species? They are more, less or equal abundant in relation to the present? More ☐ Less ☐ Equal ☐
3.6. If there are differences in abundance, what are the reasons for these differences?
3.7. What measures do you think can be done so that we continue to perform the harvesting activity in the future?
3.8. Do you think that the harvesting activity should be controlled? Yes ☐ No ☐ Why?
3.9. Do you think that it is easier to harvest these bait fishing species in the present or in the last years? Why?