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Impact of illegal glass eel (*Anguilla anguilla*) fishery on estuarine fish stocks: a case study in the Mondego Estuary

João Filipe Bernardo Neves

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Dissertação apresentada à Universidade de Coimbra para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Ecologia, realizada sob a orientação científica do Professor Doutor Miguel Pardal (Universidade de Coimbra) e do Doutor Filipe Martinho (Universidade de Coimbra)

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Demonstra gratidão a todos os que colaboram nas tuas vitórias”
Carlos Hilsdorf .

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Nos estuários, a pesca ilegal é uma das principais atividades que afeta uma vasta gama de espécies conduzindo ao seu declínio, provocando danos nas suas populações e levando à sobre-exploração dos juvenis das espécies-alvo e não-alvo (pesca acessória). Nos estuários do Nordeste Atlântico, os juvenis de enguia-europeia (*Anguilla anguilla*) são um alvo preferencial durante a fase de enguia de vidro. Em Portugal, e apesar de a sua pesca não ser permitida (com a exceção do Rio Minho), uma quantidade substancial de pesca ilegal ocorre durante a estação migratória.

Este caso de estudo teve como objetivo estudar os impactos da pesca ilegal da enguia de vidro no estuário do Mondego (Portugal) em espécies alvo e não-alvo. Com este trabalho, os objetivos específicos, e tendo em conta dois cenários diferentes em termos hidrológicos (ano regular vs chuvoso), foram: a) determinar a variabilidade sazonal e inter-anual das capturas de enguias de vidro e das espécies não-alvo, e b) estimar a quantidade total de capturas considerando vários cenários hidrológicos e de pressão de pesca. A amostragem foi realizada entre novembro de 2011 e março 2013. As capturas de enguia de vidro foram semelhantes entre os dois anos de estudo. No entanto, ocorreram diferenças entre as duas campanhas de pesca, com um maior número de capturas acessórias em 2012-2013 (ano chuvoso), especialmente no outono.

Os resultados também indicam uma maior diversidade de espécies no ano chuvoso, durante os meses de outono, bem como o maior número de indivíduos. Capturas mais elevadas das espécies mais abundantes foram também observados durante o ano chuvoso, quando comparado com o ano regular, o que sugere que a magnitude do impacto destas práticas ilegais pode estar relacionada com os ciclos hidrológicos.

O trabalho efectuado demonstra que práticas ilegais e não-seletivas tais como esta têm um impacto significativo nas espécies capturadas, e em última análise no funcionamento do ecossistema estuarino.

Palavras chave: estuário; pesca ilegal; *Anguilla anguilla*; espécies não alvo; variabilidade climática

In estuaries, illegal fishing is one of main activities that affects a wide range of species leading to the decline of total abundances, damage in fish stocks and overexploitation of juveniles in both the target and non-target species (by-catch). In North-eastern Atlantic estuaries, the European eel (*Anguilla anguilla*) juveniles are particularly targeted during the glass eel stage. In Portugal, and despite that fishing eel juveniles is not allowed (with the exception of the Minho River), a substantial amount of illegal fishing takes place during the migratory season.

Our case study aimed at studying the impacts of glass eel illegal fishing in the Mondego estuary (Portugal) in both target and non-target species. With this work, the specific objectives, considering two different hydrological scenarios (regular vs rainy year), were; a) to determine the seasonal and interannual variability in glass eels and non-target species catches, and b) to estimate the total amount of catches considering several hydrological and fishing pressure scenarios. Sampling was performed in the Mondego estuary between November 2011 and March 2013 during the autumn and winter.

Results showed differences between the two fishing seasons: a higher number of bycatch was observed in 2012-2013 (rainy year), particularly in autumn. For the glass eel, no differences between years were observed. Results also indicated higher species diversity in the rainy year, during the autumn months, as well as the highest number of individuals. Higher catches of the most abundant species were also observed in the rainy year, when compared to the regular one, suggesting that the magnitude of impact of these illegal practices is related with the hydrological cycles. The present work shows that Illegal and non-selective fishing practices such as this one have high impacts on the captures species, and ultimately on the functioning of the estuarine ecosystem.

Keywords: estuary; illegal fishing; *Anguilla anguilla*; bycatch; climate variability

CHAPTER 1 – INTRODUCTION

1.1 Estuaries: ecological roles and value

Estuaries are transition areas between freshwater and marine environments and from an ecological point of view, should be treated not as an isolated water body, but as a natural gradient from river to sea without clearly defined boundaries. Another distinctive attribute of estuaries is high hydrodynamics, which combined with the effect of tides, make these systems extremely variable in space and time (Wołowicz et al. 2007). These systems also vary in geomorphology, tidal characteristics, sediment type, as well as on dissolved oxygen, salinity and water temperature. Estuaries have a very important ecological role as they are inhabited by a large range of invertebrates, birds and fishes (Beck et al., 2001; Wołowicz et al. 2007; Agnew et al. 2009).

Estuarine areas are among the ecosystems with higher economic value in the world, and with the highest total value per ha (Costanza et al. 1998), due to their characteristics and the services provided by them: disturbance regulation in flood control and drought recovery, water supply (water retention and storage), aquaculture, salt extraction, food production and many essential fisheries (Blaber et al. 2000), nutrient cycling, as well as their recreation and cultural value. At the ecological level, these habitats have a high importance, because of their role in the life cycle of bird and fish species, providing migration routes, breeding, mating and spawning areas, shelter for endemic species, as well as for maintaining coastal fish stocks (Costanza et al. 1998; Beck et al., 2001; Baeta et al. 2005). In addition, estuaries also provide nursery areas for many marine fish species that are dependent on this type of systems, especially for their early life stages (Beck et al., 2001; Lamberth & Turpie 2003; Dahlgren et al., 2006; Martinho et al. 2009; Nyitrai et al. 2013; Primo et al. 2013).

Due to high value of goods and services provided, estuaries are subjected to high human pressure, such as industrial/urban discharges, margins interventions, estuary flow regulation and excessive fishing, including illegal fishing. This makes them as one of the most extensively modified and threatened aquatic environments (Blaber et al. 2000). Taking into account the complex interrelationships between the estuarine and open sea fauna, the effects of fishing in estuaries may also have impacts on offshore fisheries (Blaber et al. 2000).

1.2 Illegal fishing

Illegal and unreported fishing contributes to overexploitation of fisheries resources, being an obstacle to the recovery of fish populations and ecosystems, as these fishing techniques are not selective, leading to the decline of target species and by-catch species (Agnew et al. 2009). At the economical and social levels, illegal fishing leads to loss of revenue and potential export, creates unfair competition in the local markets by depressing the incomes of licensed fishing (Pauly et al. 2002), generates social conflicts and competition for fishing grounds, poor social conditions for fishermen, and compromises food supply, security and livelihoods (Agnew et al. 2009).

In the ecological and resource management point of view, these practices do not respect statutory requirements to protect habitats and ecosystem components, generate damage to sensitive ecosystems, especially in nursery areas and migration routes, lead to overexploitation and cause serious damage to stocks (overfishing) by removing the fish that otherwise could create food or wealth to the country (Agnew et al. 2009). The occurrence of illegal or unreported fishing is also increasing in many areas, putting at risk national and regional efforts to manage fisheries sustainably (FAO, 2009).

1.3 Overexploitation/by-catch

For the United States National Oceanic and Atmospheric Administration (NOAA), fisheries overexploitation (overfishing) occurs when a fish stock has been fished down below the size, or excessive quantity that, on average, would support the long-term maximum sustainable yield of the fishery, leading in extreme cases, to the destruction of that resource. Currently, most estuarine fisheries (and not only) are either fully exploited or overexploited (Blaber et al. 2000).

The effects of overfishing on target organisms include decreases in their abundance, changes in age structure, and size composition and changes in species composition. This subject is clearly of growing worldwide concern, since overfishing may threaten the viability or profitability of many fisheries (Blaber et al. 2000; Pauly et al. 2002). Also, due this overexploitation, specific trophic levels of the community and their populations can be affected, if fishing removes or reduces these populations, or even lead to habitat losses and nutrient imbalance, by fishing discards (Blaber et al. 2000; Morato et al., 2006).

For Hall (1996), a capture can be divided into three components: (a) the portion retained because it has economic value (catch), (b) the portion released alive (release), and (c) by-catch, that part of the capture that is discarded. Generally, most of the fish discarded will be dead, but in some cases, even if the fish are alive when returned to the water, their survival rate is low (Hall et al. 2000). Catch could be subdivided further into two main components: target catch and non-target catch, the latter including other species caught incidentally but retained because of their economic value.

By-catch is one of the most significant issues affecting fisheries management today and can affect biodiversity through impacts on top predators, elimination of prey, and the removal of individuals from many species (Hall et al. 2000). By-catch also has negative effects on the resources harvested through the mortality of juvenile and undersized individuals of the target species before they reach their optimal size from the point of view of future yield (Hall et al. 2000), being a main component of fishing mortality (Hall et al. 2000; Chopin et al. 1995). Discarded fish mortality is a critical problem in the management of worldwide fisheries (Davis, 2002) that might produce effects on fish size distributions, species composition, and ecosystem diversity (Pauly et al., 2001; Christensen et al., 2003). In Portuguese estuaries, many local fisheries focus mainly on migratory diadromous species, such as sea lamprey (*Petromyzon marinus*) and European eel *(Anguilla anguilla*) (Baeta et al. 2005).

1.4 Glass eel (*A. anguilla*) populations and fisheries

The European eel (*A. anguilla* L.) is an euryhaline and catadromous migratory species, with a two distinct phases in their life-cycle (ocean and continental; Fig. 1) that depend strongly of oceanic conditions, maturation, migration, spawning, larval transport and recruitment dynamics (Tesch & White 2008).

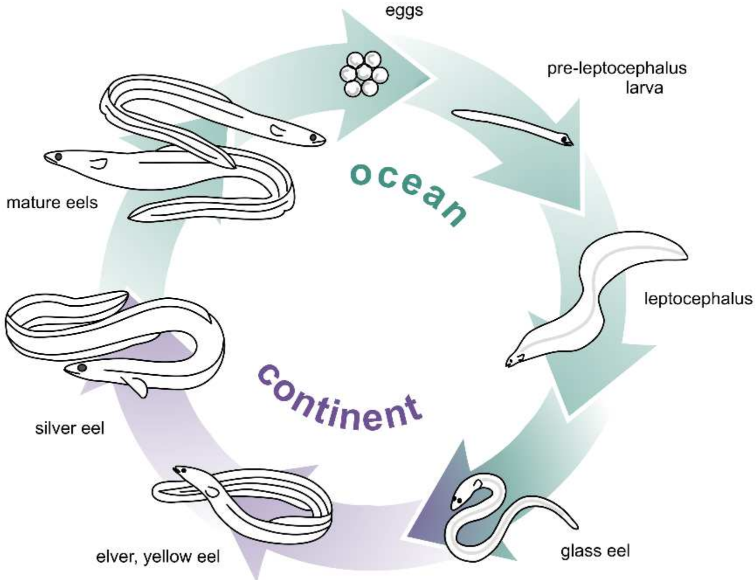

Fig. 1 - European eel (*A. anguilla*) life cycle (Henkel et al 2012)

The leptocephali larvae are transported along the Gulf Stream and North-Atlantic Drift for a journey of 8–9 months back to the eastern Atlantic coast (Arai et al. 2000), where they metamorphose to glass eels, ascent rivers till their skin begins to develop pigmentation and they metamorphose into elvers, and grow (Henderson 2011), and remain for 6-10 years until adulthood (Tesch & White 2008). This ascendance starts in the winter in the Iberian Atlantic coasts, in spring in the eastern Mediterranean and in the western and northwestern European coast (Robin 1990). Mature adults leave the continental rivers at different times, dependent on lunar phase and atmospheric conditions, swim southward using the Canary and North-equatorial currents and arrive 6–7 months later at the Sargasso Sea to spawn and then die (Ginneken & Maes 2005).

The migration of glass eels of the continental shelf to inland waters is known / studied for a long time (Schmidt 1906). However, studies of the consequences of glass eel fishing to their stocks and to estuarine communities are fewer and more recent (Robin 1990; Gisbert & López 2008; Sobrino et al. 2005). Due to their very high value (between 300€ and 500€/kg), illegal captures are very common, posing an important threat to the overall eel stocks.

Estuarine environments are one of the main sites for glass eel capture in the Iberian Peninsula coast, where glass eels are captured with artisanal and nonselective fish traps, with the fishing season extending usually from November to March (Gisbert and López, 2008). This period coincides also with the glass eel entry in Portuguese estuaries, where a great amount of illegal fishery also takes place (Jorge et al 2002; Leitão et al 2007; Antunes 2008). This fishery is performed by fishermen using artisanal and rudimentary sorting methods, however not a great deal of care is taken in relation to glass eel manipulation and health, and even less to by-catch fish (Gisbert and López, 2008). The captured fish are therefore exposed to high levels of stress during their capture and handling, exacerbated by air exposure, hypoxia and skin lesions (Robin, 1990). These factors, which normally do not affect the glass eel, might have a great impact on the health and survival of discarded fish species. Despite this, discard mortality rates in specific fisheries, such as that of the glass eel, are rarely known and there exist very few field studies on this topic (Robin, 1990). Hence, it is critical to evaluate the impacts of illegal fisheries on target and non-target species due to the disruptive potential of this practice in fish stocks.

At an European scale, a reduction in eel captures have been reported over the last decade, resulting from a global over-exploitation of this species combined with long-term climatic changes (Moriarty & Dekker, 1997; Dekker, 2003; Ringuet et al., 2002; EI-FAC/ICES, 2003; Dekker, 2002, 2005; Wirth & Bernatchez, 2003). This situation has also been observed for the Portuguese and Spanish fisheries, despite some inaccuracy of the available data (Antunes 2008). In fact, the ICES (International Council for the Exploration of the Sea) advice for 2014, applicable for the widely-distributed and migratory stock of European eel (*A. anguilla*), reinforces the need for all human-caused mortality (e.g. recreational and commercial fishing, hydropower and pollution) to be reduced to as close to zero as possible, at least until there is clear evidence of a continued increase in both recruitment and the adult stock (ICES ADVICE 2013, Book 9, Section 9.4.7)

In Portugal, as in other European countries, glass eel fishery is illegal, being an activity with poor economic and environmental sustainability, and with the parallel and international markets its main target (Baeta et al. 2005). The Portuguese legislation includes a national plan for the conservation of the stock of European eel (Plano de Gestão da Enguia 2009-2012), which meet the targets set by the European Union (Regulation (EC) nº 1100/2007 of 18 September). In the case of Minho river transboundary basin, glass eel fishing is allowed, with a maximum limit of 200 national fishing licenses, in the first 25 km upstream of the river, to be able to monitor the fishery. Presently, and at national level, the information about glass eel fishing effort is incomplete, scattered (Antunes, 2008) and its impacts are still unknown.

1.5 Objectives

This study aimed at evaluating of the impacts of illegal glass eel fishing in the Mondego estuary (Portugal) in both target and non-target species, comparing two distinct hydrological years. The specific objectives of the present study were: a) to evaluate the effect of the glass eel fishery on the target species, by evaluating number of individuals and biomass captured during the fishing season; b) to evaluate the impact of glass eel fishery on the bycatch ichthyofauna in terms of species diversity and biomass; c) to evaluate the impact of glass eel fishery on the functional composition of the bycatch fish fauna; d) to evaluate the impact of glass eel fishery on the most abundant ecological groups of the fish fauna; e) to determine the influence of changes in hydrological regimes in the glass eel and bycatch fisheries; f) to estimate the total impact of glass eel fishing considering several number of fishing nets deployed over the fishing season.

CHAPTER 2 – MATERIALS AND METHODS

2.1 Study area

The Mondego estuary is a small intertidal system with 8.6 km^2, located in the western Atlantic coast of Portugal (40º08'N, 8º50'W; Fig. 2). It comprises, in its terminal part, two arms, separated by Murraceira Island, with distinct morphological and hydrological characteristics. The north arm is deeper, with 5–10m depth at high tide and tidal range of 2–3 m, while the south arm is shallower, with 2–4m depth at high tide and tidal range of 1–3 m (Flindt et al. 1997, Pardal et al. 2000, Martinho et al. 2009, Baptista et al. 2010). The northern arm corresponds to the main navigation and is the location of the commercial port of Figueira da Foz. The southern arm is mostly composed of large areas of tidal mudflats. The freshwater flows mainly through the north arm, and in the south arm the water circulation is mainly dependent on tides and inflow of freshwater to a lesser amount by Pranto River, which is a small tributary, regulated by a sluice according to the water requirements of the nearby rice fields. In 2006, the connection between the two arms was expanded, allowing an increased flow of fresh water through the southern arm (Nyitrai et al. 2013).

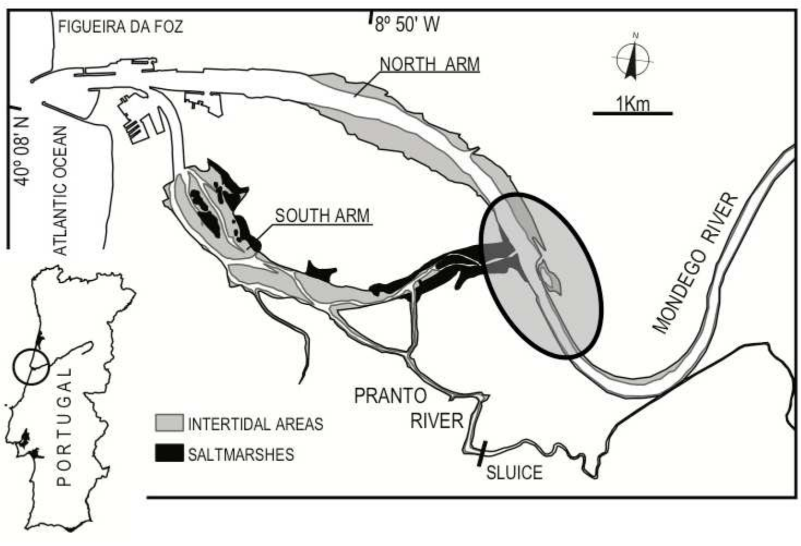

Fig. 2 – The Mondego estuary. The shaded area represents the sampling location.

The most important fisheries within the Mondego estuary target the seasonal diadromous migratory species, such as the European eel (*A. anguilla*), the sea lamprey (*P. marinus*) and Allis shad (*Alosa alosa*) (Duarte et al. 2003; Leitão et al. 2007; Mota and Antunes 2011).

2.2 Sampling procedures

Fish were collected in the Mondego estuary in two consecutive fishing seasons, from November 2011 to January 2012, with a total of 9 fishing nets (3 in autumn and 6 in winter); and between October 2012 and March 2013, with a total of 9 fishing nets (6 in autumn and 3 in winter). The nets were provided by the local Maritime Police authority, collected during surveillance operations in the estuary, covering the shaded area represented in Fig. 1. These illegal fishing nets - adaptations of fyke and stow nets ("tela") - have a 1mm mesh size, a 10m width mouth, and an average length of 50m, 30m body and 20m tail, called "rapeta". These nets are artisanal and nonselective in terms of ichthyofauna. The nets remain in the bottom over a tidal cycle, being deployed by fishermen during low tide and collected the following tide. This ensures that the sampling effort was constant throughout the study period.

In the laboratory, samples were frozen until further processing. The contents of all fishing nets were sorted and the fish separated from the other material. All fish were identified, measured (total length to the nearest mm, TL) and weighed (wet weight with 0.001g precision, WW) individually. Salinity and temperature data were obtained from fieldwork campaigns in the Mondego estuary, in order to characterize both year periods.

2.3 Data analysis

For each species captured in the nets, the average number of individuals and biomass per net for each season (autumn (October - December) and winter (January - March) were determined, as well as their average total length.

In order to determine differences on functional aspects of the fish assemblage captured as by-catch, all species were assigned to an ecological (related with habitat use) and feeding guild (relate with feeding preferences), following the classification by Elliott et al. (2007). The ecological guilds were: (1) marine stragglers (MS), species that breed and spawn at sea and usually enter estuaries in low numbers; (2) marine estuarine-opportunists (MMO), marine species that regularly enter estuaries in considerable numbers especially as juveniles but use nearshore marine waters as an alternative habitat; (3) marine estuarine-dependents (MMD), marine species that live along coasts but require sheltered estuarine habitats as juveniles therefore, these species depend on estuaries; (4) estuarine residents (ER), species that complete their entire life cycle within the estuary; (5) catadromous species (CA) that spend all of their life in freshwater and subsequently migrate to sea to spawn; (6) freshwater stragglers (FS), freshwater species found in low numbers in estuaries and whose distribution is restricted to low salinity areas of the upper reaches of estuaries. The feeding guilds were: (1) planktivorous (PS), species that feed predominantly on zooplankton and phytoplankton; (2) invertebrate feeders (IS), species that feed predominantly on invertebrates associated with the substratum; (3) species feeding on invertebrates and fishes (IF); (4) omnivorous (OV), that feed mostly on filamentous algae, macrophytes, periphyton, epifauna and infauna (Elliott et al. 2007). Particular attention was given the estuarine residents and marine estuarine-dependents, given that previous studies in the Mondego estuary determined them as the most abundant species in the fish assemblage and also related with the nursery value of the estuary (e.g. Martinho et al. 2007; Baptista et al. 2010; Nyitrai et al. 2012).

In order to analyze the similarity between seasons and years in terms of fish composition, a multidimensional scaling (MDS) ordination plot was generated considering the number of individuals and biomass. The MDS was performed on a Bray-Curtis similarity matrix using square root transformed data in PRIMER software package (version 5.0) (Clarke and Warwick, 2001). Due to data variability and an unbalanced design, differences between seasons and years in the fish assemblages captured were analyzed using the PERMANOVA+ package for PRIMER. A Permutational Anova (PERMANOVA) was performed, using years and seasons as fixed factors, based on the Euclidian distances between samples and unrestricted permutations of raw data. Whenever significant differences were found, the specific pairwise comparisons were performed. A significance level of 0.05 was considered in all test procedures.

In order to quantify the global impact of these fishing practices in the Mondego estuary, several projections were made taking into account the average biomass of glass eels per net per hydrological year (regular and rainy), by considering the duration of the fishing season to be 150 days, according with Antunes and Weber (1993), and three different scenarios concerning the numbers of fishing nets deployed daily: 25 (conservative), 50 (moderate) and 75 (excessive). These projections were performed for the glass eel alone, the marine-estuarine dependent species that use the estuary as a nursery ground, given their high commercial value, and for the whole fish assemblage, based on the average ratios between them and glass eel. The ratios for each fishing season were calculated dividing the total wet weight of marine-estuarine dependent species, and the total wet weight of glass eel. The same procedure was made for the whole fish assemblage.

The projections were calculated based on the following formulas:

- **Glass eel catches = “average glass eel wet weight” x “fishing season duration” x “daily fishing nets”**, for glass eel alone;

- **Marine-estuarine dependent species/fish assemblage catches = "Glass eel catches" x "fish:glass eel ratio"**, for marine-estuarine dependent species and whole fish assemblage

The projection results were expressed in tonnes.

CHAPTER 3 – RESULTS

3.1 Environmental background

The study period encompassed two hydrological different scenarios: regular years in 2011 and 2013, and a rainy year in 2012. This situation translated into higher average salinities in the estuary in the 2011/12 fishing season (26.8 ± 3.2) than in the same period of 2012/13 (15.3 ± 7.9) (Fig. 3). This difference in salinity was particularly noticeable when comparing the winter periods of 2011/12 and 2012/13. In fact, the month of March 2013 was considered as the second rainiest of the last 50 years in Portugal mainland (IPMA 2013), highlighting the differences in terms of hydrology between both periods. Regarding average water temperatures, similar results were obtained for both periods (2011/12: 13.4 ± 2.2 ºC; 2012/13: 12.6 ± 0.5 ºC) (Fig. 3).

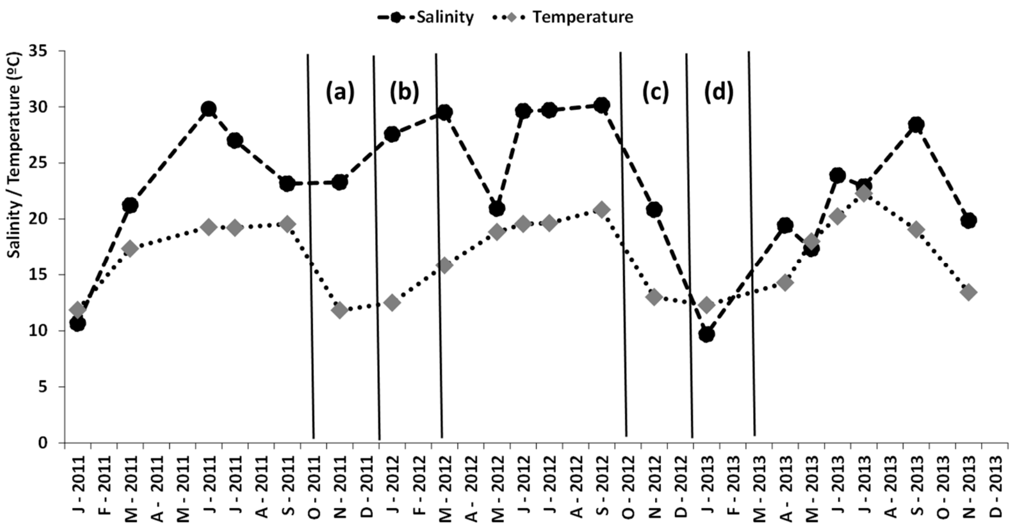

Fig. 3 - Environmental conditions in the Mondego Estuary between January 2011 and December 2013: average bottom water salinity (black circles) and temperature (grey squares); (a) autumn 2011; (b) winter 2012; (c) autumn 2012; (d) winter 2013.

3.2 Glass eel

In terms of glass eel catches, the average number of individuals was higher in both winters, when compared with the autumn samples (Fig. 4a). A similar trend was observed for the total average wet weight of glass eels per net, with biomass values up to 4 times higher in the winter, when compared to autumn samples (Fig. 4b). No differences were observed between the same seasons of both years. Still, average total length and average wet weight of glass eel individuals did not vary significantly between seasons and years (Fig. 4c,d).

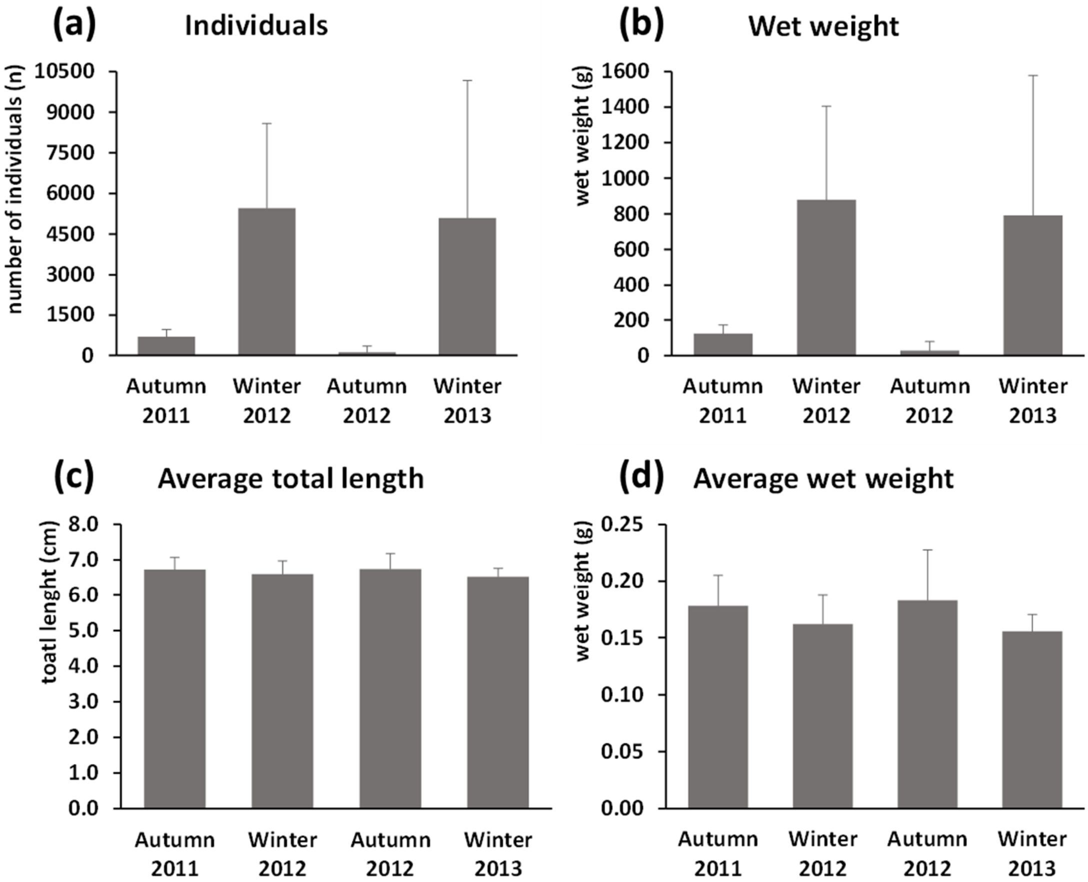

Fig. 4 - Glass eel (a) average number of individuals per net, (b) average wet weight per net, (c) average individual total length and (d) average individual wet weight.

3.3 Non-target Ichthyofauna composition

A total of 35 fish species and 61.973 individuals were found during the study period (Table 1). However, the number of species was not equal among seasons and years: autumn 2011 – 19; winter 2012 – 20; autumn 2012 - 32; winter 2013 – 9 species. Besides eel, the more abundant non-target species were the common goby *Pomatoschistus microps*, sand goby *Pomatoschistus minutus*, mullet Mugilidae fry, European seabass *Dicentrarchus labrax* and the greater pipefish *Syngnathus acus* dominated by the total catches (see Table 1). In parallel with glass eel catches, higher total numbers of individuals were also observed in winter samples. Higher fish biomass was observed in the autumn 2012. In both winters, eel was the dominant species in terms of average number of individuals (>97%), while in the autumn their overall contribution to the fish assemblage was considerably lower (2011 – 33%; 2012, 12%). A similar trend was also observed for the contribution of eel to the average biomass of the whole fish captures (Table 1). Higher eel catches were associated with lower species number.

Within the non-target species, two new species that had never been described in published literature for the Mondego estuary were observed: the European hake *Merluccius merluccius* and turbot *Scophthalmus maximus*. The total length of the captured species also varied considerably (Fig. 5). Larger specimens (TL > 25 cm) were only captured of the catadromous *A. anguilla* and *L. ramada*, the marine estuarine dependent *P. flesus*, the marine estuarine opportunists *C. lucerna* and *S. senegalensis*, and the marine straggler *C. conger*. Most species presented a range of TL < 25cm. Consistently, the smaller fish were the estuarine residents.

Analyzing the functional composition of the fish catches in terms of habitat use patterns, differences between autumn and winter were apparent (Fig. 6). In the autumn 2011, the samples were mainly composed by catadromous, estuarine resident (mainly *Pomatoschistus microps* and *Pomatoshistus minutus*) and marine estuarine opportunist species in terms of number of individuals; in terms of biomass, the marine estuarine dependent also contributed significantly.

Table 1 – Average number of individuals and biomass per net, and average total length of all species that occurred in the samples during the two years, (standard deviation in parentheses).

	AUTUMN 2011			WINTER 2012		
SPECIES	Individuals (n)	Total biomass (g)	Average total length (cm)	Individuals (n)	Total biomass (g)	Average total length (cm)
Ammodytes tobianus	2.7 (2.5)	8.15 (7.59)	9.70 (0.58)	13.5 (11.1)	24.52 (18.82)	8.02 (3.47)
Anguilla anguilla	696.7 (264.6)	124.01 (48.56)	6.73 (0.35)	5459.2 (3123.8)	896.31 (507.18)	13.20 (1.56)
Aphia minuta	11.0 (3.6)	3.98 (2.36)	4.07 (0.67)	52.7 (66.8)	8.04 (6.47)	3.51 (0.67)
Atherina boyerii	1.0 (1.4)	0.48 (0.68)	5.10 (0.60)	1.0 (1.8)	1.21 (2.21)	6.00 (0.50)
Atherina presbyter	-	-	-	0.7 (1.1)	0.93 (1.40)	6.28 (0.53)
Blenniidae NI	-	-	-	0.2 (0.4)	0.01 (0.01)	1.90 (0.00)
Chelidonichthys lucerna	0.7 (0.5)	0.39 (0.38)	3.85 (0.85)	-	-	-
Ciliata mustela	-	-	-	-	-	-
Conger conger	-	-	-	-	-	-
Dicentrarchus labrax	4.7 (6.6)	106.92 (151.21)	12.71 (2.46)	0.7 (0.9)	7.15 (10.12)	11.23 (0.63)
Diplodus annularis	-	-	-	-	-	-
Diplodus vulgaris	1.0 (0.0)	16.68 (1.66)	10.32 (0.85)	-	-	-
Echiichthys vipera	-	-	-	0.2 (0.4)	1.23 (2.75)	8.90 (0.00)
Engraulis encrasicolus	7.3 (7.7)	5.33 (6.06)	5.10 (0.20)	-	-	-
Gobius niger	0.3 (0.5)	0.24 (0.34)	4.60 (0.00)	1.3 (1.4)	2.25 (3.20)	4.89 (2.28)
Hippocampus hippocampus	2.0 (0.8)	1.32 (0.78)	5.83 (0.55)	-	-	-
Liza aurata	-	-	-	-	-	-
Liza ramada	-	-	-	-	-	-
Merluccius merluccius	-	-	-	-	-	-
Mugilidae NI	621.0 (506.7)	26.00 (23.03)	1.76 (0.20)	29.5 (27.5)	2.41 (2.09)	2.29 (0.31)
Platichthys flesus	1.3 (1.2)	39.21 (35.17)	13.85 (0.26)	3.8 (3.1)	65.20 (47.13)	11.62 (2.51)
Pomatoschistus microps	457.3 (276.2)	121.45 (76.09)	3.60 (0.62)	30.7 (16.6)	11.15 (5.32)	3.67 (0.92)
Pomatoschistus minutus	277.7 (128.0)	317.61 (181.85)	5.17 (1.52)	6.0 (5.3)	8.79 (10.11)	5.50 (1.57)
Sardina pilchardus	-	-	-	0.3 (0.7)	2.74 (6.13)	10.55 (0.05)
Scophthalmus maximus	-	-	-	0.5 (0.8)	30.67 (52.65)	16.33 (1.72)
Scophthalmus rhombus	-	-	-	0.2 (0.4)	0.05 (0.11)	2.90 (0.00)
Solea senegalensis	1.3 (0.9)	41.16 (46.07)	13.65 (3.75)	0.8 (0.9)	6.77 (8.13)	9.02 (2.73)
Solea solea	3.0 (2.2)	63.86 (59.81)	12.69 (2.73)	2.0 (1.6)	42.34 (33.90)	12.46 (4.34)
Sparus aurata	-	-	-	-	-	-
Spondyliosoma cantharus	-	-	-	-	-	-
Symphodus bailloni	-	-	-	-	-	-
Syngnathus abaster	0.7 (0.5)	0.08 (0.11)	7.15 (3.45)	1.8 (3.0)	0.44 (0.64)	7.75 (2.38)
Syngnathus acus	37.3 (9.0)	2.3 (1.75)	6.08 (1.95)	2.2 (2.9)	0.50 (0.66)	7.20 (2.31)
Trachurus trachurus	2.0 (2.8)	1.99 (2.81)	5.18 (0.64)	-	-	-
Trisopterus luscus	-	-	-	-	-	-
SPECIES NUMBER	19			20		

Table 1 – Average number of individuals and biomass per net, and average total length of all species that occurred in the samples during the two years, (standard deviation in parentheses); (continuation)

	AUTUMN 2012			WINTER 2013		
SPECIES	Individuals (n)	Total biomass (g)	Average total length (cm)	Individuals (n)	Total biomass (g)	Average total length (cm)
Ammodytes tobianus	20.3 (34.0)	115.34 (188.86)	12.49 (1.59)	0.7 (0.5)	6.95 (8.76)	9.60 (0.0)
Anguilla anguilla	124.5 (227.9)	52.33 (32.05)	12.30 (2.98)	5092.7 (5078.4)	795.19 (782.13)	11.31 (0.2)
Aphia minuta	0.8 (1.9)	0.55 (1.23)	4.96 (0.55)	-	-	-
Atherina boyerii	11.3 (17.2)	12.27 (18.00)	6.00 (0.86)	-	-	-
Atherina presbyter	5.7 (4.2)	28.38 (31.03)	8.68 (2.30)	-	-	-
Blenniidae NI	2.2 (3.7)	0.19 (0.30)	2.95 (0.29)	-	-	-
Chelidonichthys lucerna	11.7 (7.3)	794.54 (556.64)	20.19 (3.67)	-	-	-
Ciliata mustela	1.8 (1.2)	13.29 (11.62)	10.93 (2.58)	-	-	-
Conger conger	0.5 (0.8)	17.23 (33.46)	29.70 (7.47)	-	-	-
Dicentrarchus labrax	31.0 (18.5)	272.27 (192.86)	9.26 (2.50)	29.7 (29.0)	224.98 (223.64)	9.70 (1.6)
Diplodus annularis	0.2 (0.4)	0.36 (0.81)	5.70 (0.00)	-	-	-
Diplodus vulgaris	5.8 (4.8)	77.05 (68.95)	9.85 (1.12)	-	-	-
Echiichthys vipera	1.0 (0.8)	5.18 (6.00)	7.97 (1.98)	-	-	-
Engraulis encrasicolus	10.7 (6.8)	66.73 (43.54)	9.28 (3.14)	-	-	-
Gobius niger	0.5 (0.8)	1.21 (2.12)	6.40 (0.54)	2.7 (3.1)	19.16 (17.98)	8.30 (2.1)
Hippocampus hippocampus	-	-	-	-	-	-
Liza aurata	0.5 (0.8)	4.75 (6.78)	10.70 (2.06)	-	-	-
Liza ramada	0.3 (0.5)	40.26 (88.32)	19.00 (11.0)	-	-	-
Merluccius merluccius	2.2 (1.7)	64.81 (48.38)	17.85 (2.54)	-	-	-
Mugilidae NI	153.3 (241.4)	6.31 (9.22)	1.70 (0.40)	-	-	-
Platichthys flesus	14.7 (10.2)	838.00 (297.37)	15.47 (5.97)	1.7 (1.7)	34.44 (39.54)	12.40 (2.5)
Pomatoschistus microps	405.3 (550.0)	227.91 (403.58)	3.37 (0.72)	5.3 (6.8)	3.74 (4.21)	4.40 (0.5)
Pomatoschistus minutus	196.3 (133.2)	252.88 (137.49)	5.81 (1.43)	4.3 (3.1)	6.35 (6.25)	5.70 (1.5)
Sardina pilchardus	22.3 (7.9)	141.69 (53.66)	9.23 (1.89)	-	-	-
Scophthalmus maximus	-	-	-	-	-	-
Scophthalmus rhombus	-	-	-	-	-	-
Solea senegalensis	2.0 (1.9)	86.51 (130.88)	14.62 (6.55)	-	-	-
Solea solea	7.8 (5.5)	173.62 (137.30)	13.39 (3.91)	2.3 (2.6)	36.34 (48.81)	12.90 (0.9)
Sparus aurata	3.7 (7.3)	41.33 (82.17)	9.18 (0.63)	-	-	-
Spondyliosoma cantharus	0.2 (0.4)	1.11 (2.49)	8.20 (0.00)	-	-	-
Symphodus bailloni	0.2 (0.4)	0.20 (0.45)	4.70 (0.00)	-	-	-
Syngnathus abaster	0.8 (0.7)	0.21 (0.18)	8.70 (1.84)	-	-	-
Syngnathus acus	16.7 (18.1)	3.39 (1.93)	7.79 (2.94)	1.3 (1.2)	0.78 (1.07)	10.50 (5.3)
Trachurus trachurus	1.8 (2.3)	16.24 (32.24)	9.09 (3.89)	-	-	-
Trisopterus luscus	0.2 (0.4)	16.60 (37.12)	20.20 (0.00)	-	-	-
SPECIES NUMBER	32			9		

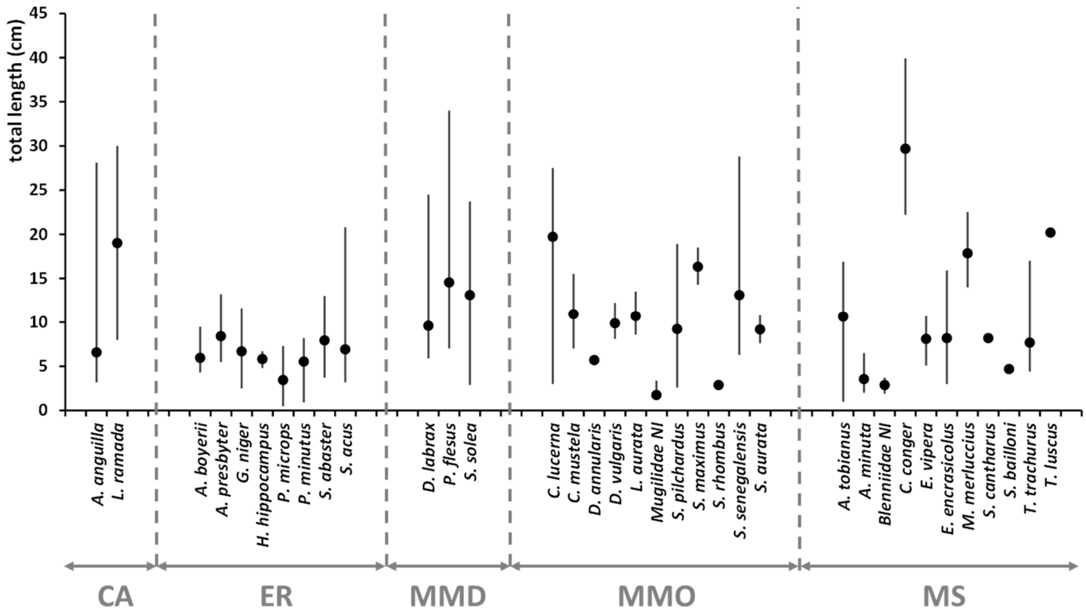

Fig. 5 - Total length range (maximum and minimum observed TL, black circles represent the average) of all species that occurred in the samples during the two years, grouped by ecological guild (CA—catadromous; ER—estuarine residents; MMD— marine estuarine dependent; MMO—marine estuarine opportunist; MS—marine stragglers).

In the autumn 2012, the percent composition of the fish catches was similar, despite the higher relative abundance of estuarine residents and higher relative biomass contribution of marine estuarine dependent and opportunist species (Fig. 6c). An increase in marine stragglers (MA) was also noticed in the autumn of 2012, as observed in Fig. 6c. As for the winters, both years were characterized by a large contribution of catadromous species (that include eels) in both number of individuals and biomass (Fig. 6b,d).

Considering the feeding preferences of the fish caught, the results showed that during the two periods the invertebrate feeders (IS) represented the main occurrences in both number of individuals and biomass (Fig. 7). An exception was observed in the autumn 2012, when the fish feeders (IF) were dominant in terms of biomass (Fig. 7c).

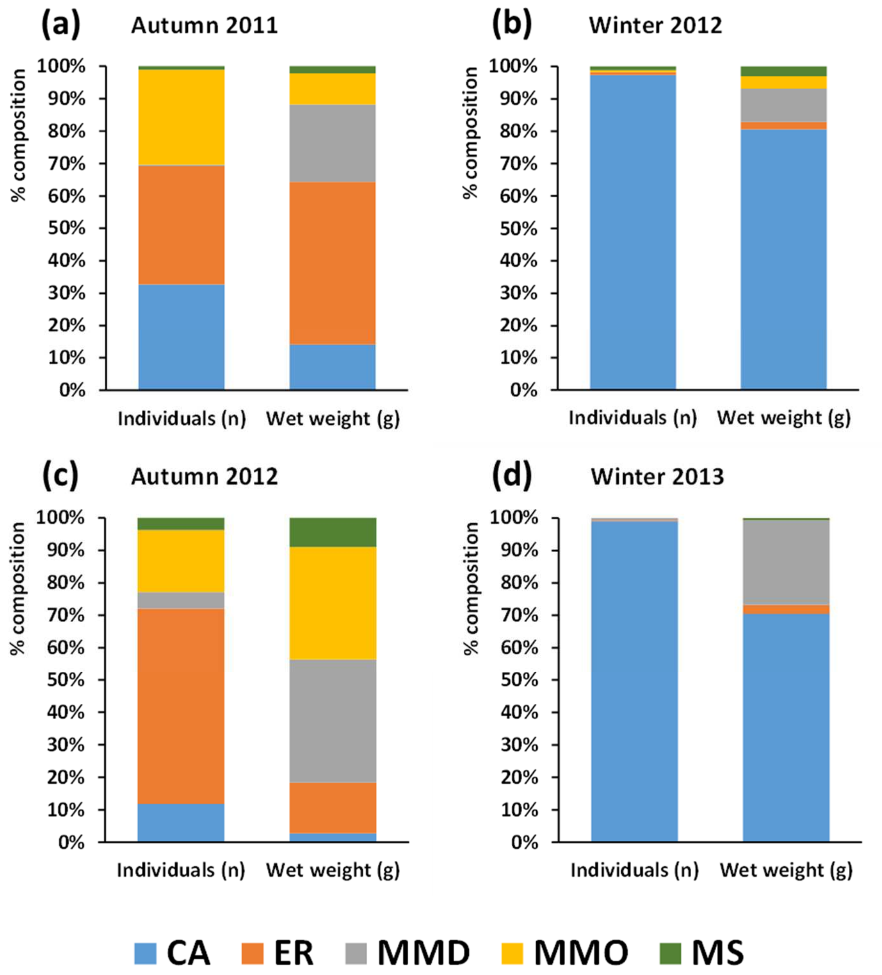

Fig. 6 – Ichthyofauna captured during (a) autumn 2011, (b) winter 2012, (c) autumn 2012 and (d) winter 2013, by ecological guild (CA—catadromous; ER—estuarine residents; MMD— marine estuarine dependent; MMO—marine estuarine opportunist; MS—marine stragglers).

This increase in fish feeders, as well as of planktivorous species, matched the increase in marine stragglers (MA), in both number of fish and biomass. In both autumns, omnivorous species (OV) were also important in terms of number of individuals (Fig. 7a,c); however, this was not observed in terms of biomass. Omnivorous species were also not relevant in the winter samples (Fig. 7b,d).

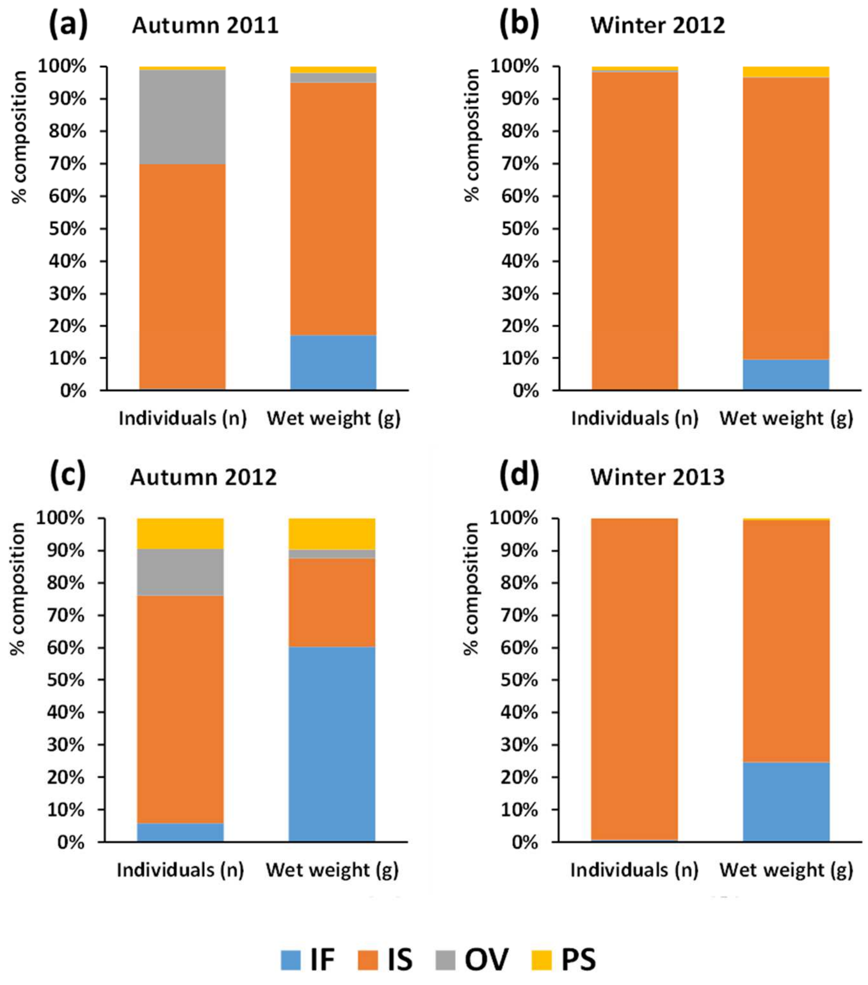

Fig. 7 – Feeding guild composition of the fish fauna captured during (a) autumn 2011, (b) winter 2012, (c) autumn 2012 and (d) winter 2013; (IF - invertebrate and fish feeders; IS - invertebrate feeders; OV - omnivorous; PS - plankton feeders).

Isolating the data of the two *Pomatoschistus* species (*P. microps* and *P. minutus*), which represent the majority of resident species and of the whole fish assemblage, their occurrence was constant throughout the seasons of the year of study (Fig. 8). In all seasons, higher number of individuals was observed for *P. microps*; however, *P. minutus* contributed more in terms of biomass. The only exception was in the winter 2012, when *P. microps* were more abundant in terms of individuals and biomass (Fig. 7b).

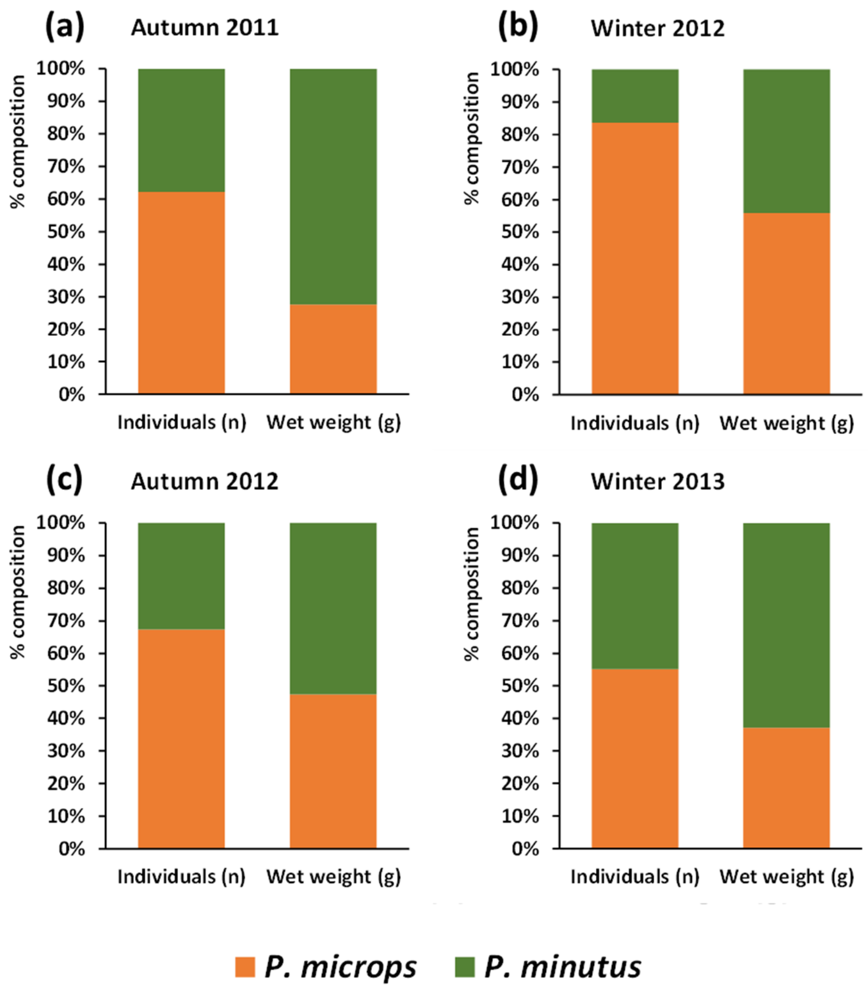

Fig. 8 – Relative composition of the main resident species (*P. microps* and *P. minutus*) in terms of number of individuals and wet weight, captured during (a) autumn 2011, (b) winter 2012, (c) autumn 2012 and (d) winter 2013.

Considering the species that use the estuary as a nursery ground (marine estuarine dependents), the results showed considerable differences over the two years of the study for *D. labrax*, *P. flesus* and *S. solea*. *While S. solea* catches represented a higher percentage of occurrence during the regular year (Fig. 9a,b), *P. flesus* corresponded to the majority of individuals and biomass, in the winter 2012 (Fig. 9b). In autumn 2012 (Fig. 9c), although *P. flesus* did not represent the majority of individuals captured, they made up the majority in terms of the biomass caught. In the winter 2013 (Fig. 9d) *D. labrax* accounted for nearly 90% of the number of individuals and 80% of the biomass.

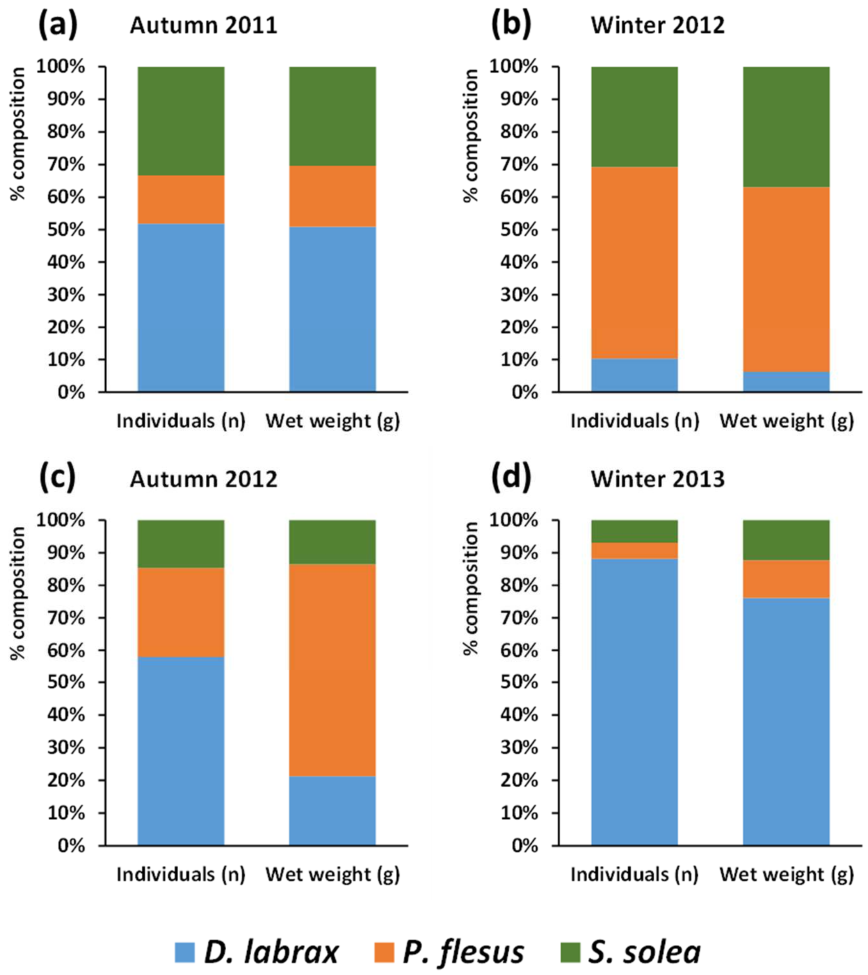

Fig. 9 – Relative composition of the marine estuarine dependent species (nursery species) *D. labrax*, P. *flesus* and *S. solea*, captured during (a) autumn 2011, (b) winter 2012, (c) autumn 2012 and (d) winter 2013.

Inter-annual and inter-seasonal differences in fish community composition were assessed by means of a multi-dimensional scaling (MDS) plot. In the MDS, considering the number of individuals (Fig. 10a), significant differences between seasons were observed (winters and autumns), but not between the distinct hydrological years, considering a 30% similarity cutoff value (green line, Fig. 10). Considering the biomass (Fig. 10b), differences were only observed between the rainy year autumn (2012) and the remaining seasons.

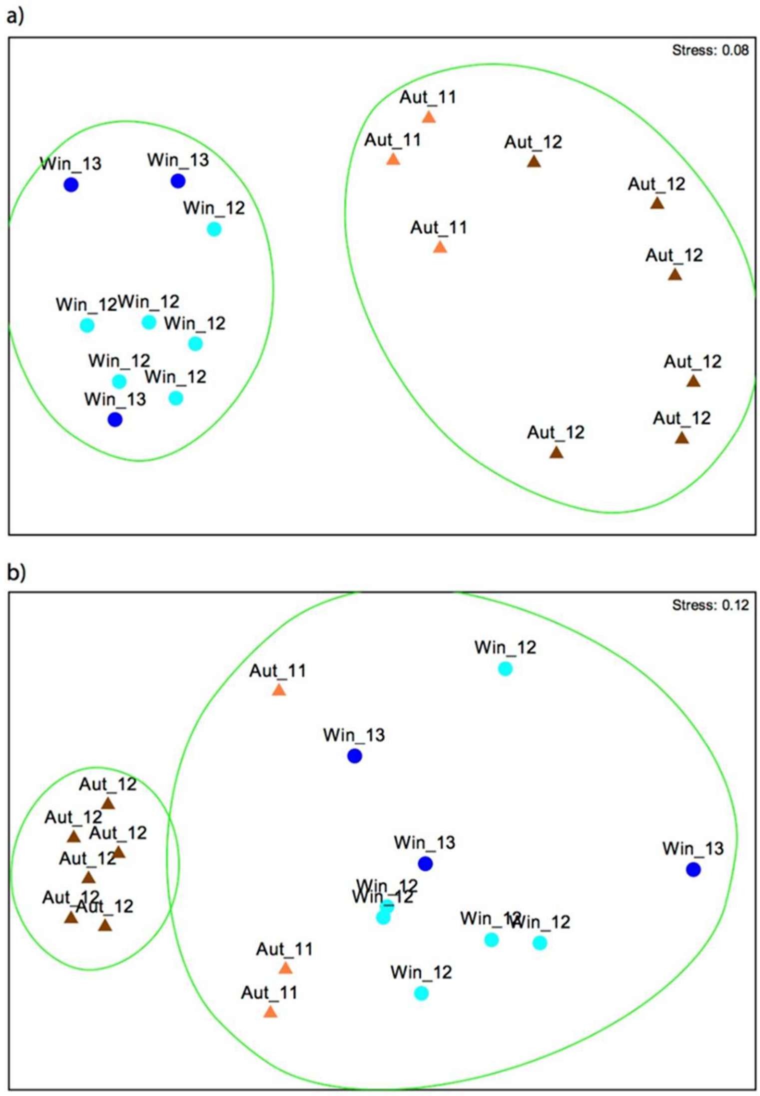

Fig. 10 - Multidimensional scaling plot (MDS) for (a) number of individuals and (b) wet weight; 30% similarity is represented by the green line.

Analyzing the differences in fish community composition in the glass ell nets in more detail, and considering the number of individuals, differences were confirmed for the factor season. However, a significant interaction between years and seasons was also observed (PERMANOVA, Years x Seasons: Pseudo F=3.5194, $p<0.05$), indicating that the differences in seasons are dependent on the year considered. In particular, the community composition was different in both autumns (PERMANOVA pair-wise test, autumn: $p<0.05$). Similar results were obtained for the wet weight data, regarding the seasonal effect and interaction between seasons and years (PERMANOVA, Years x

Seasons: Pseudo F=3.1324, p<0.05). (PERMANOVA pair-wise test, autumn: p<0.05), confirming the results obtained in the MDS plot. Overall, both analyses identified the autumn of 2012 as the most distinct season, characterized by a higher species number (32), as shown previously in Table 1.

3.4 **Estimated impacts of glass eel fisheries**

The impacts of glass eel fisheries were estimated for the glass eel alone, the marine estuarine dependent species and for the whole fish assemblage, considering the different hydrological years. As stated previously, and despite that the glass eel catches did not vary between the different years, the large difference between years was in the number of non-target species captured. In the two hydrological years, the ratios “nursery spp:glass eel” and “all spp:glass eel” were different: 0.23 and 0.49 for 2011/2012; 3.42 and 4.58 for 2012/2013.

Considering those ratios and the projections for the several scenarios, for the conservative value of 25 daily nets, the estimated catches for the fishing season of 2011/12 (Fig. 11a) were nearly 1.2 tonnes of glass eel, 0.3 tons of the nursery species, and a total of 0.6 tons in fish. For the moderate value of 50 daily nets the estimated catches for the same fishing season were 2.5 tonnes of glass eel, 0.5 tons of the nursery species, and a total of 1.2 tons in fish. The same way, for an excessive value of 75 daily nets the estimated catches for the same fishing season were 3.8 tonnes of glass eel, 0.9 tons of the nursery species, and a total of 1.8 tons in fish.

For the fishing season 2012/2013 (Fig. 11b), the estimated catches considering the conservative value of 25 daily nets were 1.0 tonnes of glass eel, 3.5 tons of the nursery species, and a total of 4.7 tons in fish. For the moderate value of 50 daily nets the estimated catches were 2.0 tonnes of glass eel, 7.0 tons of the nursery species, and a total of 9.3 tons in fish. In an excessive value scenario of 75 daily nets, for this fishing season, the estimated catches for the same fishing season were 3.1 tonnes of glass eel, 10.5 tons of the nursery species, and a total of 14.0 tons in fish.

Comparing the fishing seasons, the estimated impact should be nearly 10 times higher in a rainy year, given the higher species number and biomass of catches.

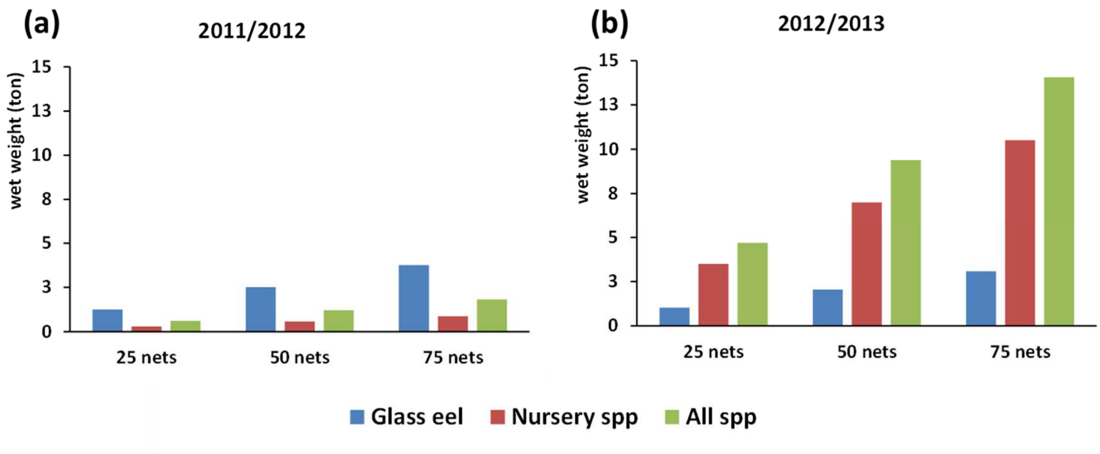

Fig. 11 – Projection of total catches (wet weight, ton) of glass eel, nursery species and all species combined for the (a) 2011/2012 and (b) 2012/2013 fishing seasons, considering a duration of 150 fishing days and for 25, 50 and 75 daily nets.

CHAPTER 4 – DISCUSSION

4.1 Environmental conditions

This study described the impacts of illegal glass eel fishery in the Mondego estuary, Portugal, considering both target and non-target fishes. The particular hydrographic conditions within the sampling period (regular vs rainy) allowed understanding in more detail the impacts of these illegal practices on the local fish fauna. During the study period, the salinity gradient showed a high temporal variation, with lower average salinity in the estuary caused by an increase in precipitation and freshwater inflow, in 2012. Hence, it was possible to characterize the sampling season of 2011/12 as a regular period, while the 2012/13 season was considered rainy. Considering that the salinity gradient is one of the major structuring forces of estuarine fish assemblages (e.g. Elliott and Dewailly 1995; Costa et al. 2007; Martinho et al. 2007), it was expected that different community composition would be present in the samples as non-target species. For instance, and according to Martinho et al. (2009), higher precipitation and river runoff were associated with higher abundance of juvenile *Platichthys flesus, Solea solea* and *Dicentrarchus labrax,* highlighting the importance of hydrology in the life cycle of marine fish within estuarine areas, including migration patterns, distribution or even occurrence of new species or uncommon species (opportunistic and strangler species) (e.g. Martinho et al. 2010), as also showed by the occurrence of different species in both periods. Since the average water temperature was relatively constant during the sampling seasons, it is expected that this parameter did not influence significantly the composition of fish catches.

4.2 Glass eel catches

Analyzing the two years of study, no significant differences in catches of glass eels could be observed between the different years, showing that in this case, the hydrological characteristics do not affect those catches. These results are in agreement with Domingos et al. (1991; 2006), who reported that river flow might have a weaker influence on the distribution and abundance patterns of the European eel than other environmental variables like habitat structure and distance from the sea. Considering the seasonal effects, catches of glass eels were much higher in both winters, corresponding to more than 97% of the total fish catches. These results reflect the migration period towards Portuguese estuaries, confirming that the most voluminous entry of this larval stage in Iberian estuaries occurs in early winter (Gisbert & López, 2008).

The lack of variability in total length and wet weight during the study period can indicate a mixing between glass eel which entered the estuary at different periods, which suggestis an extended period of migration, as also observed by Bardonnet and Riera (2005) in a French estuary (Biscay Bay), associated with an abundant food supply. In turn, Elie and Rochard (1994) demonstrated that "late" glass eels are smaller than "early" glass eels in the Gironde estuary, France, which was not observed in the Mondego estuary.

A large amount of glass eel catches will bring long-term problems in populations of European eel, leading to their declining (Antunes, 2008). For this situation, the capture or possession of glass eel, for consumption or sale was forbidden in most European countries (Moriarty and Dekker, 1997). Unfortunately, despite being a crime, illegal fishing is still a problem, contributing to the decline of the European eel populations.

4.3 Glass eel fisheries impact in local ichthyofauna

During the study period, along with the capture of the target species (*A. anguilla*), these illegal nets captured more 35 incidental species. These species account for 81% of the total species number recently demonstrated for the Mondego estuary (43 species; Nyitrai et al. 2012), including two new ones that had never been described before in published literature: the European hake *M. merluccius* and turbot *S. maximus*. Besides eel, the most abundant species were the common goby *P. microps*, sand goby *P. minutus*, Mugilidae fry, European seabass *D. labrax* and the greater pipefish *S. acus*, reflecting the overall dominance trends in the Mondego estuary fish assemblage (Leitão et al. 2007; Martinho et al. 2007; Baptista et al. 2010; Nyitrai et al. 2012). The exception is the mugillid fry, which are not frequently found in beam trawl samples, which targets more benthic and demersal species (Hemingway & Elliott, 2002). Nevertheless, mugillid fry were also among the most abundant fishes in a pilot study on the impact of this practice on species bycatch, in the Ebro River, Spain (Gisbert & López, 2008).

As expected, inter-annual seasonal differences in fish community composition and abundance were observed, in agreement with several authors (e.g. Drake et al., 2002; Sobrino et al. 2005), highlighting the role of seasonal changes on the possible impact of these illegal practices on estuarine fish assemblages. In agreement, Antunes and Weber (1996) showed a large temporal variability in size and composition of bycatch in the Minho River, Portugal. The presence of eel and other fish species demonstrated an inverse relationship, as also demonstrated by Antunes and Weber (1996): the winter samples, which were characterized by a higher abundance of eel, were also the ones with lower diversity. These results contrast with those obtained by Gisbert & López (2008), who obtained a positive relationship between glass eel and other fishes' biomass.

The present results revealed that the smaller fish were more susceptible of being captured in the glass eel nets. In fact, there were only a few species (A. anguilla, L. ramada, P. flesus, C. lucerna, S. senegalensis and C. conger) whose total length range exceeded 25 cm. This indicates that most of the bycatch is composed either by juveniles of larger species, or by all life stages of smaller species, such as the estuarine resident gobies, pipefish and sand smelts. Hence, it is expected that high size-selective juvenile mortality will hinder the production potential of most affected species (Blaber et al. 2000; Davis 2002; Gisbert & López, 2008), since many of these species use estuaries as nursery grounds. This will increase even more the bottleneck effect induced on fish growth and survival by the carrying capacity and habitat quality of the estuary (Le Pape et al., 2003; van der Veer and Leggett, 2005).

An assessment of the impact on the functional structure of the fish community was performed, indicating that the structure in terms of ecological and feeding guilds of the fish catches was similar to the one previously established for the Mondego estuary (Martinho et al. 2007; Baptista et al. 2010; Nyitrai et al. 2012), and also for other European estuaries (Elliott and Dewailly 1995, Franco et al 2008). These results also reflected the non-selectivity of the glass eel nets, since the species that compose the natural communities of the estuary and those that occurred in the net are quite similar. The results showed that there was an effect of the seasons within the years in terms of community composition: the autumn 2012 stood out, being different from the other seasons for having the highest number of species captured, associated with the increase of rainfall during this period.

From a feeding preferences point of view, although most fish species captured belonged mostly to invertebrate feeders, there was a notorious increase of piscivorous species in the autumn 2012, reflecting the increase of opportunist and strangler marine species that exhibit this type of feeding strategies, such as *Sardina pilchardus* and *Ammodytes tobianus*.

An increasing number of catadromous species was captured during the winters, justified mainly by an increased migratory pulse of glass eels, as supported by Gisbert & Lopez (2008). On the other hand, during autumns, due to the low amounts of glass eel, results indicated a high amount of incidental species captured that belongs to other ecological guilds.

Focusing on the resident species, the results showed that this group was the most affected during regular year autumn (2011), mainly the *Pomatoschistus minutus* and *Pomatoschistus microps*. Also, results showed that the proportion reflects the natural occurrence in the estuary, with a higher number of *P. microps* in relation to *P. minutus* (Baptista et al, 2010; Nyitrai et al, 2013). Still, being an important part of the total catches, the impact of the nets can influence this and higher trophic levels, since *Pomatoschistus* species are an important link between the benthos and fish top predators.

During the rainy year autumn, beyond the impact on residents, results showed an impact on marine estuarine dependent (nursery species) and opportunist species, especially in terms of biomass.

This case study also seeks to understand if glass eel illegal fishing had impact on marine fish species that use the estuary as nursery areas: *Platichthys flesus, Solea solea* and *Dicentrarchus labrax*. These species are among the most abundant marine fishes in Portuguese estuaries (Costa et al., 1989; Cabral et al., 2007; Freitas et al, 2010; Vasconcelos et al., 2010), with typical seasonal abundance patterns (e.g. Martinho et al., 2009). Results showed that the main differences were observed in the winters, dominated by flounder (*P. flesus*) in regular year winter (2012), while seabass (*D. labrax*) composed a higher percentage of the catches in the rainy year winter (2013). This may be due to fluctuations in the population dynamics of the two species, which varies depending of the hydrology (Martinho et al, 2009). In the autumn, the impact patterns were similar, but flounder (*P. flesus*) had higher biomass in rainy year (2012), while sole (*S. solea*) suffered a higher impact in autumn 2011 and winter 2012, comparing with the other seasons. The small mesh and low selectivity of glass eel nets had a high impact on marine fish that use the estuary as a nursery area, especially on the early life stages such as larvae and juveniles. In addition, part of the glass eel fishing season coincides with the onset of the period of estuarine colonization of juvenile marine estuarine dependent fish species, which will have serious impacts for these species (Martinho et al. 2007; Dolbeth et al. 2008; Primo et al. 2013). This situation reinforces the need for more targeted surveillance and enforcement of the current prohibition of this activity in Portuguese estuaries.

Another impact on these and other species comes not only from the direct mortality by being trapped in the nets, but also from the sorting procedure by the fishermen, which leads to higher air exposure and physical damage, such as scale loss, skin abrasions, superficial and internal wounds (Gisbert & López 2008). This situation is, according to the previous authors, exacerbated in the case of smaller fish, independent of species or developmental stage.

4.4 Projected scenarios and their impacts

As previously mentioned, there were no significant differences in glass eel catches in the two years, in contrast with the non-target species catches. In order to clarify the impact that glass eels fishing have on the estuarine communities, we performed a projection of the total annual catch. This projection was one of the first attempts to quantify the removal of glass eel and other accidental species over two consecutive fishing campaigns, with distinct climatic conditions. Unfortunately, since these practices are illegal, and the information and previous studies in terms of projections are virtually nonexistent, it was not possible to ascertain the exact number of nets operating simultaneously in the Mondego estuary. Still, considering previous projections of legalized and regulated glass eel catches in Spanish estuaries (Gisbert & López, 2008), we considered different scenarios: 25 (conservative), 50 (moderate) and 75 (excessive) nets deployed daily.

The projections indicated that in the case of incidental species catches, the rate of capture between them and the glass eel was about 10x higher on a rainy year, compared to a regular year. Whereas in a regular year fishing season for each ton of glass eel, 0.5 ton of incidental species would be captured, this scenario is completely altered in a rainy year, in which for the each ton of glass eels would be caught 4.6 tonnes of incidental species, out of which 76% (3.5 tonnes) would be only regarding the three species that use the estuary as nursery (*Platichthys flesus, Solea solea* and *Dicentrarchus labrax*).

During a rainy year fishing season, whatever the scenario projected, the nursery species catches values were always a signal to a serious problem, since this practice significantly influences these species' life cycle and developmental stages, due to the continuous removal of individuals, especially juveniles.

4.5 Final considerations

This work elucidated for the high negative impact of these illegal practices, especially during wet years. As shown previously, the global impact of this illegal practice might lead to several changes in some levels of biological organization within estuaries, as also suggested by Alverson (1994) and Gisbert & López (2008). This is due to the substantial removal of several species, particularly their early life stages, providing an additional mortality source that might compromise their growth and reproductive potential. Despite that the distinct hydrological conditions did not seem to influence the number of glass eels, they influenced the occurrence of the other species, leading to high unintentional catches, which in turn will alter the functioning of estuarine communities and their trophic networks. In terms of functional structure, non-target catches were mainly composed of estuarine residents, marine estuarine dependents, catadromous species and invertebrate feeders, following the typical community structure of estuarine fish assemblages. Overall, this demonstrated the non-selective and potential hazardous traits of these illegal nets. Considering the proposed scenarios in terms of number of deployed nets over the fishing season, the results suggested that the mortality of both glass eel and non-target species ranged between several hundreds and thousands of kilos depending on the hydrological features, which will have an impact at both ecological and economical scales. This work also highlighted the importance of promoting an effective protection of glass eel stocks, considering that the effects of these illegal fishing practices are far more reaching than previously anticipated.

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