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Impacts of environmental changes on bivalves harvesting in Portuguese coast

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"Mar sonoro, mar sem fundo mar sem fim.
A tua beleza aumenta quando estamos sós.
E tão fundo intimamente a tua voz
Segue o mais secreto bailar do meu sonho
Que momentos há em que eu suponho
Seres um milagre criado só para mim."

Sophia de Mello B. Andresen

Aos meus pais…

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Resumo

As preocupações com os efeitos das alterações ambientais nos ecossistemas marinhos são vastas. Estas alterações no ambiente abiótico marinho podem afetar a sobrevivência, crescimento, reprodução e distribuição das espécies, mas os impactos também podem ser exibidos ao nível da comunidade, população e ecossistema. Nas últimas décadas tem havido um interesse crescente no efeito das alterações ambientais sobre os stocks pesqueiros. Sabe-se, agora, que as alterações ambientais podem afetar a produtividade e distribuição das populações exploradas. Assim, compreender os efeitos da variabilidade ambiental na produção marinha pode ter grande valor se integrados na gestão da pesca costeira.

Em Portugal, a apanha de bivalves é uma actividade artesanal e tem grande importância ao longo da costa. Diversos fatores podem afetar o crescimento e a mortalidade de larvas de bivalves. A principal questão é saber se esses fatores ambientais têm impacto nas capturas de bivalves. Assim, esta Dissertação de Mestrado foi dividida em dois estudos.

O primeiro teve como objetivo avaliar a influência de fatores ambientais e da pesca sobre os desembarques de espécies bivalves lagunares costeiras (intertidais) e de espécies bivalves costeiras (subtidais). Os resultados mostraram que, devido à sensibilidade distinta dos dois habitats analisados, a resposta às variáveis ambientais das espécies bivalves lagonares (*Cerastoderma edule* e *Ruditapes decussatus*) e das espécies bivalves costeiras (*Chamelea gallina*, *Pharus legumen*, *Donax spp*. e *Spisula solida*) foi diferente. O índice de upwelling teve um efeito significativo nos bivalves da lagoa, enquanto o índice NAO,magnitude e direcção do vento, e as descargas fluviais afetaram as espécies de bivalves costeiras.

Compreender o efeito do clima e da pesca à escala regional é importante para ações de gestão local. Assim, no segundo estudo, foi analisado se as capturas de bivalves costeiros (*S. solida*) em diferentes regiões são afetadas da mesma forma pelas mesmas restrições ambientais e da pesca. Os modelos para a análise de dados de séries

temporais apresentaram padrões distintos de sensibilidade das capturas de *S. solida* à variabilidade climática entre as três regiões costeiras, devido às distintas características ambientais e da pesca presentes nessas regiões. Na região Noroeste, os resultados mostram que a combinação de índices NAO com a temperatura da superfície do mar teve um efeito importante sobre as populações de *S. solida*. No sudoeste, as variáveis ambientais que melhor explicaram a variação nos desembarques de *S. solida* foram a magnitude e direção do vento. O escoamento dos rios e a temperatura da superfície do mar foram os fatores que mais afetaram as capturas de bivalves na região Sul. O esforço de pesca teve um efeito positivo nas capturas de bivalves na região Sul.

Assim, esta Dissertação de Mestrado evidenciou que é necessário considerar a variabilidade dos efeitos ambientais em ações de gestão das pescas, tendo em conta a variabilidade regional e do ecossistema.

Abstract

Concerns about the effects of environmental changes on marine ecosystems are widespread. These changes in the abiotic marine environment can affect survival, growth, reproduction and distribution of species, but the impacts can be also displayed at the population, community and ecosystem level. In recent decades there has been growing interest in effects of environmental change on fisheries stocks. It is Know, now, that the environmental change can affect the productivity and distribution of exploited stocks. Thus, understanding the effects of environmental variability on marine production could be of great value if integrated into management of coastal fisheries.

In Portugal, the bivalves harvesting is an artisanal activity and have great importance along the coast. Several environmental factors may affect the growth and mortality rates of bivalve's larvae. The issue is whether these environmental factors have impact on bivalve catches. To this end, this Master Thesis was divided in two studies.

The first study aims to evaluate the influence of climatic, environmental and fisheries factors on the landings of intertidal coastal lagoon and coastal bivalve species (subtidal nearshore species). The resultas showed that, due to the distinct sensitivity of the two analyzed habitats, lagoon bivalve species (*Cerastoderma edule* and *Ruditapes decussatus*) responded to different environmental variables than the coastal bivalve species (*Chamelea gallina*, *Pharus legumen*, *Donax spp*. and *Spisula solida*). Upwelling index had a significant effect on the lagoon bivalves while the NAO index, wind magnitude and direction and offshore discharges only affected the coastal species.

Understanding the effect of climatic and fishery at regional scale is therefore important for local management actions. Thus, in second study, it was analyzed if coastal bivalve catches (*S. solida*) in different regions are affected similarly by the same environmental and fishery constraints. The models for the analysis of time series data, in second study, showed distinct sensibility patterns of *S. solida* catches to climatic variability between three Portuguese coastal regions, due to the distinct environmental and fisheries characteristics present in these regions. In Northwestern, the results show that

combination of NAO indexes and sea surface temperature had a major effect over *S. solida* populations. In Southwestern, the environmental variables that most *explain S. solida* catches variation were both magnitude and wind direction (wind components). River discharges and sea surface temperature showed to be the factors most affect species trend in South region. The fishing effort was only correlated with changes in LPUE trends in South region.

Thus, this Master Thesis propose that is necessary considering the background effects environmental variability in fisheries management actions taking in account the regional and ecosystem variability.

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CHAPTER 1

General Introduction

General Introduction

In recent times there has been growing interest in environmental variability and its effects of fisheries and ecosystems. In past, was assumed that marine communities was naturally stable, and that majority of changes was provoke by the man. Only in recent decades, the variability of marine ecosystems has been linked to climate variability (Morri and Bianchi, 2001).

The environmental variability denotes changes in environment at seasonal, annual and decadal scales (Brander, 2007; Lehodey *et al*., 2006). The environmental variability such as in the field of air and water temperature, precipitation, salinity, wind, currents, ocean circulation, river flow, nutrients levels, sea level, ice cover, glacial melt, frequency and intensity of storms and floods can affect the productivity and distribution of exploited stocks (Barange, 2002; Brander, 2007; Harley *et al.*, 2006; Lehodey *et al*., 2006; Lloret *et al*., 2001; Stenseth *et al*., 2003).

The temperature is essential for the structure and function of biological systems due to her penetrating effects on physiology, behavior, distribution and migration (Bertram *et al*., 2001). The NAO index (North Atlantic Oscillation), the dominate mode of atmospheric variability in winter above climate of northern Europe (Parsons and Lear, 2001), influences a series of ocean characteristics: velocity and wind strength, modulation of depth ocean temperature, salinity punctual alteration, storms trajectory in Atlantic Ocean, evaporation and precipitation patterns, etc. (Boelens *et al.*, 2005). All of these characteristics are implicated on changes in timing of reproduction, population dynamics, abundance, distribution and inter-specific relationships such as competition and predator-prey interactions (Ottersen *et al.*, 2001). Alterations in strength and direction of wind influence the circulation and water mixture and disturb upwelling intensity in coastal regions, affecting the primary productivity and, eventually, the productivity of superior levels. The primary productivity can also be influenced through changes in precipitation and river flow (Rijnsdorp *et al*., 2009).

The impacts of fishing activity and climate changes interact in different ways. The fishing activity provokes direct and indirect changes in commercial exploited species and in marine ecosystems (Brander, 2007, 2010). The direct effects includes alterations in abundance (growth, reproductive capacity and mortality) and distribution of exploited species (Brander, 2007, 2010; Dulvy *et al.*, 2008; Lehodey *et al*., 2006; Perry *et al*., 2005). The indirect effects change the productivity, structure and composition of marine ecosystems which individuals are dependents (Brander, 2007, 2010). The biodiversity loss and reduction of the demographic and geographic structure, due to fishery, results in a greater sensibility of halieutic resources and marine ecosystems to climate change. Moreover, the climate changes may reduce, or even in some cases improving, the stocks productivity through of effects on production, survival, growth and offspring (Brander, 2007).

Most of the major global fisheries have been affected by regional climatic variability (Brander, 2007), leading to an increasing concern about the consequences of climate change for the fisheries production and condition of marine ecosystems (Brander, 2010; Coyle *et al*., 2011). Examples of climate impacts on fisheries are well documented. Daskalov (1999) found a significant relationship between environmental fluctuations (sea surface temperature, wind speed, wind stress, wind mixing, sea level atmospheric pressure and river run-off) and stock biomass of sprat (*Sprattus sprattus*), whiting (*Merlangius merlangus*), anchovy (*Engraulis encrasicolus*) and horse mackerel (*Trachurus mediterraneus*) in Black Sea. Planque and Frédou (1999) suggest that Atlantic cod recruitment is positively related to temperature for cold-water stocks and negative for stocks habiting relatively warm waters. Sirabella *et al.* (2001) assert that a positive NAO (North Atlantic Oscillation) phase with high sea temperature is unfavorable for North Sea cod recruitment. Drinkwater (2005) reported the slow growth and cod in poor condition of the Northern cod fisheries off southern Labrador and northeast Newfoundland due the persistent cold ocean temperatures in the region.

Along the Portuguese coast environmental conditions have been reported by Santos and Miranda (2006) in SIAM II Project. The sea surface temperature increased consistently in coastal regions (+ 0.010 ºC/year) between 1941 and 2000, leading to increase of thermal gradient between the surface and the bottom (Sousa Reis *et al.*, 2006). The systematic increase of North Atlantic Oscillation (NAO) index in 1960s and the 1990s was associated with a reduction in rainfall in late winter and early spring (Miranda *et al*., 2006). The yearly strength of wind in western coast decreased significantly among 1941 and 2000, in contrast to the Algarve coast, where the wind intensified slightly during the same period. It was observed a remarkable weakening in upwelling regime on the

Western coast, due to weakening of north winds (upwelling favorable) on several months of the year, especially between April and September, and only intensified in March (Sousa Reis *et al.*, 2006). And, in the coming years, it is expected that Portugal faces rapid alterations in temperature and precipitation which are expected to be more marked than the global mean alterations rate (IPCC, 2001). For Portuguese waters, some studies were carried, proving that the biology and ecology of fisheries resources are influenced by relatively small changes in sea water temperature, the direction and intensity of winds, precipitation and river runoff, among other factors. Santos *et al*. (2001) reported a negative impact of upwelling events observed off Portugal during winter months on recruitment of sardine (*Sardina pilchardus*) and horse mackerel (*Trachurus trachurus*). Sousa Reis *et al.* (2001) analyzed long-term changes in sardine (*S. pilchardus*), bluefin tuna (*Thunnus thymus*) and octopus (*Octopus vulgaris*) in relation to upwelling, NAO and turbulence indices. They concluded that the intense upwelling can lead to decrease of sardine biomass in Southwestern coast of Portugal. Bluefin tuna dynamics seem to be related with NAO and in other hand it is likely that an increase in sea surface temperature will considerably change the population response in the Northeastern Atlantic, expecting an enhancement of recruitment and a recovery in bluefin abundance in the next decades. In the octopus case, the rise of sea surface temperature in future can negatively affect the recruitment process. Borges et al. (2003) showed long-term changes in sardine (*S. pilchardus*) abundance off the Western coast of Portugal with similar decadal periodicity to wind and NAO time series, and concluded that recruitment is lower when the frequency and intensity of northerly winds exceeds a certain limit in winter. Erzini (2005), studied interactions between coastal fisheries and climatic data series, showing that the Guadiana River flow is the environmental variable that most affects Algarve landings.

In case of bivalve's molluscs, a substantial part of the recruitment variability seems related to the climate (Beukema, 1992; Philippart *et al.*, 2003; Young *et al.*, 1996). Several environmental factors such as temperature and salinity (Calabrese, 1969; Chícharo and Chícharo, 2000), food supply (Chícharo and Chícharo, 2000, 2001; Pechenik *et al.*, 1990), advection effects (or physical mechanisms) (Richards *et al.*, 1995), predation, or fixation (Chícharo and Chícharo, 2000) may affect the growth and mortality rates of bivalves larvae. The issue is whether these environmental factors have impact on bivalve catches, and how these drivers operate.

Bivalves constitute the second largest class, in terms of number of species, of the phylum Mollusca. These animals are compressed laterally and the soft body parts are completely or partially enclosed by the shell, which is composed of two hinged valves (Afonso, 2010; Helm and Bourne, 2004). These molluscs are distributed in the most diverse habitats from marine environments to fresh and brackish waters. Some species, such as the cockle and the donax, live burrowed in soft substrate, while others such as the oyster and the common musse lived attached to rocks and other hard substrates or , can live free such as scallops (Afonso, 2010). The size (age) of the bivalve along with temperature and quantity and quality of food are undoubtedly important in sexual maturity and initiating gametogenesis. Spawning may be triggered by several environmental factors including temperature, chemical and physical stimuli, or a combination of these and other factors. In temperate areas, spawning is usually confined to a particular time of the year (Helm and Bourne, 2004). The large majority of bivalves have separate sexes, although hermaphrodites and change of sex along the life cycle (e.g. oyster) also exist. In most species the gametes are discharged into the water, with fertilization being either external, when it occurs in open water (e.g.cockles, clams), or internal (e.g. oyster). The majority of species have pelagic larvae that after few weeks (18-30 days) settle to the bottom, where metamorphosis begins when a suitable substrate is found. This process is a critical time in the development of bivalves, during which the animal changes from a swimming, planktonic to a sedentary benthic existence (Afonso, 2010; Dame, 1996; Helm and Bourne, 2004). Most of bivalves are filter feeders and feed mainly on micro-algae present in plankton filtered from the surrounding water. However, small groups feed fine particles of non-living organic material (detritus) along with associated bacteria and also dissolved organic material (Afonso, 2010; Helm and Bourne, 2004). The growth varies greatly between species, climate, location (subtidal or intertidal zones), etc. Growth can also vary greatly from year to year and in temperate areas there are seasonal patterns in growth, that is, growth is generally rapid during spring and summer when food is abundant and water temperatures are warmer, and it virtually ceases in winter. Bivalves can die from a variety of causes. For example, too high temperatures or prolonged periods of cold temperatures can be lethal to bivalves as can be sudden swings in temperature; severe extremes in salinities, particularly low salinities after periods of heavy rain, can also cause extensive mortalities; heavy siltation can smother and kill juveniles and adults; bivalves can be preyed upon by a wide variety of animals that can cause severe mortalities, it is the case of plankton feeders that probably consume large quantities of larvae; yet, bivalves can also be hosts to parasites that can cause mortalities (Helm and Bourne, 2004). On the other hand, in coastal zones a great fishing mortality occurred.

The molluscs bivalves harvesting is a common activity in many areas of Southern Europe. It is an ancient and traditional activity that occurs along the oceanic coast of Portuguese mainland (Gaspar *et al.*, 1999, 2001, 2005b). The harvesting of bivalves was restricted to estuaries and lagoons until the 1960s. So, the exploitation of bivalve ocean beds along the Portuguese coast is recent and was initiated in 1969 by the Spanish fleet under the auspices of the ''Portuguese-Spanish Fishery Agreement''. The high economic value of ocean bivalve species in the external market soon aroused great interest in the Portuguese fleet (Gaspar *et al.*, 1999). Presently, bivalves are socially and economically important for local population (Chícharo *et al.*, 2002; Gaspar *et al.*, 2005a; Rufino *et al*., 2010). The coastal bivalve populations are target by the artisanal fleet, making use of dredge gear (Gaspar *et al.*, 1999; Leitão *et al*., 2009). The most important target species are *Spisula solida*, *Donax trunculus*, *Venus striatula*, *Pharus legumen*, *Chamelea gallina*, *Callista chion* and *Ensis síliqua* (Chícharo *et al.*, 2002; Gaspar, 1996; Leitão *et al*., 2009). For other hand, in a coastal lagoon system (Ria Formosa) also has a long tradition of bivalve harvesting, especially *Ruditapes decussatus* and *Cerastoderma edule* (Chícharo and Chícharo, 2000; Gaspar *et al.,* 2003), due to excellent conditions to development and maintenance of these species. In the lagoon systems, bivalves harvesting has been using a local traditional fishing gear called harvesting-knife, and more recently with hand-dredges (Gaspar *et al.,* 2003; Leitão and Gaspar, 2007).

The environmental conditions present in bivalves grounds is important for stock development, and these conditions should be analyzed for a correct management because these conditions can varies in spatial scale.

There is a strong dynamic between a lagoon coastal system (Ria Formosa, South Portugal) and the adjacent coast, since due to the daily renewal of water masses (about 75%; Newton and Mudge, 2003) there is a constant renewal of nutrients between lagoon system and the adjacent coast (Falcão and Vale, 1990, 2003). This dynamic will be a key factor for the survival and development communities that inhabit these two interconnected systems. Moreover, due to different environmental conditions between regions of a geographical area, stocks may experience different impacts of abiotic factors according to the region where they are inserted (Planque and Frédou, 1999). This is the case of the Portuguese coast that has a great regional variability of environmental factors (Sousa *et al*., 2006) due in part to the Portuguese coast to be under unique biogeographic circumstances, receiving climatic influences from the North Atlantic Ocean and the Mediterranean Sea (Cunha, 2001). In fact, according Najjar *et al.* (2000), the impacts of environmental change on coastal regions will have a regional signature that depends on the local climate change and ecological that affects the sensitivity to climate.

Thus, it is necessary to know to what extent do the change in the environment, and those that are anticipated to happen, have an impact on the commercial exploitation of bivalve stocks.

Objectives:

This study intends to determine the role of environmental changes and fishing activity on bivalve catches. To this end, this study aimed:

1. Compare coastal and lagoon (Ria Formosa lagoon) bivalve species sensibility to environmental and fisheries variables effects.
2. To evaluate the effect of fishery and environmental change on coastal bivalve species, *S. solida*, along three distinct regions (Northwestern, Southwestern and South) of Portuguese coast with distinct environmental conditions.

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CHAPTER 2

Bivalve's fisheries in inshore lagoons and nearshore coastal areas: influence of environmental variables and fishing pressure (South Portugal, eastern Algarve)

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Bivalve's fisheries in inshore lagoons and nearshore coastal areas: influence of environmental variables and fishing pressure (South Portugal, eastern Algarve)

Abstract: Climate changes affect marine ecosystems and the survival, growth, reproduction and distribution of species, including those targeted by commercial fisheries. The impact of climate change has been reported for many fish species but studies focusing on the effects of climate on bivalve resources are lacking. In Portugal, the harvesting of bivalves is an old and artisanal activity, of special importance along the Algarve coast (South of Portugal). This study aims to evaluate the influence of climatic, environmental and fisheries factors on the landings of intertidal coastal lagoon and coastal bivalve species (subtidal nearshore species). The environmental and fisheries parameters considered to affect the landings of bivalves in the eastern Algarve were the fishing effort (number of fishing events), sea surface temperature, NAO index, upwelling index, wind magnitude and direction and river discharges. Analysis of time series data using Min/Max Autocorrelation Factor Analysis (MAFA) and Dynamic Factor Analysis (DFA) showed that for all species, effort was positive related with landings per unit effort (LPUE) trends in the following year. Lagoon bivalve species (*Cerastoderma edule* and *Ruditapes decussatus*) responded to different environmental variables than the coastal bivalve species (*Chamelea gallina*, *Pharus legumen*, *Donax spp.* and *Spisula solida*). Upwelling index had a significant effect on the lagoon bivalves while the NAO index, wind magnitude and direction and offshore discharges only affected the coastal species. This study highlighted the need adapt fishing effort regimes, while considering the background effects of environmental variability, in order to improve fisheries management actions.

Keywords: Algarve; Bivalve fisheries, Climate change; Coastal and lagoon bivalves; Dynamic Factor Analysis; Min/Max Autocorrelation Factor Analysis

Introduction

As demonstrated by an increasing number of studies, concerns about the effects of climatic changes on marine ecosystems are widespread (Bertram *et al.*, 2001; Brander, 2010; Philippart *et al.*, 2011). For instance, climatic oscillations can change water temperature, nutrient dynamics, increase CO_2 levels (reduced pH), and alter wind and circulation patterns (Harley *et al.*, 2006). These changes in the abiotic marine environment can affect survival, growth, reproduction and distribution of species, but the impacts can be also displayed at the population, community and ecosystem level (Brander, 2007). A factor related to all these environmental changes is the North Atlantic Oscillation (NAO) index that strongly influences the precipitation regimes, temperature and winds above Northwest of Europe (Lebreiro *et al.*, 2006; Witbaard *et al.*, 2005) as well as a series of ocean characteristics, including velocity and wind strength, sea surface temperature, salinity, trajectory of storms in the Atlantic Ocean, evaporation and precipitation patterns (Boelens *et al.*, 2005). All of these characteristics affect the water circulation and stratification patterns (Witbaard *et al.*, 2005). Because of all these effects, the NAO is implicated in changes in marine ecosystems (Ottersen *et al.,* 2001; Parsons and Lear, 2001).

Climate variables such as alterations in air and water temperature, precipitation, salinity, oceanic circulation, river runoff, nutrients concentration, sea level, ice melting, frequency and intensity of storms and floods influence fishing (Barange, 2002; Boelens *et al.*, 2005; Brander, 2007; Drinkwater and Frank, 1994; Lehodey *et al.*, 2006), because they affect the abundance and distribution of exploited species (Lehodey *et al.*, 2006; Perry *et al.*, 2005), modifying habit quantity and quality, ecosystem productivity and distribution and abundance of competitors and predators (Brander, 2010; O'Reilly *et al.*, 2003).

Although the impact of climate change has already been reported for marine exploited fish assemblages (for example: Allison *et al*., 2009; Brander, 2007, 2010; Erzini, 2005; Erzini *et al.*, 2005; Klyashtorin, 1998; Lehodey *et al.*, 2006), the effect of these changes on bivalves catches remains largely unknown. However, studies have been made that relate the environmental changes with biological effects on bivalve molluscs, such as abundance (Beukema, 1992; Philippart *et al.*, 2003), growth (Beiras *et al*., 1994; Dekker and Beukema, 1999; Gaspar *et al*., 2004; Menesguen and Dreves, 1987; Sobral and Widdows, 1997; Witbaard *et al*., 2005), recruitment (Beukema 1992; Beukema *et al.*, 1998, 2001; Beukema and Dekker, 2005; Honkoop *et al.*, 1998; Philippart *et al.*, 2003;

Strasser *et al.*, 2001; Young *et al.*, 1996), spawning (Baba *et al*., 1999) and larval stage (Calabrese, 1969; Chícharo and Chícharo, 2001b).

Bivalves are considered sensitive biological indicators (Carroll *et al.*, 2009; Helmuth *et al.*, 2006; Simboura and Zenetos, 2002; Somero, 2002), in other words, they are a good tool for monitoring changes in marine ecosystems (Grémare *et al*., 1998), with most species having relatively short life cycle bivalve populations reflect rapidly the environmental changes (Zeichen *et al.*, 2002). Moreover, the bivalve molluscs compose a large fraction of littoral benthic communities (Rufino *et al.*, 2010).

In Portugal, the catch of bivalve molluscs represents one of the most important artisanal fisheries, being an old and traditional activity with special importance along the Algarve coast, in the south of Portugal (Gaspar *et al.*, 1999a, 2001, 2005). In this region, either in coastal areas or in the adjacent lagoon systems, such as the Ria Formosa lagoon, bivalve communities are known to have high year to year variation (Ferreira *et al.*, 1989; Gaspar 1996; Leitão and Gaspar, 2007). In the Ria Formosa, bivalve production reached 10000 tons/year in 1988, but has declined to 3000 tons/year over the last 6 years. In the latter period, bivalve production has decreased from 3-4 kg/m2 to less than 500 g/m2, with bivalve annual mortality increasing to 50%, although 100% mortality has occurred in some Ria Formosa areas (Ferreira *et al*., 1989). In Portugal, the IPIMAR (Instituto de Investigação das Pescas e do Mar) is responsible for monitoring, assessment and management of bivalve stocks in coastal areas. Gear restrictions, such as minimum mesh size, have been enforced in coastal areas to prevent the harvest of undersized individuals, allowing bivalves to grow to a more marketable size and reproduce at least once before capture (Gaspar, 1996; Gaspar *et al*., 1995, 2002b). Fishing surveys have mainly focused on the adult (spawning biomass) to juvenile (recruits) ratio as a proxy tool for evaluating the status of fishing beds and establishing landing limits (Gaspar *et al*., 1999a, 2002a). Moreover, new and more selective gears have been introduced in the fishery to prevent overexploitation of bivalves in coastal fishing grounds (Gaspar *et al.*, 1999a, 2003c, 2003d; Leitão *et al*., 2009). Despite these efforts, scientific surveys have shown high yearly variation in the abundances of bivalve populations (Joaquim *et al*., 2008a). The cause of such variation remains largely unclear, but environmental factors that operate during the pelagic life cycle of the larvae should, at least partially explain some of this variability (see references above). For example, in a similar lagoon (Wadden Sea) temperature changes were found to be detrimental to bivalve recruitment (Beukema, 1992).

Despite environmental variables being frequently assumed to play a major role in bivalve mortality, few studies have focused on this important commercial group. Moreover, coastal systems (including Ria Formosa lagoon) are considered to be quite sensitive to environmental changes (Kennedy, 1990). Some fisheries and aquaculture enterprises and communities would benefit from climate change while others would suffer losses, with economic and population dislocations probably inevitable in many parts of the world. Thus, flexibility in policy-making and planning will be vital if global climate is modified as rapidly as is anticipated by some scientists (Kennedy, 1990). Accordingly, this study aimed to evaluate the influence of different environmental and fisheries variables on commercial bivalve landings of coastal and lagoon (Ria Formosa lagoon) inshore bivalves species.

Materials and Methods

Coastal and lagoon bivalve species might respond differently to environmental forces. Therefore, this study considered two distinct areas, with different bivalve communities. The first area comprises the nearshore coastal shellfish grounds (Figure 1). The second area is the Ria Formosa (Figure 1), a shallow, coastal lagoon system with a mesotidal regime (Newton and Mudge, 2003), and intertidal bivalves communities. The Algarve coastal bivalve fisheries take place in the zone between Quarteira and Vila Real de Santo António (Figure 1), mostly at depths shallower than 15 meters (Gaspar *et al*., 1999a, 1999b, 2003a, 2005). The Ria Formosa has a long tradition of intertidal bivalve harvesting and accounts for almost all (90%) of Portuguese intertidal bivalve (mostly cockles and clams) production (Chícharo and Chícharo, 2001b). The communication between the lagoon and the sea is permanent, through six inlets. The shallow depth, strong tidal currents and high water renewal make this type of lagoon vertically well-mixed. Therefore, it is considered a coastal water mass according to the classification of the EU Water Framework Directive (Bettencourt *et al*., 2003).

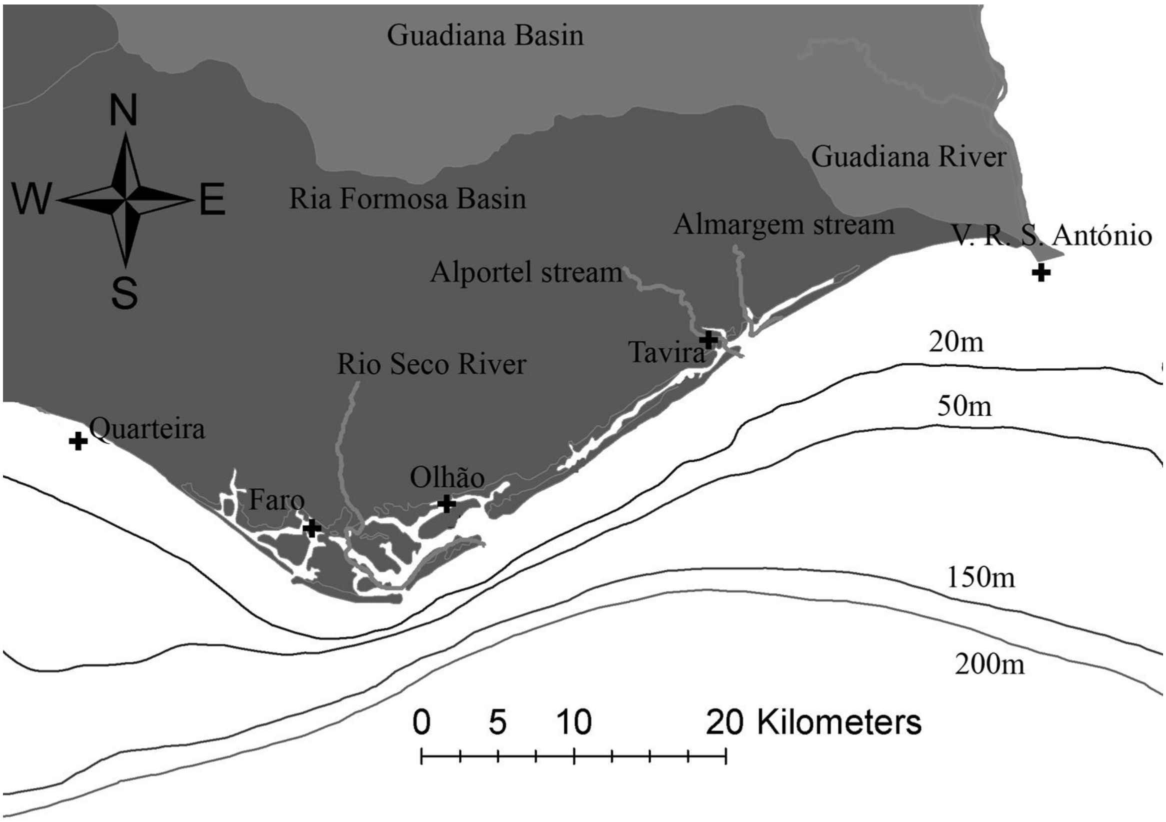

Figure 1. Location of the rivers and Algarve (south Portugal) ports where bivalves are fished (from Vila Real de Santo António to Quarteira).

Landings and fishing effort data from 1989 to 2009 were obtained from the Direcção Geral das Pescas e da Aquicultura (Directorate-General of Fisheries and Aquaculture – DGPA). These data include detailed information regarding the bivalve fishery, namely monthly effort (number of fishing days and/or events) and monthly landed catches per boat. The following bivalves species were selected due to their commercial importance and availability of data for the time period considered: *Cerastoderma edule* (Linnaeus 1758) and *Ruditapes decussatus* (Linnaeus 1758) from Ria Formosa (lagoon species); *Chamellea gallina* (Linnaeus 1758), *Donax spp.* (Linnaeus 1758), *Pharus legumen* (Linnaeus 1758) and *Spisula solida* (Linnaeus 1758) from the coast nearshore areas. Near the coastal bivalves are harvested with dredge boats. In the Ria Formosa cockles and clams are harvested with a hand-held harvesting knife used to dig the sediment during low tide. Catches of *C. edule* are limited by a minimum landing size of 25 mm, which is usually reached within one year or less (Graça, 2001). Catches of *R. decussatus* are mainly from bottom cultures or shellfish farming. Shellfishermen seed their beds (extensive bottom cultures) with juveniles clams caught in natural grounds until they reach the commercial size (25 mm). As most of adult *R. decussatus* clams are not caught in natural beds there is no landings limit regarding this species, with exception of the commercial minimum landed size. Therefore, the link between fishing and environment variables was established under the assumption that shellfishermen want to produce as many clams as they can in order to maximize their incomes.

Different types of explanatory variables were used: climatic, oceanographic, hydrologic and fisheries. The climatic explanatory variables used were both the NAO and NAO winter (December–March) indexes (http://www.cgd.ucar.edu/jhurrell/nao.html, last accessed 2010; Hurrell, 1995). These indexes are defined as the difference between sea level atmospheric pressure at the Azores and Iceland.

The oceanographic environmental explanatory variables include Sea Surface Temperature (SST - http://gdata1.sci.gsfc.nasa.gov), Upwelling index (UPW - www.pfeg.noaa.gov) and eastward (u) and northward (v) wind components (http://podaac.jpl.nasa.gov/dataset/CCMP_MEASURES_ATLAS_L4_OW_L3_5A_MONTHLY_WIND_VECTORS_FLK?ids=&values= accordingly to Atlas *et al.* 2011). All data were obtained through satellite monthly data. Base on u- and v-wind the magnitude [WMag: SQRT(u^2 + v^2)] and wind direction [WDir: degree Arc tangent^2 (u, v)] were estimated and used in the statistical models rather than original wind u and v data. Coastal oceanographic data from satellites were collected to 200m depth to cope with the lack of some satellite data (cloud effect) near to shore (Figure 1). Therefore, the oceanographic information (SST, UPW, WMag and WDir) regarding the study area should be interpreted as average values. All oceanographic environmental data collected for coastal areas were also considered to be representative of lagoon condition, since the Ria Formosa lagoon water body mass classified as a coastal water type (Bettencourt *et al*., 2003). In fact, most bivalve beds and extensive shellfish farms in the lagoon are located near the inlets, where favorable hydrodynamic condition are known to play a major role in bivalve production (Gaspar *et al*., 2003d; Leitão, 2003).

The Ria Formosa is influenced by freshwater discharge into the lagoon mainly from river run-off, that increases the levels of silicates and nitrates (Falcão and Vale, 1990) and consequently primary production (Barbosa *et al*., 2010). Therefore, one of the explanatory variables considered to affect lagoon bivalve production was the input of freshwater from the Ria Formosa Basin Streams, hereafter referred to as inshore discharge (Figure 1). Monthly runoff data were obtained for the Seco River, Alportel and Almargem Streams. Coastal areas are also affected by river run-off and the Guadiana River, which is the largest river in the Algarve region, is particularly important in this respect. The monthly discharge of freshwater into the coastal area, include the cumulative contribution of all streams and rivers within the area, including those from the Ria Formosa, are here named as offshore discharge (Figure 1). River discharge data was obtained from the Portuguese Water National Institute (http://snirh.pt/ last accessed in October 2011).

Fishing effort, in number of fishing days/events was another explanatory variable, while landings were response variables. Detailed information on fishing effort is available for each species since in general, only one bivalve species is dominant in each bed (Gaspar *et al.,* 1999a), allowing targeted harvesting. Yearly landings per unit effort (LPUE – response variable) were estimated dividing the total landings per year by the total number of fishing days of the year (LPUE units: kg per fishing day/event). Therefore, LPUE were considered a proxy of bivalve biomass production. However, the effort, in number of fishing days, was also used as an explanatory variable. This decision allows incorporating into the models the short term effect of effort on catches of bivalves.

Data analysis and modeling

To evaluate seasonal effects on LPUE trends, data were organized quarterly: winter (January to March); spring (April to June); summer (July to September); and autumn (October to December). We labeled the explanatory variables with numbers 1, 2, 3 and 4, denoting winter, spring, summer and autumn, respectively. The Algarve (South Portugal) is a typically Mediterranean region. Thus, in the case of river discharges (lagoon and coastal discharges) we first tested the quarterly data, but in the end, we pooled the data in wet (December to May) and dry (June to November) seasons, due to the typical Mediterranean hydrologic regime of the south coast.

Data exploitation included several statistical procedures. Quantile-Quantile plots (QQ-plots) were used to display to test data normality. If the distribution of X is normal, the plot will be close to linear. In the case of *C. edule* LPUE a cubic root transformation was applied, in the case of *C. gallina*, *P. legumen* and *S. solida*, square root transformations were used, in order to generate a normal probability plot of the data. Pair plots were used to identify and exclude explanatory variables that present collinearity (correlation higher than 0.8) among them. The variables excluded were annual wind magnitude and direction, and therefore only seasonal data were used in the case of the latter variables.

Given that the scale and dimension of the units varied considerably among variables, both response and explanatory variables were standardized (Zuur *et al.*, 2003a, b). The mean normalization was applied; all variables were centered around zero ($X_i=(Y_i-\hat{Y})/\sigma_y$), where σ_y is the sample standard deviation. The transformed values X_i have unit variance and are unit-less.

Knowledge of the species life histories was taken into account in the modeling of LPUE. Thus, explanatory variables were lagged one year because this is the age of first maturity for all the bivalve species studied (Gaspar *et al*., 1999b; Leitão, 2003; Leitão and Gaspar, 2007). In other words, the climatic, environmental and hydrologic data were considered to affect bivalve recruitment or/and larvae survivorships, and consequently adult biomass in the following year. Moreover, due to the short life cycle of the species, the effort of the year before (year-1) might also affect spawning biomass (adults) and consequently recruitment in the following year through density dependent mechanisms. Thus, effort (number of fishing days/events) was also lagged one year.

Min/Max Autocorrelation Factor Analysis (MAFA) and Dynamic Factor Analysis (DFA)

Min/Max Autocorrelation Factor Analysis (MAFA) can be describe as a type of Principal Component Analysis (PCA) for short time series that can be used to extract trends from time-series that represent the common behavior of the original time series and for smoothing. A set of orthogonal linear combinations of the original time series (MAFs) of decreasing smoothness as measured by lag-one autocorrelation are constructed (Solow, 1994). The MAFA axes represent autocorrelation with lag 1, the first MAFA axis represents the main trend in the data, while the others represents the other less important trends (Solow, 1994). Loadings can be estimated and used to determine the relationship of individual response variables to particular MAFA axes. Canonical correlations or cross-correlations between MAFA axes and the landings time series can also be calculated for the same purpose. Cross correlations between MAFA axes and explanatory variables can also be estimated, allowing significant relationships between trends and explanatory variables to be identified (Erzini, 2005; Erzini *et al.*, 2005). Therefore, providing the type of fishery (target on single species due to beds species-specific) and the fishing effort information available (effort information per species), the MAFA analyses considered only a single MAFA trend (autocorrelation time lag 1 year) for each species.

Dynamic Factor Analysis (DFA) is another multivariate time-series analysis technique that can be used for non-stationary time series analysis (Zuur *et al.*, 2003a, b; Zuur and Pierce, 2004). DFA is used to estimate underlying common patterns in a set of time-series, evaluate interactions between response and explanatory variables and determine the effects of explanatory variables on response variables (Zuur *et al*., 2003a). The time-series are modeled in relations of a linear combination of common trends, a constant level parameter, explanatory variables and a noise component (Zuur *et al*., 2003b, 2007). A variety of DFA models ranging from the simplest (with one common trend plus noise) to the most complex (with M common trends, two or more explanatory variables, plus noise) can be fitted. Here, DFA was used to model the individual LPUE time series as a single trend, plus one or two explanatory variables, plus noise. Models were fitted with a diagonal covariance matrix and the Akaike Information Criterion (AIC) was used as a measure of goodness of fit, with the best model having the smallest AIC value. Results presented for MAFA and DFA were obtained with the software package Brogdar (http://www.brogdar.com).

Results

Standardized LPUE time series showed considerable variability across species (Figure 2). *P. legumen* showed a decreasing trend. *R. decussatus* showed a peak in 1994 followed by a decline thereafter. *S. solida* and *C. edule* displayed similar trends, as did *Donax spp.* and *C. gallina* and these trends were characterized by oscillations over time.

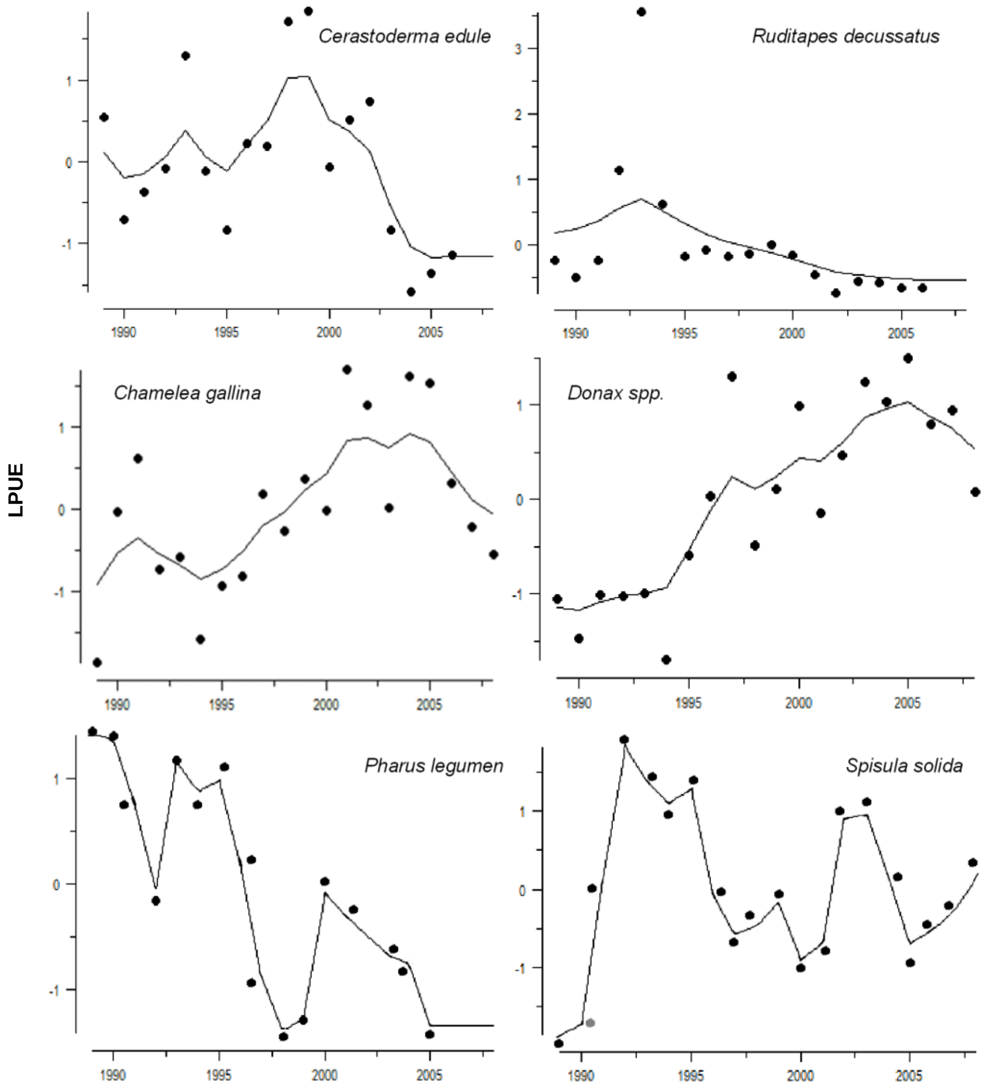

Figure 2. Observed (filled circles) and fitted (lines) LPUE trends for 1989-2008, for the best DFA model.

The trends for environmental variables, sea surface temperature, NAO index, upwelling index, wind magnitude and direction, and lagoon and coastal discharges, are given in Figure 3. Sea surface temperature (Figure 3a) presented tendencies for negative anomalies, between 1992 and 1994 and in 2001 a strictly negative pattern for both annual and trimestral means. The SST annual mean was relatively consistent in relation to trimestral SST means. The NAO and NAO winter indexes (Figure 3b) presented similar patterns, with positive values for most of the time period. However, from the mid-90's the two NAO indexes showed more variability between negative and positive phases. In relation to yearly upwelling index, downwelling regimes were predominant during the period of study. However, upwelling regimes (Figure 3a) become more manful in both spring (UPW2) and summer (UPW3). The autumn (UPW4) upwelling index showed a larger variation, reaching a very pronounced downwelling value in 2001. The wind magnitude (Figure 3a) displayed a large oscillation over time namely in winter (WMag1) and spring (WMag2). Despite the oscillations, and with exception of the winter season, wind magnitude showed a slightly increasing trend over time. Lagoon and coastal discharges (Figure 3a) showed a similar pattern, with negative anomalies values dominating in most of the years. For both lagoon and coastal discharges, large positive peaks were recorded in 1996 and 1997 for annual and wet season river discharges. In 1989, 1990, 2000 and 2002 the lagoon discharge values peaked in the dry season and in 2000 and 2007 a positive peak was also observed for coastal discharges. The wind direction is presented in Figure 3c. In winter (WDir1) and autumn (WDir4) the wind blows predominantly from Southwest, and in spring (WDir2) and summer (WDir3) predominantly from Southeast.

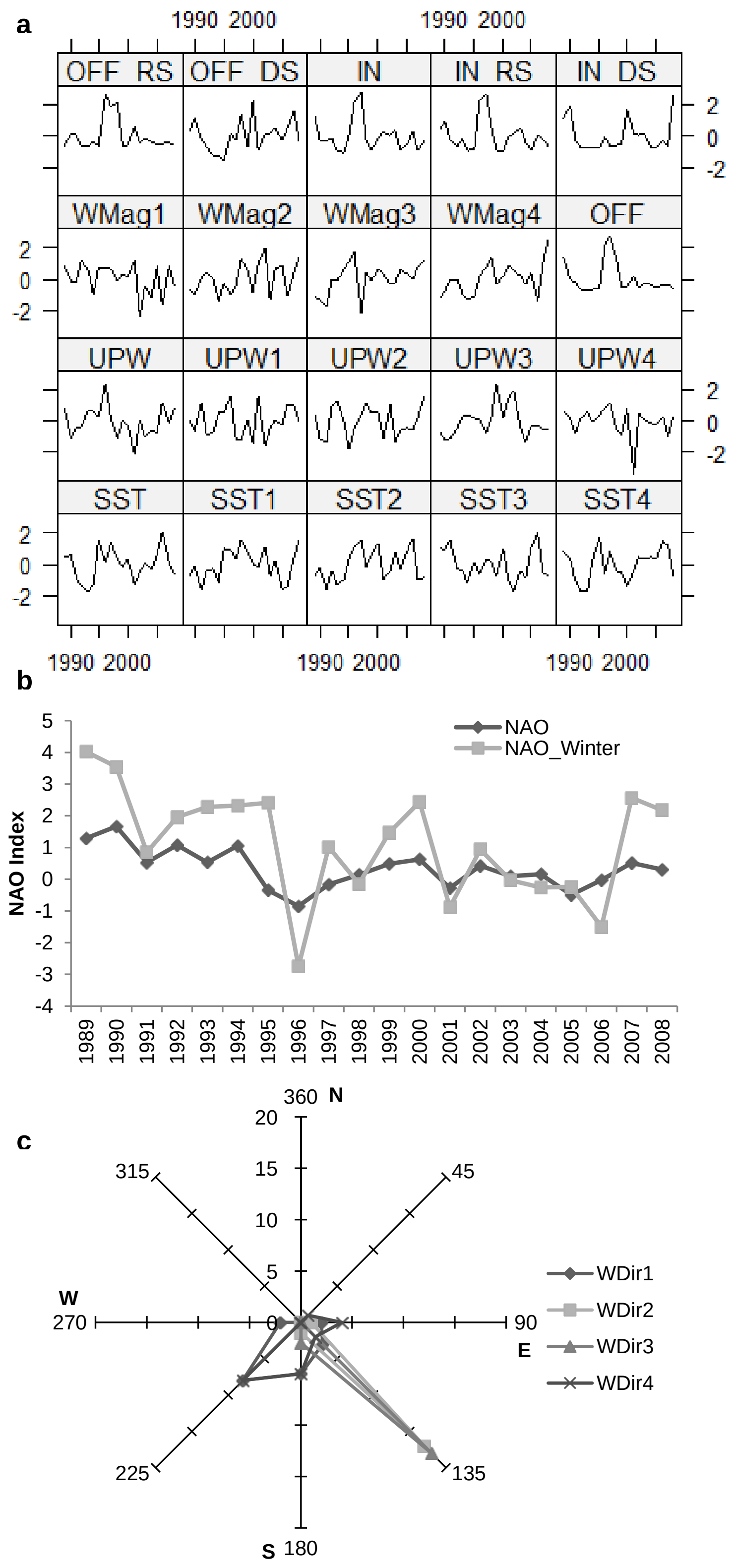

Figure 3. Climatic and oceanographic environmental variables during the period 1989-2008: **(a)** Standardised values for sea surface temperature (SST), upwelling (UPW), wind magnitude (WMag) and coastal (OFF) and lagoon (IN) discharges; **(b)** North Atlantic Oscillation (NAO) and North Atlantic Oscillation in winter (NAO_Winter) index; **(c)** Frequency distribution of wind direction (WDir).

Relationships between the explanatory variables and bivalve LPUE trends were evaluated with Min/Max Autocorrelation Factor Analysis (MAFA) and Dynamic Factor Analysis (DFA).

The MAFA results for the different species and the effect of explanatory variables on LPUE trends are shown in Table 1. Most species presented significant positive correlations with fishing effort, with the exceptions of *Donax* spp. and *S. solida*. SST was positively correlated with *C. edule* (SST1) and *Donax* spp (SST2) LPUE trends, and was negatively correlated with *R. decussatus* (SST and SST4) and *S. solida* (SST and SST3) LPUE trends. NAO and NAO winter indexes significantly affected the catches of coastal bivalve species, but the direction of that effect varied according to species. NAO negatively affected *C. gallina* and *Donax* spp. and positively *P. legumen* LPUE trends. Upwelling index had a positive correlation with inshore species *C. edule* (UPW2 and UPW3) and *R. decussatus* (UPW2), and a negative correlation with *C. gallina* (UPW and UPW4) LPUE common trends. Catches of the latter species are affected positively by wind magnitude (WMag2). In contrast, wind magnitude had a negative relation with *P. legumen* (WMag4). *Donax* spp. was the only species that showed a significant (positive) correlation with wind direction (WDir2). River discharge was negative correlated, with *S. solida* during the dry season (OFF_DS).

Table 1. Correlations between explanatory variables and MAFA trends for the LPUE of the different species. Significant correlations are in bold (significant level for correlations: 0.45). The abbreviations refer to six bivalve species: Ce (*Cerastoderma edule*), Ru (*Ruditapes decussatus*), Ch (*Chamelea galina*), Do (*Donas spp.*), Ph (*Pharus legumen*) and Sp (*Spisula solida*).

Explanatory variables	Code	Ce	Ru	Ch	Do	Ph	Sp
Number of days (each specie)	ND	**0.55**	**0.65**	**0.83**	0.08	**0.72**	0.44
Sea surface temperature	SST	-0.36	**-0.56**	-0.01	0.42	-0.14	**-0.46**
Sea surface temperature (Jar-Mar)	SST1	**0.46**	-0.04	-0.07	0.08	-0.22	0.07
Sea surface temperature (Apr-Jun)	SST2	-0.24	-0.38	0.11	**0.61**	-0.44	-0.21
Sea surface temperature (Jul-Sep)	SST3	-0.36	-0.19	-0.07	0.02	0.16	**-0.50**
Sea surface temperature (Out-Dec)	SST4	-0.42	**-0.55**	0.01	0.28	0.03	-0.23
North Atlantic Oscillation índex	NAO	0.14	0.23	-0.38	**-0.58**	**0.50**	-0.12
North Atlantic Oscillation index (Dec-Mar)	NAO_W	0.14	0.30	**-0.49**	**-0.45**	**0.53**	-0.06
Upwelling índex	UPW	0.07	0.25	**-0.56**	-0.09	0.34	0.16
Upwelling index (Jar-Mar)	UPW1	-0.22	-0.15	-0.02	-0.12	0.22	-0.08
Upwelling index (Apr-Jun)	UPW2	**0.63**	**0.45**	-0.23	-0.05	-0.17	0.11
Upwelling index (Jul-Sep)	UPW3	**0.61**	0.06	0.18	-0.01	-0.23	0.20
Upwelling index (Out-Dec)	UPW4	-0.13	0.18	**-0.47**	0.05	0.24	0.12
Wind magnitude (Jar-Mar)	WMag1	0.18	0.28	-0.24	-0.12	0.02	-0.15
Wind magnitude (Apr-Jun)	WMag2	0.32	-0.06	**0.50**	0.16	-0.43	0.12
Wind magnitude (Jul-Sep)	WMag3	-0.05	0.05	-0.10	0.14	-0.15	0.29
Wind magnitude (Out-Dec)	WMag4	0.22	-0.20	0.30	0.39	**-0.54**	-0.06
Wind direction (Jar-Mar)	WDir1	-0.22	-0.28	0.22	0.07	0.07	0.11
Wind direction (Apr-Jun)	WDir2	0.26	0.30	-0.01	**0.49**	-0.33	0.09
Wind direction (Jul-Sep)	WDir3	0.23	-0.22	0.28	0.24	-0.21	0.07
Wind direction (Out-Dec)	WDir4	0.08	-0.05	-0.44	0.00	0.31	-0.11
Lagoon discharge	IN	0.02	-0.26	-	-	-	-
Lagoon discharge (Out-Mar)	IN_RS	0.12	-0.13	-	-	-	-
Lagoon discharge (Apr-Sep)	IN_DS	-0.03	-0.22	-	-	-	**-**
Coastal discharge	OFF	0.25	-0.17	-0.19	0.07	-0.11	-0.43
Costal discharge (Out-Mar)	OFF_RS	0.28	-0.15	-0.01	0.05	-0.27	-0.23
Coastal discharge (Apr-Sep)	OFF_DS	-0.07	-0.40	0.11	0.35	-0.18	**-0.57**

The AIC (Akaike Information Criterion) values of the different DFA model runs for the bivalves species are given in Table 2. The best explanatory variable for each species was given by the smallest AIC. For *C. edule* the environmental variables that best explain variation in LPUE were spring and summer upwelling (UPW2 and UPW3) that were positive correlated with the trend (see *t*-values in Table 2). For *R. decussatus* the explanatory variable that most affected LPUE was wind direction in spring (WDir2), which was positively correlated with the species trend. Fishing effort lagged by 1 year, affected the catches of coastal bivalves species, namely *C. gallina*, *S. solida* and *Donax* spp. The *t*-values showed that the fishing effort in the previous year was positively related with LPUE for these species. The environmental variables that most affected *C. gallina*, *S.*

solida and *Donax spp*. were upwelling, river discharge and temperature (SST2), respectively. Moreover, *C. gallina*, *S. solida* upwelling and river discharge were negatively correlated with the LPUE trend while for *Donax* spp*.* SST2 is positively correlated with the LPUE trend. The *P. legumen* catches were negatively affected by the wind magnitude (WMag4).

Table 2. Akaike's information criterion (AIC) values for dynamic factor analysis (DFA) models with one common trend and zero to two explanatory variables, based on a symmetric matrix (in bold, lowest AIC value within explanatory variables series for each species). The – sign indicates estimated *t*-values for explanatory variables with a negative relationship, while + indicates a positive relationship; -- or ++ indicates *t*-values larger than 3, indicating a strong relationship. The abbreviations refer to six bivalve species: Ce (*Cerastoderma edule*), Ru (*Ruditapes decussatus*), Ch (*Chamelea galina*), Do (*Donas spp.*), Ph (*Pharus legumen*) and Sp (*Spisula solida*).

Explanatory variables	**Code**	**Ce**	**Ru**	**Ch**	**Do**	**Ph**	**Sp**
1 time series = trend + noise		54.460	55.524	59.512	48.262	38.976	56.284
1 time series = trend + explan, var(s) + noise							
Number of days (each specie)	ND	56.414	57.401	**49.165**$^{++}$	**45.821**$^{+}$	40.961	**50.617**$^{++}$
Sea surface temperature	SST	**53.362**$^{--}$	**51.075**$^{-}$	61.424	**46.480**$^{++}$	41.228	57.714
Sea surface temperature (Jar-Mar)	SST1	**52.830**$^{+}$	57.473	61.508	49.501	41.141	57.284
Sea surface temperature (Apr-Jun)	SST2	**53.807**$^{+}$	**54.978**$^{-}$	61.456	**41.535**$^{++}$	40.970	57.971
Sea surface temperature (Jul-Sep)	SST3	**54.214**$^{-}$	56.385	61.368	**47.283**$^{+}$	41.112	**56.238**$^{-}$
Sea surface temperature (Out-Dec)	SST4	54.497	**50.593**$^{--}$	60.350	50.054	40.747	58.254
North Atlantic Oscillation index	NAO	56.331	57.050	59.744	**47.706**$^{--}$	41.140	58.100
North Atlantic Oscillation index (Dec-Mar)	NAO_W	56.386	56.295	**57.798**$^{-}$	50.155	40.147	57.945
Upwelling index	UPW	55.874	56.881	**56.025**$^{--}$	50.075	40.259	58.104
Upwelling index (Jar-Mar)	UPW1	56.218	56.728	61.390	49.054	40.580	57.854
Upwelling index (Apr-Jun)	UPW2	**46.342**$^{++}$	**51.803**$^{++}$	60.273	50.043	**38.857**$^{--}$	57.690
Upwelling index (Jul-Sep)	UPW3	**45.689**$^{++}$	56.922	61.505	**47.015**$^{-}$	41.290	57.085
Upwelling index (Out-Dec)	UPW4	56.112	57.240	59.753	**46.293**$^{+}$	40.701	57.799
Wind magnitude (Jar-Mar)	WMag1	56.423	56.459	61.454	48.902	40.824	57.797
Wind magnitude (Apr-Jun)	WMag2	**52.747**$^{+}$	57.473	**58.950**$^{+}$	48.951	**37.810**$^{--}$	57.013
Wind magnitude (Jul-Sep)	WMag3	56.437	57.158	59.685	46.982	40.236	58.005
Wind magnitude (Out-Dec)	WMag4	55.919	56.761	60.438	50.246	**35.208**$^{--}$	58.106
Wind direction (Jar-Mar)	WDir1	55.975	56.204	61.443	49.650	40.137	58.153
Wind direction (Apr-Jun)	WDir2	55.107	**48.680**$^{++}$	61.231	48.335	40.793	58.322
Wind direction (Jul-Sep)	WDir3	**52.866**$^{++}$	57.132	61.143	48.718	40.978	56.506
Wind direction (Out-Dec)	WDir4	56.450	57.287	**56.731**$^{--}$	**46.281**$^{+}$	40.119	57.425
Lagoon discharge	IN	56.205	55.610	-	-	-	-
Lagoon discharge (Out-Mar)	IN_RS	56.446	56.930	-	-	-	-
Lagoon discharge (Apr-Sep)	IN_DS	55.209	**55.496**$^{-}$	-	-	-	-
Coastal discharge	OFF	56.301	56.227	61.006	**47.286**$^{+}$	40.543	**53.931**$^{-}$
Coastal discharge (Out-Mar)	OFF_RS	56.304	56.633	61.088	50.028	40.288	**54.532**$^{-}$
Coastal discharge (Apr-Sep)	OFF_DS	56.009	**54.442**$^{-}$	61.475	49.191	40.860	56.331
	UPW3+WDir3	**44.938**$^{++,-}$	-	-	-	-	-
	ND+UPW	-	-	**39.958**$^{++,-}$	-	-	-
	ND+OFF	-	-	-	-	-	**47.289**$^{++,--}$

The best final models based on the AIC values included the combined effects of more than one explanatory variables (Table 2). All possible combinations of significant explanatory variables within the same time period were tested, but only the combinations with smallest AIC values are shown in Table 2. No more than two explanatory variables were found to improve final model fitness. For *C. edule* these explanatory variables include the upwelling index and wind direction in summer season (UPW3 and WDir3). The combination of both yearly fishing effort and upwelling index contributed to reduce AIC value for the *C. gallina* model. Finally, for *S. solida* the best DFA model included yearly fishing effort (number of fishing days) and annual coastal river discharges (OFF) as explanatory variables.

Discussion

The bivalve species in this study have great commercial importance in the Algarve coastal region (southern Portugal). *C. edule* e *R. decussatus* are the most abundant bivalves in the Ria Formosa (Chícharo and Chícharo, 2001a), while *C. gallina*, *Donax* spp., *P. legumen* and *S. solida* are the most important commercial bivalve species along the Portuguese south coast (Gaspar *et al.*, 1999a, 1999b, 2004; Rufino *et al*., 2010).

Bivalve populations and their spatial distributions can vary in response to multiple environmental and fisheries variables. For each hypothesis regarding the effect of explanatory variables on bivalve populations, different models have been used and these models can be evaluated, combined and compared. For instance, the DFA results showed that, for the same species, the combination of two variables has a more significant effect on the short term trends in catches. Thus, in these circumstances, the combined effect of the environmental variables has a more pronounced impact on bivalve catches than each variable separately. However, the application of two techniques, Min/Max Autocorrelation Factor Analysis (MAFA) and Dynamic Factor Analysis (DFA) give similar results in most circumstances. That is, the effect of explanatory variables on bivalves catches of a given species might coincide among the two techniques used (MAFA and DFA). In fact, in most of the cases the effects of explanatory variables on bivalves LPUE trends were explained by the same variables in both statistics analyses. Nevertheless, significant effects of one explanatory variable were in a minor number of times only highlighted in one of the techniques. However, both techniques can be considered in fact was complementary (Erzini, 2005; Erzini *et al.*, 2005). Decision about complementarity or "coincidence" of results regarding the statistical analysis used were herein after discussed based on the knowledge regarding the biological sensibility of each species into environmental or fisheries effects.

Overall, both MAFA and DFA showed that effort is positively related with LPUE in the following year. In the Algarve, fishing beds are exploited intensively until the bivalve yields drops below economically profitable values. Both coastal and lagoon harvesting methods are highly efficiency and selective (Gaspar *et al*., 2003d, 2003e). The limitations for the catches of coastal bivalves are size limits and the daily quota. Fishing quotas at coastal areas are fixed annually, but they can change according to the state of the stock. Accordingly, the decrease of adult biomass, due to controlled fishing effort, can be a determinant factor for the success of next year catches. In contrast, the uncontrolled fishing effort in the Northwestern coast of Portugal (1986-1989) has led to overexploitation of *S. solida* populations, leading to the closure of the fishery in 1995 and 1996 (Sobral, 1996).

Significant variation in LPUE trends are induced by environmental forces that affect bivalves in different stages of the species life cycle. Large fluctuations in yearly recruitment are characteristic of marine organisms with planktotrophic larvae (Beukema and Dekker, 2005; Philippart *et al.*, 2003; Strasser *et al.*, 2001). Larval recruitment may represent a large proportion of the population and fluctuations from year to year are largely the result of differential mortalities which can occur during three critical phases: 1) fertilization, 2) the free-swimming planktonic stage and 3) the early post-settlement phase. The environmental factors with the greatest effect on the survival of estuarine bivalves, especially the surface-dwelling juveniles, are temperature, salinity, dissolved oxygen, substrate, water movement, sediment transport and food availability. Moreover, biotic factors such as competition, predation, disease and parasitism also significantly affect natural mortality, with this effect depending on the size (age) of the individual (Brosseau, 2005).

Our results showed different responses of bivalves to climatic factors, especially between lagoon and coastal species. Ria Formosa is a mesotidal coastal lagoon (Newton and Mudge, 2003), highly productive, permanently connected to the sea, with strong tidal influence (Falcão and Vale, 1990); its conditions are very similar to the adjacent coastal area. This coastal lagoon system has favorable conditions year round (Sprung, 1993), although the intertidal bivalve grounds are exposed to extreme conditions of temperature, salinity, and desiccation during spring tides (Loureiro *et al.*, 2006). The lagoon species (*C. edule* and *R. decussatus*) were positively related with upwelling in spring and summer seasons, because the dynamics of coastal upwelling events can influence the chemical, physical and biological characteristics of this coastal system (Duxbury, 1979; Loureiro *et al.*, 2006; Tilstone *et al.*, 2000). The daily renovation of 75% of the water mass in the lagoon (Newton and Mudge, 2003) also contributes to explain the influence of upwelling. Upwelling events are associated with an increase in the supply of nutrients from deep waters. With the constant renovation of lagoon water, these nutrients can get into the lagoon, increasing the productivity of intertidal bivalve populations. Furthermore, as the intertidal bivalves are exposed to desiccation in low tides, the nutrient rich and cold upwelling water can also contribute to improve their physiological condition. The peak of phytoplankton and zooplankton production in the Ria Formosa is generally in summer (Barbosa, 2010), the period of strong upwelling events that are related to bivalve harvests the following year. The upwelling of cold deep waters can also be related to reproduction. In fact, both the lagoon species, *C. edule* and *R. decussatus* spawn when upwelling occurs, principally during spring and summer seasons (Chícharo, 1996; Coelho *et al*., 2006; Leitão, 2003).

Sea surface temperature was another environmental factor that was found to affect intertidal lagoon bivalves. In fact, temperature is described as the main factor affecting bivalve reproduction (Chícharo and Chícharo, 2001b), their activity level and energetic balance (Sobral, 1995), feeding rate (Dame, 1996; Gaspar *et al.*, 1995), metabolism and growth (Witbaard *et al.*, 1999) and, consequently, survival (Dame, 1996). The development of bivalve populations depends on water temperature during winter (Beukema, 1992; Beukema *et al*., 1998, 2001; Honkoop *et al*., 1998; Strasser *et al*., 2001). The yearly average sea surface temperature had a negative effect on *R. decussatus* population's density (LPUE). This effect was recorded also by Sobral (1995) and Sobral and Widdows (1997) who verified that warm temperatures (above 27ºC) were stressful to the clams *R. decussatus,* resulting in low growth rates. Moreover, higher temperatures can weaken species resistance to air exposure, increasing mortality rates. Cockles, *C. edule*, can be very sensitive to temperature variations also, which can cause their death as reported for the Wadden Sea by Beukema *et al*. (1998). In the present study results showed that the decreasing of sea surface temperature in winter season has a negative effect in cockles due to the sensitivity of this species to low winter temperatures that enhance mortality (Beukema *et al.*, 2001). However, for many other species cold winters increase species recruitment, as bivalves slows their metabolic rate, consequently contributing to an increasing in number and eggs size (Beukema *et al*., 1998; Honkoop and van der Meer, 1997; Younge *et al*., 1996).

The NAO and NAO winter indexes were important only for the coastal nearshore bivalve species. During the positive NAO phase the north winds are predominant (Borges *et al.*, 2003; Lehodey *et al.*, 2006), causing cold and dry weather in the Mediterranean regions, while the negative phase is characterized by warmer temperatures and increased precipitation (Lehodey *et al.*, 2006). For *C. gallina* and *Donax* spp*.* the NAO indexes had negative effects in LPUE trends. That is, years with predominant NAO negative phase, warmer temperatures and wet conditions, are favorable to *C. gallina* and *Donax* spp*.*

recruitment. According to Ottersen *et al.* (2001), the ecological responses to NAO comprise changes in timing of reproduction, population dynamics, abundance, distribution and inter-specific relationships such competition and predator-prey interactions. In fact, differences in the sensitivity of different species and populations to NAO are related to species biology. The environmental factors that are affected by NAO, such as temperature, wind and precipitation, will influence recruitment and growth (Carroll *et al.*, 2009; Witbaard *et al.*, 2005), support higher metabolic rates (Ottersen *et al.*, 2001) and improve food availability (Carroll *et al.*, 2009).

In bivalves, spawning is triggered by water temperature during spring. More precisely, an increase of water temperature is necessary for bivalves to spawn (Joaquim *et al*., 2008b). In fact, a relationship between growth delay and decreasing water temperature was observed for *Donax trunculus* (Gaspar *et al.*, 1999b). In the present study, sea surface temperature during spring was an important factor, influencing *Donax* spp*.* harvests. In fact, this period represent the first peak in the spawning season that occurs between March and August with two major peaks, in March and May-August (Gaspar *et al.*, 1999b). The other bivalve species affected by temperature was *S. solida*. This species showed a negative correlation with sea surface temperature during summer (SST3). In fact, according Gaspar and Monteiro (1999), between June and September (summer season) *S. solida* specimens were found to be in the resting stage and the condition index increased, probably due to the accumulation of reserves for the gametogenic activity that begins in autumn. For this reason, bivalves are extremely sensible to environmental forces, and the abnormal increases of temperature can have a negative effect on this species.

The annual mean and upwelling index had a negative effect on the harvests of *C. gallina*. Shanks and Brink (2005) showed that the effect of upwelling in bivalve recruitment varied according to the type of species. Upwelling events during summer cause the offshore flow of the surface layer, contributing to transport of invertebrates larvae so far from shore that they cannot return to settle, resulting in high larval wastage (Connolly *et al.*, 2001; Shanks and Brink, 2005). In downwelling the reverse occurs: larvae in the surface layer are carried to shore, leading to high settlement (Shanks and Brink, 2005). *C. gallina* spawns between June and September (Gaspar *et al.*, 2004). Therefore, summer upwelling regimes rather than annual upwelling would be expected to affect species recruitment. The effect of upwelling on *C. gallina* is somehow unclear because upwelling has no effect on most of the coastal species, while significantly affecting all lagoon species.

In the Algarve, coastal drift currents, until approximately 30 meter depth, are strongly affected by the strength of the wind and wind direction (Melo, 1989; Moita, 1986; Vila-Concejo *et al*., 2003). Coastal currents influence the bivalves because they are essential for their food supply (Gaspar *et al.,* 1995; Sobral and Widdows, 2000), larvae settlement and growth of adults (Sobral and Widdows, 2000). *P. legumen* catches were negatively affected by wind strength in autumn while *C. gallina* landing trends were positively affected by wind magnitude during spring. Therefore, the seasonal effect of wind magnitude seems to differ according to species. Differences in results achieved for coastal species are related to larvae sensitivity to wind turbulence regimes. Wind magnitude leads to dynamic perturbations in superficial sediments (Strasser *et al*., 2001; Walne, 1972; Wildish and Peer, 1983), affecting the settlement behavior of bivalve larvae (Chícharo and Chícharo, 2001a, 2000). Moreover, wind magnitude can affect the swimming behavior of larvae during the pelagic stages before settlement, and consequently, their recruitment to the harvestable stocks.

Wind direction is another important factor affecting bivalve species. In the Algarve, westerly winds are necessary for upwelling and SST changes. The Southeast winds during spring were found to be related to *Donax* spp*.* LPUE trends. These winds transport Mediterranean warm waters, stimulating spawning events in the species. In addition, the species is also affected positively by wind direction in autumn that brings Atlantic cold water favoring gonad (gametogenesis) development (starting in November, according to Gaspar *et al.*, 1999b).

The Guadiana River is the main contributor to coastal river discharge in south Portugal (Algarve). River discharges had a significant negative impact on *S. solida* species (nearshore species). Changes in freshwater discharges from rivers increase turbidity and sediment transport, affecting shallow water nursery areas (feeding and settlement; Boelens *et al*., 2005), bivalve filtration rates (Higano, 2004) and the composition of bivalves assemblages (Rufino *et al.*, 2008). In fact, Erzini (2005) showed that for several commercial fish and invertebrate species in the south coast of Portugal, the Guadiana River was the main factor contributing to the observed pattern in the LPUE trends.

The autoregressive nature of the interactions between response and explanatory variables has been shown to provide the best model fits (DFA and MAFA) with a time lag of 1 year for all bivalve species. These results are not surprising, given that all considered species need one year to reach adult age. However, the environmental factors that affected Ria Formosa species (lagoonary species) are distinct from factors that affected coastal species. That is, the sensitivity of coastal and lagoon bivalves to environmental changes varied considerably. The upwelling index had a significant effect on the lagoon species while the NAO index, wind magnitude and direction and offshore discharges only affected the coastal species. For most of the species, seasonal LPUE trends were mostly affected by fishing effort and seasonal climatic variability. Changes in the recruitment of marine resources have been attributed to either changes in the environment or variations in fishing effort. Disentangling the effects of environment and effort has proven to be problematic and has resulted in recurrent controversy between studies supporting one or other hypothesis. For most species, effort was shown to effect LPUE trends in the subsequent year. This shows that for improved conservation and management, it is necessary to adapt fishing effort regimes, while considering the background effects of the environmental parameters. Understanding the effects of environmental variability on marine production could be of great value if integrated into management procedures and the possible ways by which this could be done have not yet been fully explored. Therefore, the main difficulty will likely be in reconciling results on environmental–recruitment relationships that are evident at local scales and management strategies that take place at the level of individual stocks. Thus, future models of stock assessment should include annual data series on catch and effort of a fishery on a single stock, and annual (or seasonal) data series on environmental variables known to influence the abundance or the catchability of this stock (or combined variables, as was showed by the DFA). This will contribute to explain how environment and fishing effort governs the yields of the fishery during the period under study. The results of this study have shed light on the stock dynamics of bivalve fisheries in Algarve, and will be useful for management of these valuable resources.

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CHAPTER 3

Effect of environmental variables on catch rates in three different bivalve stocks in the Atlantic Iberian Coast

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Effect of environmental variables on catch rates in three different bivalve stocks in the Atlantic Iberian Coast

Abstract: The knowledge on the effects of environmental variability on marine production could be of great value if integrated into management of coastal fisheries. In Portugal dredge fleet target directly on *Spisula solida* clam along three distinct zones of the coast. Understanding the effect of climatic and fishery at regional scale is therefore important for local management actions. Herein, we studied the effect of environmental variables and fishing pressure on catch rates (landing per unit effort - LPUE, as abundance index proxy) in three different *S. solida* populations in the Atlantic Iberian Coast. The three distinct regions of Portuguese coast (Northwestern, Southwestern and South coast) showed distinct oceanographic and hydrological profiles. Models for the analysis of time series data showed distinct sensibility of *S. solida* to environmental factors across regions. In Northwestern, the results show that combination of NAO indexes and sea surface temperature had a major effect over *S. solida* populations. In Southwestern, the environmental variables that most *explain S. solida* catches variation were both magnitude and wind direction (wind components). River discharges and sea surface temperature showed to be the factors most affect species trend in South region. The fishing effort was also correlated with changes in LPUE trends in South region. Providing the different role that local environmental forces might exert on different *S. solida* populations regional based actions should be considered for better management of the fisheries.

Keywords: Bivalve’s catches; environmental variability; intra-regional fisheries changes; Portugal; *Spisula solida*; time-series analyses.

Introduction

The marine ecosystems around the world are affected by climate changes, (Bertram *et al.*, 2001). The climate changes affect the survival, growth, reproduction and distribution of species (Brander, 2007), through of changes in morphology, physiology and behavior (Harley *et al.*, 2006), but the impacts can also be exhibited in populations, communities and ecosystems levels (Brander, 2007, 2010; Lehodey *et al.*, 2006; O'Reilly *et al*., 2003; Perry *et al.*, 2010; Pörtner and Knust, 2007).

There has been a growing concern about the consequences of climate changes on marine ecosystems with many studies showing that many fisheries are affected by the environmental variability (Brander *et al.*, 2007, 2010; Coyle *et al.*, 2011). The environmental changes, such as variations in temperature, salinity, wind, currents and oceanic circulation, precipitation and river run-off, and nutrients dynamic, may affect productivity, abundance and distribution of exploited stocks (Barange 2002; Brander *et al.*, 2007, 2010; Drinkwater & Frank, 1994; Dulvy *et al.*, 2008; Lehodey *et al*., 2006; Perry *et al*., 2005). Most of the studies of climate change on fisheries has been focused on fish catches (for example, Allison *et al*., 2009; Brander, 2007, 2010; Erzini, 2005; Erzini et al., 2005; Klyashtorin, 1998; Lehodey *et al.* 2006; Lloret *et al*., 2001; Planque andFrédou, 1999), with studies on invertebrates groups, such as bivalves molluscs, almost lacking in coastal areas (Fernández-Reiriz *et al*., 2011, 2012).

It is recognized however that bivalves can be sensitive indicators of climate changes (Helmuth *et al.,* 2006; Somero, 2002). They are considered good biological indicators (Carroll *et al.*, 2009; Simboura and Zenetos, 2002) and consequently a good taxonomic group for monitoring changes in marine ecosystems (Grémare *et al*., 1998). Moreover, many bivalve species in shallow temperate coastal waters have a short life cycle, allowing to reflect environmental changes rapidly (Zeichen *et al.*, 2002), and bivalves are accessible because they constitute a large fraction of benthonic communities in littoral (Rufino *et al.*, 2010).

Coastal bivalves are socially and economically important for professional shelffishermen and local populations (recreational fisheries) (Gaspar *et al*., 2005a; Leitão, 2003; Leitão and Gaspar, 2007; Rufino *et al*., 2010). In Portugal, the bivalves molluscs catches is very important, being one of the major artisanal fisheries and traditional activity (Gaspar *et al.*, 1999, 2001, 2005b) having been initiated in 1969 (Chícharo *et al*., 2002; Gaspar *et al.*, 1999). The bivalves fisheries have high volume of catches (in 2009 had superior to 2600 ton) and commercial value (with an average value superior to 2 euros.kg^{-1}). Although several bivalves species of great commercial importance are caught be commercial fleet only the white clam *Spisula solida* (Linnaeus 1758) is captured along the whole Portuguese continental shelf, Northwestern, Southwestern and South leeward regions (Gaspar *et al*., 2003b). In Portugal, the IPIMAR (Instituto de Investigação das

Pescas e do Mar) has developed, since 1983, a monitoring program of bivalve molluscs resources, through monitoring cruise of commercial bivalve in coastal areas aiming evaluate bivalves stocks for management. Therefore, management measures have been applied in bivalve's dredge fisheries. These measures include totals allowable catch (TACs), limitations in number of licenses, closure periods (from 1 May until 15 June), daily quotas, minimum legal landing length and minimum mesh size (Chícharo *et al*., 2002; Gaspar *et al*., 1999, 2002; Joaquim *et al*., 2008a; Leitão *et al*., 2009). A minimum legal landing length of 25 mm for *S. solida* was introduced to allow spawning at least once before capture (Gaspar *et al*., 1999, 2002), and the closure period have as objective protect spawning individuals (Chícharo *et al*., 2002). The dredges, used in the *S. solida* catches (Gaspar *et al*., 1999), are gears with high selectivity and efficiency of capture (Gaspar, 1996). Generally, in Portuguese temperate waters commercial bivalves have short lives. In fact, despite bivalve management plans, scientific surveys showed that the size of bivalve's populations is often variable at annual time-scales, region independently (Gaspar, 1996; Joaquim *et al*., 2008a). Such variations are related to both external (e.g. environmental factors that operate during larvae pelagic life cycle) and internal controls (e.g. density-dependence control) of marine exploited populations that can explain spatio-temporal variability in recruitment (Planque et al., 2010).

Short-term bivalve predictions should be based on estimates of bivalves catch rates considering the interactions with the environment affecting growth and mortality. General hypotheses on fisheries management should be tested using data sets from several stocks from different regions within an area. It is probable that the exploited populations display different responses to environmental changes according region because, the abiotic factors differ between regions and show different impacts in biological and ecological level of species and ecosystems (Planque and Frédou, 1999). It may be difficult to separate pure environmental control from combined space-environment control, but recent studies have developed ways to evaluate this shared component (Borcard *et al*., 1992, 2004; Borcard and Legendre, 1994, 2002). This study aimed to evaluate the effect of fishery and environmental variability on coastal *S. solida* populations, along three distinct regions of Portuguese coast.

Materials and Methods

The Portuguese coast is under unique biogeographic circumstances, receiving climactic influences from the North Atlantic Ocean and the Mediterranean Sea (Cunha, 2001). The location of Portugal West (Northwestern and Southwestern) coast in subtropical eastern boundary of North Atlantic Ocean determines many of its atmospheric and oceanographic characteristics (Santos *et al.*, 2001). The South region constitutes the transition from the Atlantic Ocean to the salt and warm Mediterranean Sea (Cunha, 2001; Rufino *et al*., 2010) contributing to typical Mediterranean climate. In Portugal bivalve fisheries target on *S. solida* occurred on three distinct regions (Gaspar *et al*., 2003b; Figure 1). Each one of the studied areas presented also different conditions regarding oceanography (Bettencourt *et al*., 2004; Cunha, 2001), ecological communities and species assemblages (Sousa *et al.*, 2005). The *S. solida* fleet that target on the species, at each region, are the following (Figure 1): (i) the Northwestern, include the Matosinhos and Aveiro fishing ports; (ii) the Southwestern, comprise the Cascais, Trafaria, Setúbal and Sines fishing ports; and (iii) the South, comprise the Algarve Leeward ports, that is Quarteira, Faro, Olhão, Tavira and Vila Real de Santo António. The S*. Solida* species, form extensive and dense beds on clean sandy bottoms across the three areas (Gaspar, 1996; Gaspar *et al.*, 2002; Leitão *et al.*, 2009). However, along the Portuguese coast, the clam *S. solida* presents a distinct distribution depth pattern between regions: in Northwestern region, this species is caught between 5 and 34 meters depth (Gaspar *et al*., 2005b), in Southwestern showed a distribution among 3 and 25 meters depth (Gaspar *et al*., 2003a), and in South region this species inhabit sand bottoms at depths between 3 and 14 m (Dolbeth, 2006; Gaspar *et al*., 1995; 1999; 2003a; 2005b).

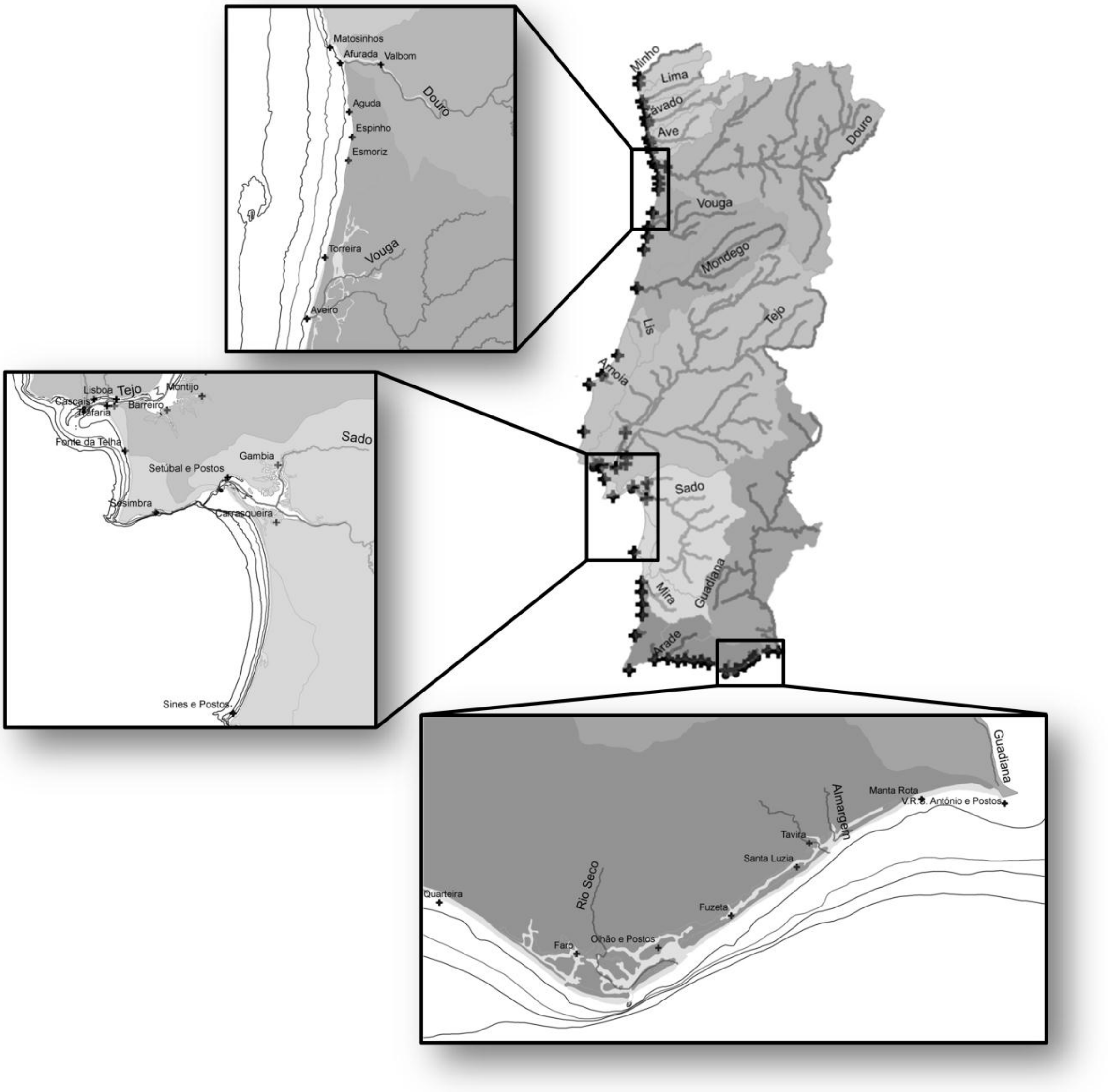

Figure 1. Location of the rivers and ports from three regions where bivalves are fished: Northwestern (Matosinhos and Aveiro), Southwestern (Cascais, Trafaria, Setúbal and Sines) and South (Quarteira, Faro, Olhão, Tavira and Vila Real de Santo António).

As a proxy of bivalve biomass production (abundance index) we used yearly landings per unit effort (LPUE). LPUE, as response variable, were estimated dividing the total landings of the year by the total number of fishing days of the year (LPUE units: kg per fishing day/event). The landings data, period between 1989 and 2009, where obtained from DGPA (Directorate-General of Fisheries and Aquaculture) and includes high detail information regarding the bivalve fishery, such as monthly effort (number of fishing days and/or events) and monthly landed catches per boat.

Different climatic, oceanographic and hydrologic explanatory variables were used. The NAO and NAO winter (December–March) indexes were used as climatic explanatory variables (http://www.cgd.ucar.edu/jhurrell/nao.html, last accessed 2010; Hurrell, 1995). The NAO indexes are defined as the difference between sea level atmospheric pressure at the Azores and Iceland and it largely regulates the precipitation regimes, temperature and winds above northwest of Europe (Witbaard *et al.*, 2005).

The annual and seasonal mean Sea Surface Temperature (SST), annual and seasonal upwelling index (UPW), and yearly and seasonal eastward (u) and northward (v) wind components were included on oceanographic explanatory variables. SST data was obtained through satellite data, from NASA Ocean Color Giovanni web page products, from the Modis-Aqua 4Km satellite (http://gdata1.sci.gsfc.nasa.gov). The upwelling index was obtained from Pacific Fisheries and Environmental Laboratory (www.pfeg.noaa.gov). Both u- and v-wind components were achieved, from PO.DAAC (http://podaac.jpl.nasa.gov/dataset/CCMP_MEASURES_ATLAS_L4_OW_L3_5A_MONTHLY_WIND_VECTORS_FLK?ids=&values=) according Atlas *et al.* (2011). The magnitude [WMag: SQRT(u^2 + v^2)] and wind direction [WDir: degree Arc $tangent^2$ (u, v)] were estimated with u- and v-wind components and used in the statistical models. Coastal oceanographic data collected through satellites were compiled until 200m depth to cope with the lack of some satellite data (cloud effect) near to shore (Figure 1). Thereafter, the oceanographic information (SST, UPW, WMag and WDir) should be interpreted was area average mean values.

Coastal marine areas are affected by river run-off (hydrologic variable). The Northwestern shelf is characterized for a highly energetic hydrodynamic regime (Abrantes *et al.*, 2005), the main contributors are the Douro and Vouga Rivers. In Southwestern river discharges used for purpose of this study include the Tagus and Sado Rivers. In South the river discharges are mainly due to Guadiana River and input of freshwater from the Ria Formosa given by Seco River and Alportel and Almargem Streams. River discharges (RD) information was collected from Portuguese Water National Institute webpage (http://snirh.pt/ last access October 2011).

Data analysis

For test temporal effect of environmental (explanatory) variables on LPUE trend, we organized the explanatory variables in yearly and quarterly (seasonal) data such as:

(1) winter (January to March); (2) spring (April to June); (3) summer (July to September); and (4) autumn (October to December).

We used Quantile-Quantile plots (QQ-plots) to test data normality. In the *S. solida* LPUE the square root transformation was used in south region data aimed to generate a normal sample and a normal probability plot of the data. Pair plots were used for help to excluded explanatory variables that present collinearity among them.

For purpose of this study we used the Dynamic Factor Analysis (DFA). DFA is a multivariate time-series analysis technique that can be used to non-stationary time series analysis in terms of common trends and explanatory variables (Zuur *et al.*, 2003a, b; Zuur and Pierce, 2004). DFA is used to estimate underlying common patterns in a set of time-series evaluate interactions between response and explanatory, variables and determine the effects of explanatory variables above response variables (Zuur *et al*., 2003a). The time-series are modeled in relations of a linear combination of common trends, a constant level parameter, explanatory variables and a noise component (Zuur *et al.*, 2003b). Zuur *et al*. (2003a) shows a detail statistical description of Dynamic Factor Analysis. There are several DFA models (Zuur *et al*., 2007) including models for univariate series only. The model best fit our design as: 1 time series = trend + noise. Each region was different environmental condition and models should also account for spatial independency among regions. Therefore, one DFA analysis was made for each region. So, a unique trend (autocorrelation time lag 1 year) was fitted individually for each species (LPUE). Models were fitted with a diagonal covariance matrix and Akaike's Information Criterion (AIC) was used as a measure for goodness of fit and the numbers of parameters in the model. Using the AIC we can compare the models, the best model containing the smallest AIC value. Results presented for DFA were obtained with the software package Brogdar (http://www.brogdar.com).

Both response and explanatory variables were standardized before run dynamic factor analysis model, such advised by Zuur *et al.* (2003a, b). For this, the mean normalization was apply, that consist in center all variables around zero ($Xi=(Yi-\hat{Y})/\sigma y$) where σy is the sample standard deviation. The transformed values Xi are now centered around zero, have unit variance and are unit-less.

The availability of reliable biological information about species is important for the effective management of any fishery. *S. solida* reaches sexual maturity during the first year of life (Gaspar and Monteiro, 1999). Bivalve's larvae phase is pelagic and sensitivity to changes in the environment renders them good models to interpret and understand the impact of climate variability on recruitment processes and bivalve yields. Thus herein we considered that climatic, oceanographic and hydrologic data affect bivalve recruitment or/and larvae survivorships and consequently bivalves adults biomass for the fishery in the following year. Moreover, due to the short life cycle of the species the effort of the year before (year-1) might also affect spawning biomass (adults) and recruitment in the year after. Therefore, environmental data and effort (number of fishing days) were delayed one year. Herein, we considered the hypothesis that coastal bivalve's production is affected by distinct environmental conditions along the three regions. Therefore, DFA models were constructed area independently.

Results

The LPUE for *S. solida* (Figure 2) presented a distinct longitudinal variation. In the Southwestern and South regions the LPUE trends had a similar pattern along the study time, while Northwestern region showed an opposite LPUE trend. During 1992, 1995 and 2003 it was observed LPUE positive peaks in the Southwestern and South, with subsequent large decreases of *S. solida* LPUE in the subsequent years. In the Northwestern occurred a large decrease after 1989 with predominating negative anomalies in following years.

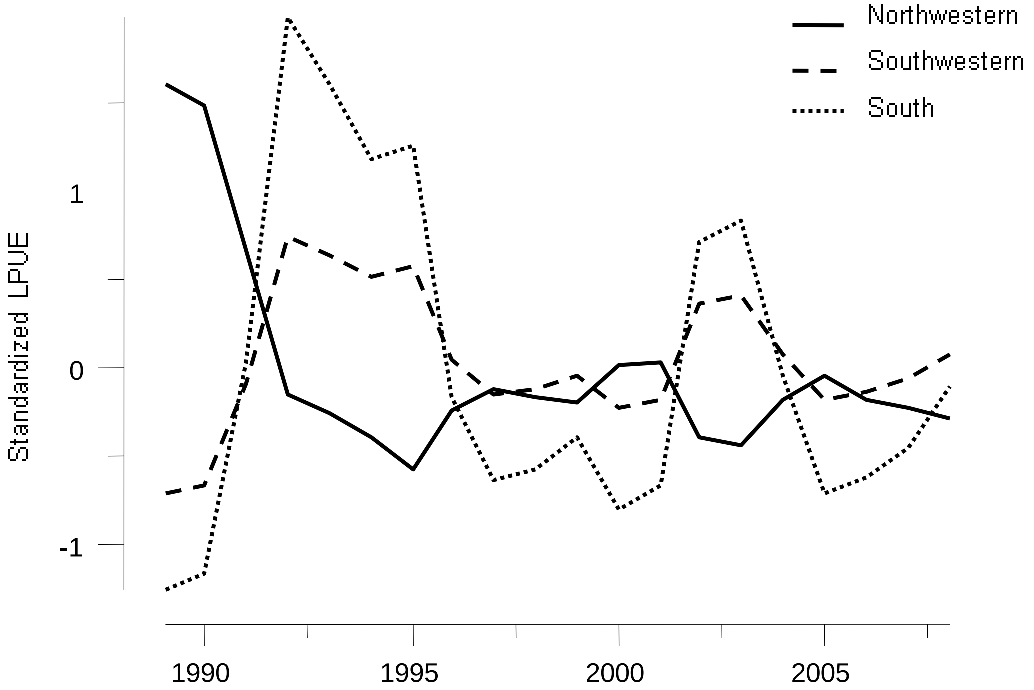

Figure 2. Standardize landings per unit effort (LPUE) for *Spisula solida* from 1989 to 2008 in Northwestern, Southwestern and South Portugal.

The sea surface temperature (SST) presented colder temperatures in Northwestern and warmer temperatures in South (Table 1). Within the same regions it was observed a distinct pattern in SST across seasons (Figure 3a, b, 3). However the spring (SST2) and autumn (SST4) have similar SST, along Portuguese coast. The *S. solida* biological temperature range for Portuguese coast varied between 13 and 23ºC (∆SST = 10; Fig. 4). In all regions, the river discharges showed a very oscillatory trend (Figure 3d, e, f), reaching a highest peak in winter (RD1) and a smallest peak in summer (RD3). Season independently, the river run-off presented higher values in the Northwestern, followed by the Southwestern and finally the South (Table 1), the latter being very low compared to Northwestern and Southwestern coast. In Northwestern, Southwestern and South river discharges peaks occurred in the same years, reflecting the effect of the hydrological years (rain). Along Portuguese coast, the upwelling was predominant in spring (UPW2) and summer (UPW3), while downwelling regimes predominated in other seasons, winter (UPW1) and autumn (UPW4) (Figure 3g, h, i; Table 1). The Northwestern and Southwestern regions presented a similar upwelling index values, with very intense upwelling regimes (spring and summer). The downwelling, in winter and autumn seasons, was strongest in Northwestern region. In South, the upwelling, in spring and summer, was weakest in relation to western regions. Downwelling conditions in South prevail during winter and autumn. In general, wind magnitude was strongest in the Southwestern coast, followed by the Northwestern coast, and finally in the South coast (Figure 3j, k, l; Table 1). Moreover, the seasonal wind magnitude varied considerably across the three areas, but in the South seasonal pattern oscillations/peaks becomes less evident. Generally, region independently, wind magnitude was stronger in the spring (WMag2) and summer (WMag3). In relation to wind direction the predominance of South and Southwest winds were verified along the Portuguese coast, however the three regions showed distinct patterns (Figure 3m, n, o). In the Northwestern region, during winter (WDir1) and autumn (WDir4) predominated winds blow from South and Southwest, during spring (WDir2) predominated winds arrives from Southwest, and in summer season (WDir3) dominated winds blow from South. In Southwestern, during winter (WDir1) the South winds prevail while during spring (WDir2), summer (WDir3) and autumn (WDir4) winds direction becomes frequently from South and Southwest. In South region, during winter (WDir1) the wind arrives frequently from Southwest and Southeast while during spring (WDir2) and summer (WDir3) the predominant winds blow from South and Southwest; in autumn (WDir4) winds arrives from South, Southwest and East.

Table 1. Mean and standard deviation of yearly and seasonal environmental variables during the period 1986-2008 in Northwestern, Southwestern and South of Portugal: SST – Sea Surface Temperature; RD – River Discharges; UPW – Upwelling Index; WMag – Wind Magnitude.

	SST	SST1	SST2	SST3	SST4	RD	RD1	RD2	RD3	RD4	UPW	UPW1	UPW2	UPW3	UPW4	WMag	WMag1	WMag2	WMag3	WMag4
Northwestern	16,12	14,00	16,07	18,50	15,92	1,56E+07	6,72E+06	3,08E+06	1,20E+06	4,60E+06	-8,75	-41,81	23,82	44,92	-61,92	2,75	1,92	4,07	4,50	2,74
	±0,51	±0,69	±0,77	±0,66	±0,96	±7,55E+06	±6,57E+06	±1,38E+06	±4,44E+05	±2,99E+06	±18,70	±41,98	±16,18	±12,76	±55,66	±0,58	±1,00	±0,98	±0,70	1,03
Southwestern	17,02	15,11	16,74	19,17	17,05	9,40E+06	3,97E+06	1,26E+06	9,13E+05	3,26E+06	10,56	-13,62	32,85	53,41	-30,38	3,65	2,81	4,83	5,18	2,85
	±0,39	±0,61	±0,62	±0,72	±0,82	±6,34E+06	±4,85E+06	±6,40E+05	±4,96E+05	±3,03E+06	±10,96	±25,79	±18,72	±15,12	±34,80	±0,57	±0,87	±0,94	±0,69	±1,34
South	18,79	16,28	18,36	21,61	18,90	2,15E+06	1,08E+06	1,87E+05	8,42E+04	7,92E+05	-2,47	-18,01	9,33	9,88	-11,08	2,06	2,37	2,88	3,13	2,17
	±0,32	±0,43	±0,49	±0,71	±0,68	±2,45E+06	±1,62E+06	±1,35E+05	±6,00E+04	±1,39E+06	±6,83	±26,06	±10,34	±8,12	±29,74	±0,43	±0,59	±0,66	±0,60	±0,81

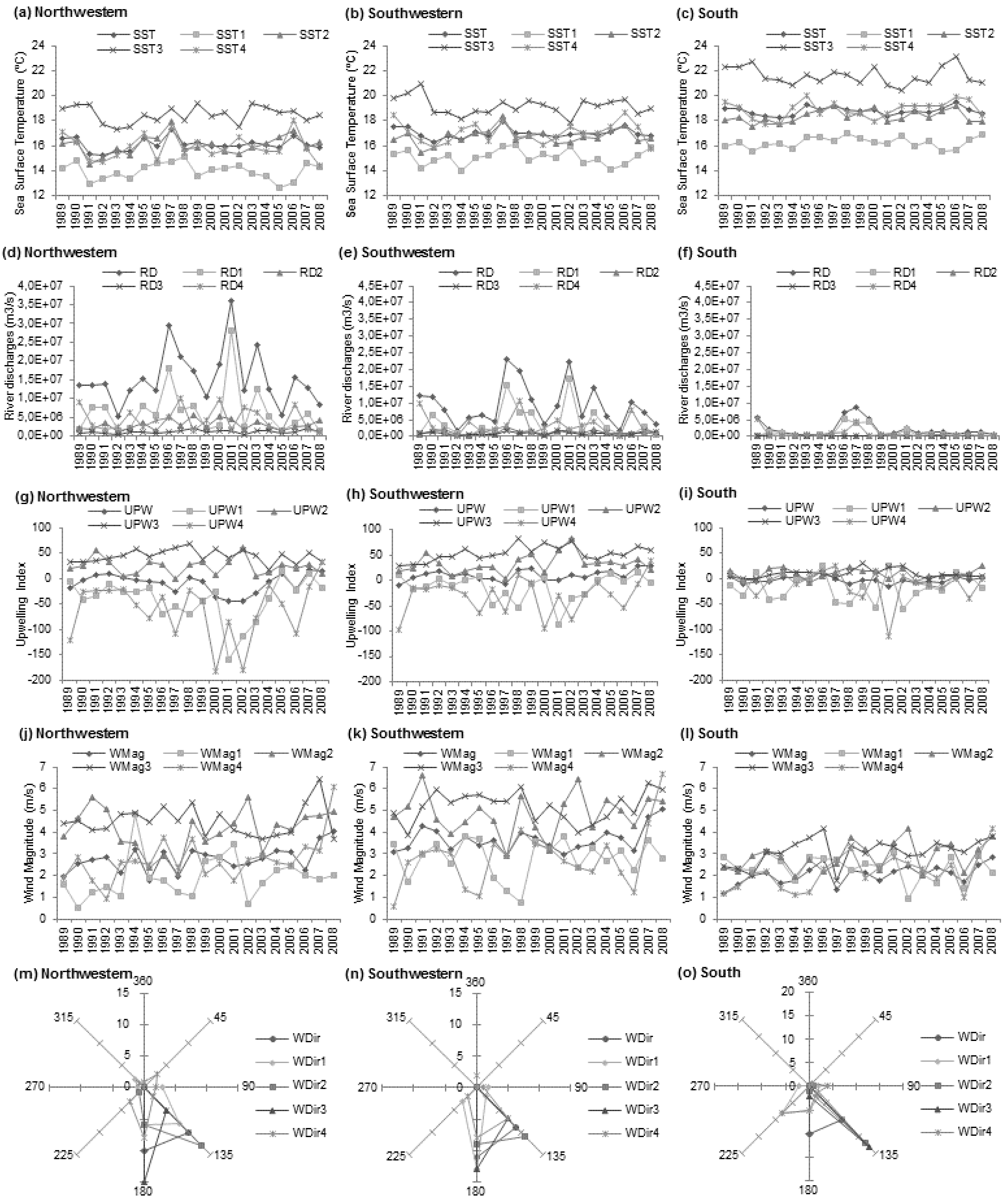
(a) Northwestern
(b) Southwestern
(c) South
SST
SST1
SST2
SST3
SST4
Sea Surface Temperature (°C)
(d) Northwestern
(e) Southwestern
(f) South
RD
RD1
RD2
RD3
RD4
River discharges (m3/s)
(g) Northwestern
(h) Southwestern
(i) South
UPW
UPW1
UPW2
UPW3
UPW4
Upwelling Index
(j) Northwestern
(k) Southwestern
(l) South
WMag
WMag1
WMag2
WMag3
WMag4
Wind Magnitude (m/s)
(m) Northwestern
(n) Southwestern
(o) South
WDir
WDir1
WDir2
WDir3
WDir4
360
45
90
135
180
225
270
315

Figure 3. Environmental variables during the period 1986-2008 in Northwestern (1), Southwestern (2) and South (3) of Portugal: (A) sea surface temperature; (B) river discharges; (C) upwelling index; (D) wind magnitude; and (E) wind direction (monthly frequency occurrence).

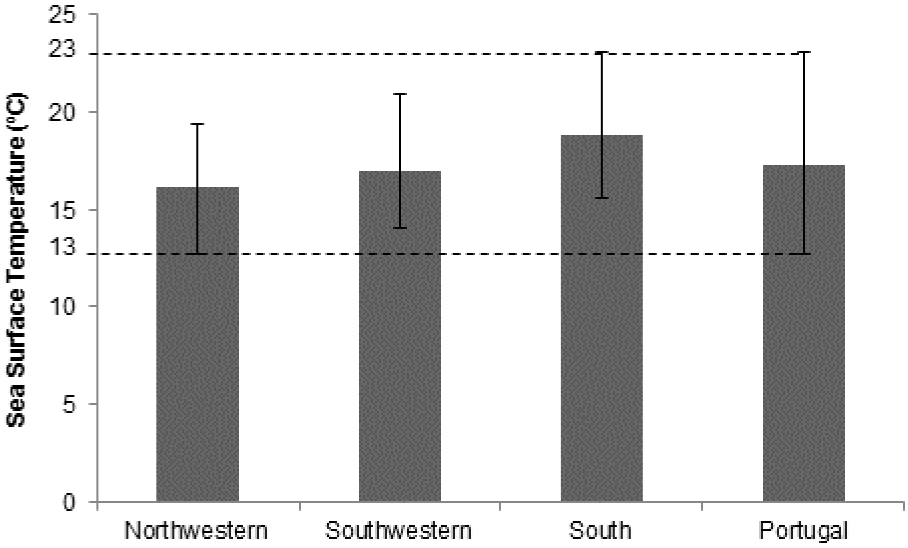

Figure 4. Optimal temperature range variation according distribution of *S. solida* in Portuguese coast.

The NAO and NAO winter indexes exhibited similar patterns (Figure 5), being in positive phase for most of the study period. However, from the mid-90's the NAO indexes showed great variability between positive and negative phases.

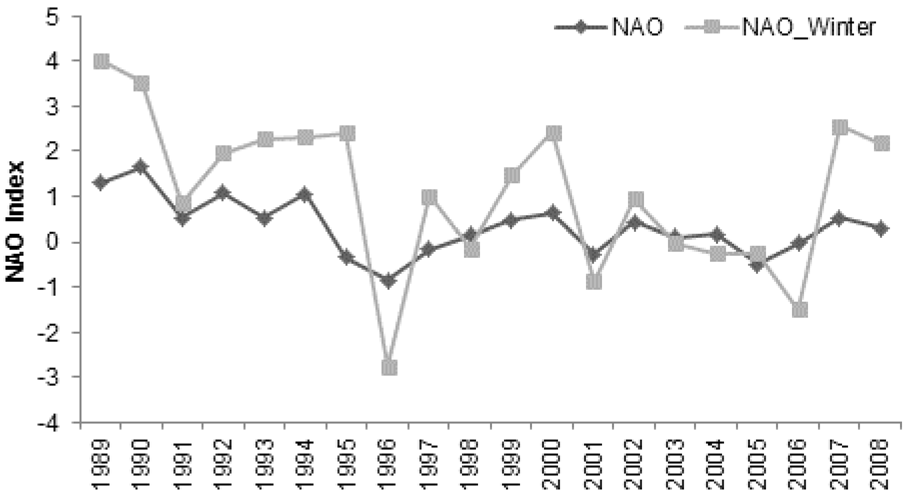

Figure 5. North Atlantic Oscillation (NAO) and North Atlantic Oscillation in winter (NAO_Winter) indexes during the period 1986-2008 in north, southwest and south Portugal.

After the analyses of environmental explanatory variable trends, relationships between LPUE trends and environmental variables, in the three study regions, were analyzed.

The best explanatory variable for explain *S. solida* LPUE trends variability was given by the smallest AIC (Akaike's Information Criterion) values (Table 2). In North region the environmental variables mostly explains variation in *S. solida* LPUE were sea surface temperature, mainly during cool seasons (SST, SST1 and SST2) and NAO indexes (NAO and NAO winter), both positively correlated with the LPUE trend. However, the best model, for Northwestern region, was the one include combined effects of NAO indexes and SST (yearly and during winter). In Southwestern region, the wind magnitude (WMag and WMag2) and wind direction (WDir, WDir2 and WDir3) were the variables that mostly explain changes in *S. solida* fishing trends, with positive and negative correlations with LPUE, respectively. Both yearly (RD) and winter (RD1) river discharges and SST in summer (SST3) affect LPUE trend in South region, with the latter variables presenting a negative correlation with the DFA fishing trend. Moreover, the fishing effort affects positively Algarve (South region) catches.

Table 2. Akaike's information criterion (AIC) values for dynamic factor analysis (DFA) models with one common trend and zero to one and two explanatory variables, based on a symmetric matrix (embolded, lowest AIC value within explanatory variables series for each specie). (The signal – indicates estimated *t*-values for explanatory variables with a negative relationship, and signal + indicates a positive relationship; -- or ++ indicates *t*-values larger than 3.)

Explanatory variables	Northwestern					Southwestern					South				
1 time series = tred + noise	57.005					50.373					56.341				
1 time series = tred + explan var(s) + noise	Annual	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn	Annual	Winter	Spring	Summer	Autumn
Fishing Effort	58.940	-	-	-	-	52.312	-	-	-	-	**56.336**$^{+}$	-	-	-	-
SST	**54.758**$^{+}$	**54.501**$^{+}$	**54.038**$^{+}$	58.592	58.623	51.920	51.681	51.246	50.698	51.043	57.520	57.179	57.993	**56.114**$^{-}$	58.177
UPW	58.469	58.987	57.202	58.178	58.984	52.152	51.820	51.992	51.253	52.355	57.781	57.914	57.425	56.975	57.818
WMag	58.570	57.833	58.848	58.646	58.792	**50.116**$^{-}$	52.315	**49.679**$^{-}$	51.935	52.317	56.771	57.818	57.281	58.197	58.264
WDir	57.854	57.459	57.361	58.791	58.974	**48.668**$^{+}$	50.972	**38.873**$^{++}$	**49.615**$^{+}$	52.366	57.026	58.161	58.218	56.595	57.306
RD	58.847	58.860	57.605	59.001	58.813	52.269	52.209	51.404	51.379	52.164	**53.991**$^{-}$	**54.580**$^{-}$	56.589	56.769	57.785
NAO	**50.863**$^{+}$	**54.976**$^{+}$	-	-	-	52.356	52.267	-	-	-	58.338	57.911	-	-	-
NAO:SST	**46.924**$^{+/++}$	**53.913**$^{+/++}$	-	-	-	-	-	-	-	-	-	-	-	-	-

Discussion

Bivalve populations and their spatial distribution can vary in response to multiple environmental and fisheries variables. In this study, significant variation in *S. Solida* LPUE (fisheries-based biomass index) was induced by environmental forces. The role of climatic variability in bivalves depends of different stages of the species life cycle. In marine invertebrates with indirect development (planktotrophic larvae) large fluctuations are observed in yearly recruitment (Brosseau, 2005). These fluctuations depends of several environmental factors that affect larval production (Queiroga et al., 2007), such as temperature, salinity, dissolved oxygen, substrate, water movement, sediment transport and food availability (Brosseau, 2005).

The effect of environmental variables on *S. solida* catches varied according regions. Along the Portuguese coast, *S. solida* showed a biological temperature range around 10ºC (Figure 4). Despite this optimal temperature range, small variations in water temperature can affect bivalves life cycle, such as reproduction (Chícharo and Chícharo, 2001b), energetic balance (Sobral, 1995), feeding rate (Dame, 1996; Gaspar *et al*., 1995), metabolism and growth (Witbaard *et al*., 1999), and consequently the survival (Dame, 1996) of larvae and adult bivalves. For example, according Joaquim *et al*., (2008b) increases on medium temperature values provoke positive effects in *S. solida* recruitment, because these increases of water temperature are necessary for bivalves to spawn. In additional, Gaspar and Monteiro (1999) report that the onset of spawning takes place in February when the seawater temperature begins to increase. In fact, in Northwestern region the DFA results showed that SST combined with NAO were the variables that better explained *S. solida* trends. The NAO index might be seen as a proxy for SST (Becker and Pauly, 1996), since has a strong effect on this variable (Hurrell *et al*., 2003; Ottersen *et al.*, 2001). During positive phase of NAO index the North winds are predominant (Borges *et al*., 2003; Lehodey *et al*., 2006), causing cold and dry climate in the Portuguese coast (Lehodey *et al*., 2006), and in addiction the Northwestern region presented the lower yearly average temperature along Portuguese coast (Figure 3; Table 1).

In Southwestern, the environmental variables that better explain the *S. solida* catches variation were the wind components. Indeed, this region presented the greater variability in wind magnitude (Figure 3). Nevertheless, in relation to wind direction this region was the one that evidence most constant winds (with predominance of South and Southeast winds; Figure 3). The strength of the wind and wind direction strongly affect coastal drift currents (Melo, 1989; Moita, 1986; Vila-Concejo *et al*., 2003), essentials for food supply (Gaspar *et al.,* 1995; Sobral and Widdows, 2000), larvae settlement and growth of adults bivalve's benthonic species (Sobral and Widdows, 2000). The wind magnitude showed a negative relationship with *S. solida* catches, probably due the dynamic perturbations in superficial sediments (Strasser *et al*., 2001; Walne, 1972; Wildish and Peer, 1983) that affect species bivalve larval settlement behavior (Chícharo and Chícharo, 2000, 2001a). On the other hand the spring wind direction was a positively short term affect (time lag 1 year) on *S. solida* LPUE. The South and Southeast winds, which predominate in spring in Southwestern coast, are responsible for the downwelling events. During downwelling, due to the sinking of surface water, the larvae in the surface layer are carried to shore, leading to high settlement (Shanks and Brink, 2005). In other hand, these winds transport Mediterranean warm waters stimulating spawning events*,* in fact part of spawning period of this species occurs in this season, February to May (Gaspar and Monteiro, 1999).

In South of Portugal, the Guadiana River is the main contributor to coastal river discharges. However, a significant statistical negative relationship was found between river discharges and *S. solida* catches. In fact, changes in freshwater discharge, increased turbidity and sediment transport may affect shallow water nursery areas (feeding and settlement; Boelens *et al*., 2005), bivalves filtration rates (Higano, 2004) and population composition (Rufino *et al*., 2008). Erzini (2005) showed that, in the south, Guadiana River was the main factor that affected LPUE trends in a large range of commercial fish and cephalopods species. The SST during summer also showed to be a factor that affects negatively *S. solida* landings in Algarve (South Portugal). In this season, *S. solida* specimens are extremely sensible to environmental forces with the abnormal increases of temperature have a negative effect above this species (Gaspar and Monteiro, 1999). This is due to the fact that between June and September this species are in the resting stage, probably due to the accumulation of reserves for the gametogenic activity that begins in autumn (Gaspar and Monteiro, 1999).

In South, the fishing effort was positively related to *S. solida* catches. Defeo (1996a) reported the existence of dependent-density processes that affect growth, recruitment and natural mortality in coastal bivalve species. In other words, high adult densities resulted in extremely low rates of recruitment, and moderately densities of spawning stock resulted in a good recruitment (Defeo, 1996a), due to competition for food and habitat (Beukema *et al*., 2001; Brazeiro and Defeo, 1999) and settling larvae can be filtered passively by adults individuals, inhibiting the settlement and subsequent recruitment (Beukema *et al*., 2001; Defeo, 1996b). On the other hand, the decrease of spawning/adult biomass, due to fishing, can be a determinant factor for the next year catches, because fishing beds (adults clams) are exploited intensively until the bivalve yields drops below economical satisfactory values. In fact, Dolbeth (2006) concluded that overfishing of *S. solida* in consecutive years can cause a drastic stock decrease. However, this situation is not expected to occur. Fishing limits (quotas and TACs) and high gear selectivity have prevented the fisheries in South to be sustainable. Moreover, fishing effort is distributed both spatially and seasonally (Gaspar *et al.*, 2002), so its effects on the fishing beds also vary in space and time. The fleet concentrates the fishing effort during short periods on a specific *S. solida* beds, until catch rates drop below economically acceptable levels, after which the clam bed remains unfished (Gaspar *et al.*, 2002) until yields are profitable, which depends both on the growth rate of juveniles and on their density (minimum 1 year). This fact leads to a highly patchy distribution of fishing effort and so we cannot talk about continuous and cumulative fishing effects for a specific *S. solida* bed. The effect of fishing effort was solely verified in Algarve (South region). These results may be explained due to good conditions for fishing year around due to the calmness of the sea. In Western regions (Northwest and Southwest) the fishermen are many times prevented from their fishing activity due to severe weather. For example, due to the rough sea conditions observed all year round, in northwestern dredge fleet only operate during 5-6 months per year (Gaspar *et al.*, 2002).

Changes in the environment or in the fishing effort have been referred such as factors that influence variations in the recruitment of marine resources. Separating the effects of environment and fishing effort has been challenging, resulting in recurrent controversy, because through evolutionary processes, fishing stocks adapt to a fluctuating environment and the fishery may perturb this adaptation (Planque *et al.*, 2010; Ulltang, 2003). Thus both environmental and fishing variables should be assessed. The variability of *S. solida* fisheries was affected by both environmental and fishery factors, differently in three Portuguese coastal regions in study. The big question in this study was to understand why landings profiles among regions were not affected by the same environmental forces. This is due the biological adaptations to local environmental characteristics, such as different gametogenesis and spawning times, and different development times. Understanding the effects of environmental variability on marine production could be of great value if integrated into management procedures, such as reported by Ulltang (2003) the climate, having a significant influence on the survival at critical life stages and affecting their population dynamic processes through several pathways, can be inserted into stock-recruitment models and can improve their performance.

The *S. solida* LPUE showed distinct sensibility patterns to climatic variability and fishing across three Portuguese coastal regions. With the distinct response of *S. solida* populations to above factors affecting the fishery in short term. Therefore, it is necessary to adapt fishing effort regimes, while considering the background effects of the environmental factors, for the conservation of the biological state of the resources. Moreover, management of bivalve target species exploited resources should be adapted to a regional scale.

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CHAPTER 4

General Discussion and Final Remarks

General Discussion and Final Remarks

The climate change is a global problem. However, the impacts are local and can vary qualitatively across regions. Thus, the answer for understand environmental variability effect on marine resources should be analyzed based on a strong understanding local component and its regional planning depends on the assessment of impacts (Miranda *et al.*, 2006).

Bivalve populations and their spatial distributions can vary in response to multiple environmental and fisheries variables. The role of climatic variability in bivalves depends of different stages of the species life cycle. In fact, in marine invertebrates with indirect development (planktotrophic larvae) a substantial part of the recruitment variability seems to be related with climate variability (Beukema, 1992; Brosseau, 2005; Philippart *et al.*, 2003; Young *et al.*, 1996). These fluctuations depends of several environmental factors (Queiroga *et al.*, 2007), such as temperature, salinity, dissolved oxygen, substrate, water movement, sediment transport and food availability (Brosseau, 2005), that can affect the growth and mortality rates of bivalve larvae.

In order to determine the impact of environmental changes on bivalves catches in Portuguese coast, two distinct studies were conducted. In the first study, the sensitivity of coastal lagoon (Ria Formosa) and adjacent coastal waters bivalve species to environmental variability were compared, using fishing catches (landings per unit effort) as a proxy index of marine biomass production. In the second study the objective was to determine if the variability of environmental conditions present among three regions of Portuguese coast (Northwestern, Southwestern and South) had distinct effects on catches of a specific bivalve species (*S. solida*).

Time series analysis techniques showed that environmental factors that most affect the dynamics of the bivalve stocks vary between the lagoon system (Ria Formosa) and the adjacent coast (Table 1). In fact, benthic studies of the Ria point to a distinct lagoonal assemblage in relation to the adjacent Atlantic Ocean (Loureiro *et al*., 2006). These assemblages are exposed to different physical, trophic and biological conditions that result in distinct biotic communities (Loureiro *et al*., 2006). The mesotidal coastal lagoon, Ria Formosa, offer a protected shallow habitat, which can be highly productive (Gamito 2006) and the permanent connected to the sea, with strong tidal influence (Falcão and Vale, 1990), leads the daily renovation of 75% of water mass in the lagoon (Newton and Mudge, 2003). This dynamic favours the development and settlement of lagoon communities (Gamito, 2006) due to the ocean source of inorganic nutrients required to support the productivity of this ecosystem (Falcão and Vale, 2003). Ria Formosa conditions are very similar to the adjacent coastal area, that also receive exported nutrients of the lagoon (Falcão and Vale, 2003; Newton and Mudge, 2005) proceeding from the benthic fluxes (Falcão and Vale, 1990), however, coastal areas are subjected to more hydrodynamic conditions that provoke physical stress in bivalve communities.

Table 1. Summary of the effects of environmental factors and fishing effort on bivalve catches in coastal lagoon and adjacent coast, obtained through time series analysis.

Explanatory variables	**Lagoon Species**		**Coastal Species**			
	Cerastoderma edule	*Ruditapes decussatus*	*Chamelea gallina*	*Donax spp.*	*Pharus legumen*	*Spisula solida*
Fishing Effort	+	+	+	+	+	+
Sea Surface Temperature	+	-		+		-
North Atlantic Oscillation Index			-	-		
Upwelling Index	+	+	-			
Wind Magnitude			+		-	
Wind Direction				+		
River Discharges						-

The sea surface temperature, despite being an important environmental factor on two analyzed systems, has different effects on bivalve populations. The intertidal bivalve grounds (lagoon species) experience a wide range of diurnal and seasonal temperature fluctuations, once they are exposed to extreme conditions of temperature and desiccation during spring tides (Loureiro *et al.*, 2006), while the subtidal bivalve grounds (coastal species) do not witness these extreme conditions. Thus, in lagoon stock, the temperature has more impact at their activity level and energetic balance (Sobral, 1995), feeding rate (Dame, 1996; Gaspar *et al.*, 1995), metabolism and growth (Witbaard *et al.*, 1999). On the other hand, in the coastal stocks, the water temperature effect is more related with reproductive activity, once this climatic variable affected the bivalve catches in spring and summer seasons, predominant time of spawning, or related processes, of majority of bivalve species (Gaspar and Monteiro, 1999; Gaspar *et al.*, 1999b; Joaquim *et al*., 2008). In fact, according Gaspar and Monteiro (1999), of the environmental factors that might influence the reproductive cycle of a bivalve species, temperature is considered the main environmental factor for inducing gametogenesis and spawning in coastal nearshore waters.

The effect of upwelling seems to be the predominant environmental factor in lagoon bivalve catches, influencing the chemical, physical and biological characteristics of the lagoon (Duxbury, 1979; Loureiro *et al*., 2006; Tilstone *et al*., 2000). The daily water renovation in the lagoon, approximately 80% of the water mass, contributes to explain the influence of upwelling on bivalves, due to nutrient dynamics existing between lagoon and adjacent coast. In fact, for coastal systems with permanent connections to the sea, the ocean water may be the major source of nutrients (Falcão and Vale, 2003). So, the upwelling events are associated with an increase in the supply of nutrients from deep waters. With the constant renovation of lagoon water, these nutrients entered the lagoon, increasing the productivity of intertidal bivalve populations. In fact, peak of phytoplankton and zooplankton production in the Ria Formosa, generally in spring and summer seasons (Barbosa, 2010), matched with the period of strong upwelling events. The contrary effect was verified in coastal bivalve species, where the upwelling makes high larval wastage due to the offshore flow of the surface layer contributing to the transport of larvae so far from shore that they cannot return to settle (Connolly *et al.*, 2001; Shanks and Brink, 2005).

The wind components have effect on coastal bivalve catches trends. In fact, according Dolbeth et al. (2006), bivalves may be influenced seasonally by hydrodynamics in Algarve coast, probably due to the wind stress, which, despite benefits of increased food supply and water renewal (Dame, 2006), can also cause instability in bivalve's settlement (Dame, 2006) and in larvae movement (Queiroga *et al*., 2007), due to turbulence presents in these zones (Alves *et al*., 2003). Thus, the coastal communities at shallow water (~ 20 m depth) are expected to be very vulnerable to the effects of wind (Philippart *et al*., 2011) in opposition to protected lagoons systems. Indeed, in Algarve the drift currents tend to run along the shore, to depths of 30m or more (Vila-Concejo *et al.*, 2003), influencing the shallow coastal communities.

By all above it might concluded that the environmental factors that affect the lagoon bivalves stocks, are more closely related with physiological conditions (energetic balance, feeding rate, metabolism and growth), which could be influenced by the temperature variations; and related with food supply, which could be influenced by the oceanic nutrients inputs from upwelling. On the other hand, the coastal bivalves stocks are more affected in relation to the reproductive conditions and physic stability.

It was verified that, along the three distinct regions (Northwestern, Southwestern and South) in Portuguese coast, the same species, *S. solida*, react differently to environmental and fishing factors (Table 2). The Portuguese coast is subject to great variability in oceanographic characteristics (Sousa *et al.*, 2006), leading to the adaptations development of species to this variability, such as changes of spawning season, metabolism and distribution. In fact, in clam *S. solida* distribution is observed in distinct distribution depth ranges, reaching greater depths in Northwestern region and lower depths in the South region (Dolbeth, 2006; Gaspar *et al.*, 1995, 1999a, 2003, 2005).

Table 2. Summary of the effects of environmental factors and fishing effort on catches of coastal bivalves, *S. solida*, in three study regions of Portuguese coast, obtained through time series analysis.

Explanatory variables	Northwestern	Southwestern	South
Fishing Effort			+
Sea Surface Temperature	+		-
North Atlantic Oscillation Index	+		
Upwelling Index			
Wind Magnitude		-	
Wind Direction		+	
River Discharges			-

In the Northwestern of Portugal, the sea surface temperature was the environmental variable most important for explain *S. solida* LPUE changes. This part of the Portuguese coast is the region with lower temperatures. So, any increase in mean levels of water temperature is favorable for the development of bivalve stocks, especially in the spawning season (later winter and spring; Gaspar and Monteiro, 1999). Another important factor for this region was the North Atlantic Oscillation Index (NAO) that is related to its positive phase, which makes a decreasing of precipitation and winds slowdown (Miranda e*t al.*, 2006; Sousa Reis *et al*., 2006). Accordingly present results this scenario seems to be favorable for northwestern bivalve populations, making surrounding environment more stable to the development of bivalve community, for example, slowing the turbulence caused by the current (wind) and the fluvial discharge (precipitation).

On the other hand, in the Southwestern coast, the wind components (strength and direction) showed to be the environmental variables best related with *S. solida* catches. In fact, this region, with characteristics of strong hidrodinamism (Abrantes *et al*., 2005), revealed to have great variability of wind strength, which may affects the stability of bivalve communities, due to dynamic perturbations in superficial sediments (Strasser *et al*., 2001), affecting the food supply (Gaspar *et al.,* 1995; Sobral and Widdows, 2000), larvae settlement and growth of adults bivalve species (Sobral and Widdows, 2000) through coastal drift currents (Melo, 1989; Moita, 1986; Vila-Concejo *et al*., 2003).

The registered impact of river discharges on bivalve landing in South coast, the region with lower freshwater discharges, may be related with the reduced hydrodynamic conditions in this region, that delay the mixing of water masses, comparing with very hydrodynamic west regions (Northwestern and Southwestern; Abrantes *et al*., 2005), where the mixing of water masses takes place rapidly.

A factor that stood out for their positive effect on bivalve catches was the fishing effort. Probably, the decrease of adult biomass, due to controlled fishing effort, can be a determinant factor for the success of next year catches. As the fishing effort is distributed both spatially and seasonally (Gaspar *et al*., 2002), its effects on the fishing beds also vary in space and time. The fleet concentrates fishing effort on bivalves grounds until catch rates drop below economically acceptable levels, after which the grounds remains unfished (Gaspar *et al*., 2002) until yields are profitable, which depends both on the growth rate of juveniles and their density (approximately one year or more). Between the lagoon and coastal stocks there was no difference in the effect of fishing pressure. However, in among the three regions along the Portuguese coast it is only verified the existence of an impact of the fishing effort in the South. Different environmental conditions are present along the Portuguese coast, the Western coast (Northwestern and Southwestern) having strong hydrodynamism (Abrantes *et al*., 2005), often preventing fishermen conducting their fishing activity (Gaspar *et al.*, 2002). In contrast, the Southern region has favorable conditions to fishing practice due to the calmness of the sea, permitting a larger number of fishing events (fishing effort).

The local/regional environmental characteristics (oceanographic and hydrological) are important factors affecting the population dynamics of a species. As these vary spatially they influence landings of exploited species, either by their direct impacts on life cycle (growth, recruitment, mortality and offspring) or indirect impacts such as impossibility of fishing activity due to inappropriate environmental conditions. According Planque and Frédou (1999), it is probable that the exploited populations display different responses to environmental changes according region, because the abiotic factors differ between regions and show different impacts in biological and ecological level of species and ecosystems. Thus, mechanisms for management of marine resources should take into account the characteristics of regional environment. The adoption of these management measures, for the three distinct regions (Northwest, Southwest and South) and different habitats (e.g. coastal lagoon and coastal zone), is probably the best strategy to deal with the different changes in the distribution and abundance of bivalve species. Furthermore, Sousa Reis *et al.* (2006) affirms that, according to the regional circulation models, the evolution of climate over the next 100 years may differ from region to region in the Portuguese mainland, leading to heterogeneous responses of some stocks.

Ecosystems (lagoons versus coastal areas) and regional studies are needed and can help to understand which causes the fluctuations on catches in addition to the fishing effort. Changes are expected in global climate (Santos and Miranda, 2006), and Portugal is likely to face rapid alterations in temperature and precipitation which are expected to be more marked than the global mean alterations rate (IPCC, 2001). Thus, there has been a growing increase of studies in this subject, which correlate climate change with commercially exploited resources. Another important factor to consider in this type of studies is that they can be an advantage to estimate or predict the state of stocks over time when monetary funds are scarce for monitoring activities. That is, looking at historical data of landings and relates them with historical environment data can provide a perspective on the past, present and also the future of marine resources evolution.

In conclusion, the evaluation of the impacts of environmental change in exploited stocks and the marine ecosystem is crucial for adequate management of fisheries sector and to the conservation of resources and the marine ecosystem. As it was concluded, the variability of environmental conditions has great importance in bivalve landings in the Portuguese coast. So it is suggested that with the improvement of knowledge on environmental-fisheries interactions and their integration into stock-assessment models can raise our ability to advance in managing bivalve resources.

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