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Catch composition and trends in the size of three commercial species from bottom trawlers operating in FAO fishing area 34 (NW Africa) during 2004-2012

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Abstract

In need of managing fisheries resources, a plethora of studies are globally conducted, using various indicators to determine the state of marine stocks. Eastern Central Atlantic (FAO fishing area 34) is among the richest areas of the platen in terms of diversity, and its waters are being exploited for decades by native and foreign fleets. In this study fisheries data from industrial bottom trawlers operating in FAO fishing area 34 are being analyzed, through a step by step approach. Beginning from the analysis of the catch composition and its trophic levels, we gradually focus in three commercially important species (*Octopus vulgaris*, *Mullus surmuletus*, *Penaeus notialis*) and their size trends during 2004-2012. Significant trend shifts were spotted, in the CPUE values of *O. vulgaris* and *P. notialis,* while *M. surmuletus* did not present any important alterations. Furthermore, the study concludes by attributing, in a theoretical context, the findings and comparing the analyzed data with official aggregated data in order to showcase the importance of utilizing data of pure industrial origin.

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1 Introduction

Managing the exploitation of marine resources is a challenging task, due to the complexity of marine ecosystems and the numerous human activities that affect them (Murawski, 2000; Gaichas, 2007). The recent decades have witnessed a shift in fisheries management approaches, which have escaped the classical anthropocentric point of view and now take into account the interactions between fisheries and the ecosystem, under a precautionary approach (see Article 7.5 in FAO, 1995). It is thus acknowledged that, in order to achieve sustainable marine resources, their exploitation needs to be in an optimal level that benefits both humans and the environment in a sustainable fashion (FAO, 2007).

Various indicators have been proposed in the literature to assess the state of a fisheries resource (see, for example, Trenkel and Rochet, 2003 and references therein). Among them, fish size is an important index that is commonly used either individually or in combination with other indicators (Kantoussan et al., 2009). According to Shin et al. (2005), there are four size-related factors that allow to detect the direct effects of fishing: (a) the targeting of high valued large fish; (b) the selectivity of fishing gear; (c) the deficiency of older fish due to the accumulation of fishing mortality; and (d) the vulnerability of the larger species attributed to their –potentially– low growth rate. As Jennings et al. (2017) note, shifts in the size spectra of species, such as the decrease of the mean size of individuals and the increase of their relative proportion in the community biomass, could indicate intensive fishing. In summary, a reason that size descriptors are generally useful indicators is that fishing activities force size alterations in the structure of the stocks, primarily through the targeting of the bigger fish and secondarily via the increase of smaller species (Bell et al., 2017).

The main objective of this study is to examine the size composition of captures for three commercial marine species using catch and effort data that originate from three industrial bottom trawlers that operated in the Eastern Central Atlantic Ocean (ECA, FAO fishing area 34) during the time period of 2004 to 2012. To this end, an introductory literature review is initially conducted regarding the overall state of fisheries resources in the study area. Detailed information about the total catch composition of the three bottom trawlers is then presented, in order to provide a comprehensive overview of the entire data set, and offer an informative insight into the list of species that are actually being fished in the area. Specifically, the total catch composition of all three trawlers is reported, and an analysis of the trophic levels of their catch is carried out. The work proceeds with focusing on the size composition of catches vs. time (2004 – 2012) for three of the most important commercial marine species, i.e. one cephalopod, one crustacean and one fish (*Octopus vulgaris*, *Mullus surmuletus*, *Penaeus notialis*, respectively).

1.1 Review of the fisheries and status of stocks in the study area

1.1.1 Description of FAO fishing area 34

The waters of ECA have been designated by FAO as major fishing area 34 (Figure 1), and cover a surface area of 14.2 million km^2 (FAO, 2011). For management and data collection purposes, this fishing area is further divided into smaller subareas (e.g. 34.1), divisions (e.g. 34.1.1) and subdivisions (e.g. 34.1.11), including the coastal waters that stretch from Morocco to Angola (FAO, 2004). Due to their diversity and rich marine resources, West Africa's coasts are considered to be among the most productive areas of the planet and historically, fishing has been a very important activity in the region (Carpenter & De Angelis, 2014; Polidoro et al., 2017). The marine resources of ECA are not only exploited by small-scale local fishing fleets, but also by foreign industrialized fleets. However, due to recurring political and geographical disputes, the management of the sheared resources has become a great challenge (Carpenter & De Angelis, 2014).

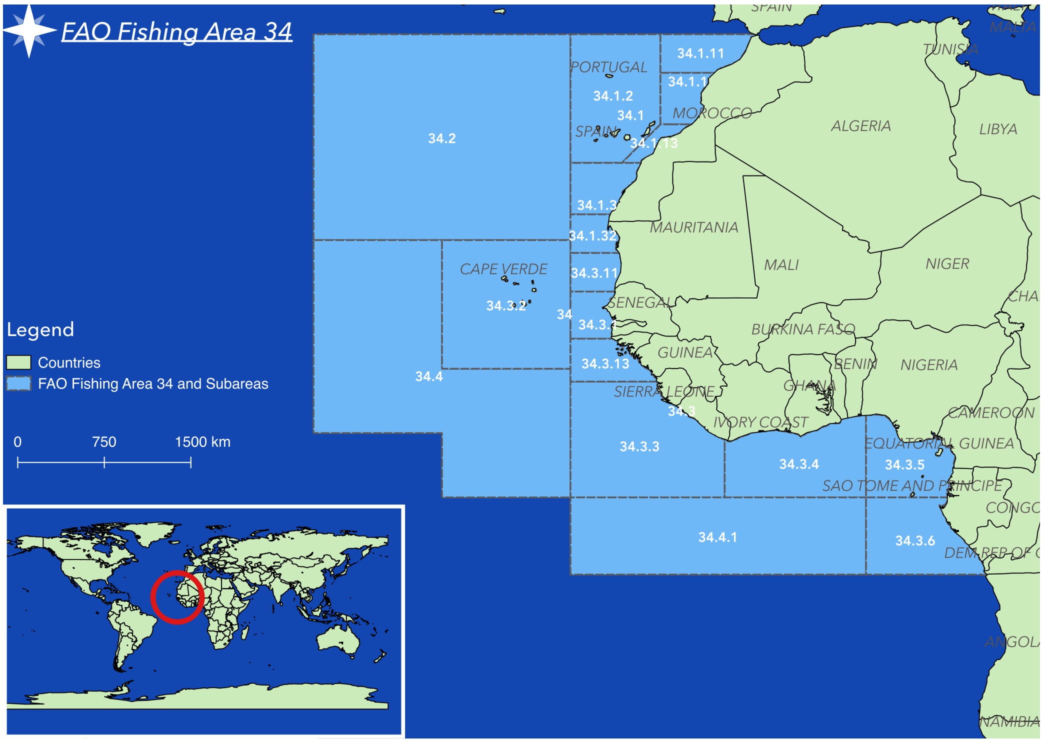

Figure 1: Map of the study area in the ECA, illustrating the FAO major fishing area 34, and its stratification in subareas, divisions and subdivisions.

In terms of geomorphology, the Eastern Atlantic is dominated by the western side of the African Plate. The Mid-Atlantic ridge is a fundamental feature of the sea bottom topography of this area, dividing the Atlantic Ocean into two sections and then into smaller numerous abyssal basins. The latter are covered by mud of organic origin and red clay, and alongside the large volcanoes of the area, form the deep water circulation of ECA (Carpenter & De Angelis, 2014). Regarding the coastal topography, the continental shelf of West Africa is rather narrow (0.65 million km^2 in total), but is characterized by great depth and width alterations (FAO, 2011). The northern coasts of West Africa are sandy and gradually shift (southern of Dakar) to more deltaic features. Mangrove forests are a predominant characteristic and cover a total area of 28,000 km^2 (Schwartz, 2006).

African coasts are influenced from three main currents, namely the Canary, Benguela and the Guinea current (Carpenter & De Angelis, 2014). Moreover, a unique coastal characteristic of the ECA area is the existence of two (Canary and Benguela currents), out of the world's four, eastern boundary current systems that are responsible for the coastal upwelling in Senegal, Zaire and Namibia (Schwartz, 2006; Carpenter & De Angelis, 2014). The surface water circulation and general oceanography of the area is significantly affected by the prevailing winds that consequently have an impact on the productivity of coastal waters (Carpenter & De Angelis, 2014).

The coastal environment of West Africa is variable, leading to notable differences in the productivity and biodiversity along the coasts (UNEP, 2008). According to FAO's report (see Carpenter & De Angelis, 2014), biodiversity patterns appear to have tree main spatial concentrations throughout the west coasts of Africa; (a) areas that present peaks in species richness off the coast of Senegal; (b) the Gulf of Guinea; and (c) around the Cape Verde islands (Polidoro et al., 2017). Coverage of the ECA area by seagrass beds is overall limited (Schwartz, 2006), while coral formations are also not common due to the small extent of the continental shelf and the large volumes of incoming fresh water. Coral reef formations do exist, however,south of Guinea Gulf and at the greater depths of the continental shelf (Carpenter & De Angelis, 2014).

1.1.2 Types of fisheries and total catch in fishing area 34

The ECA is particularly rich in marine resources, and, along its coastal zone, fishing constitutes a keystone activity for about 400 million residents (Polidoro et al., 2017). These resources are being exploited by numerous local and foreign fishing fleets, the composition of which varies broadly through time; during the last few decades, regional fleets have been steadily developing. Morocco, Senegal, Mauritania, Ghana, Sierra Leone, Nigeria and Angola are the main African countries exploiting the fisheries of area 34. Non African countries that operate in these waters are mainly from Europe and Asia, with Belize and Russia having the highest landings reported in this area (FAO, 2011; Carpenter & De Angelis, 2014).

Fishing fleets from overseas were dominant in area 34 in the late 1960s and during the 1970s (Figure 2), with their target catch being small pelagic fish and tunas. Continuously-changing legal regimes and market demands resulted to highly variable catches of these fleets after the 1970s. Following reforms that occurred in the late 1980s in European regulations, new fleets from overseas began their exploitation of the area. From the mid-1990s, European fleets have increased their fishing effort in small pelagic fish in the northwest part of the area, and managed to maintain their substantial catch levels ever since (FAO, 2011).

With respect to artisanal fisheries, their relative contribution to the total catch has been highly variable through time and region. From 1977 and until 2002, Africa's national fleets made a continuous development and increased their contribution by 43 to 72%. According to recent statistics reported by the Fishery Committee for the Eastern Central Atlantic (CECAF), the total catch in the south part of area 34 is nowadays attributed to artisanal fisheries, as opposed to the north part (FAO, 2011).

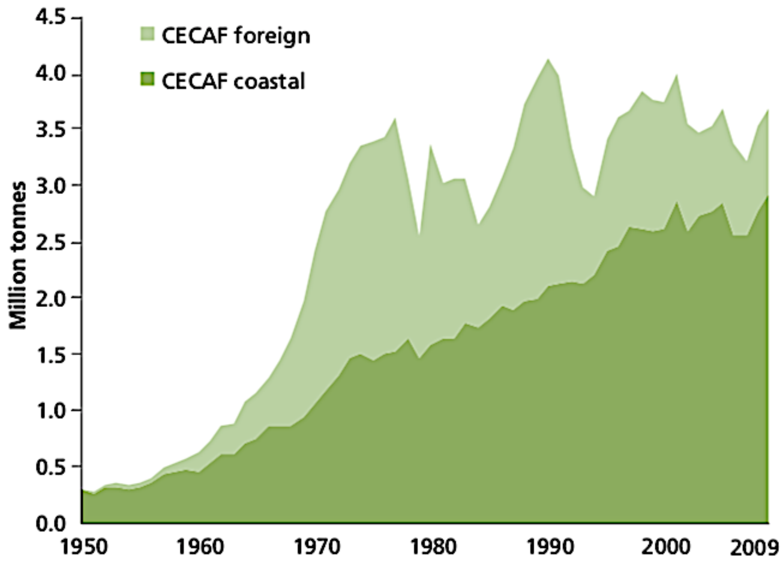

Figure 2: Annual catches in fishing area 34 of native and foreign fleets (source: FAO, 2011).

1.1.3 Historical catches from 1950 to 2014

The global catch in 1950 was approximately 20 million tonnes (Figure 3), with only 300,000 tonnes corresponding to fishing area 34. By 1977, catches from the ECA area reached 3.6 million tonnes and peaked to 4.4 in 2014. It is important to note that, even though the year 1990 was globally a year with declining catch trends, the total catches in fishing area 34 were still 4.1 million tonnes (Figure 4). According to FAO reports, this difference is due to environmental changes that affect fish stocks, changes that occurred in the markets and to fishermen attempting to hide information (FAO, 2011; Carpenter & De Angelis, 2014; FAO, 2016).

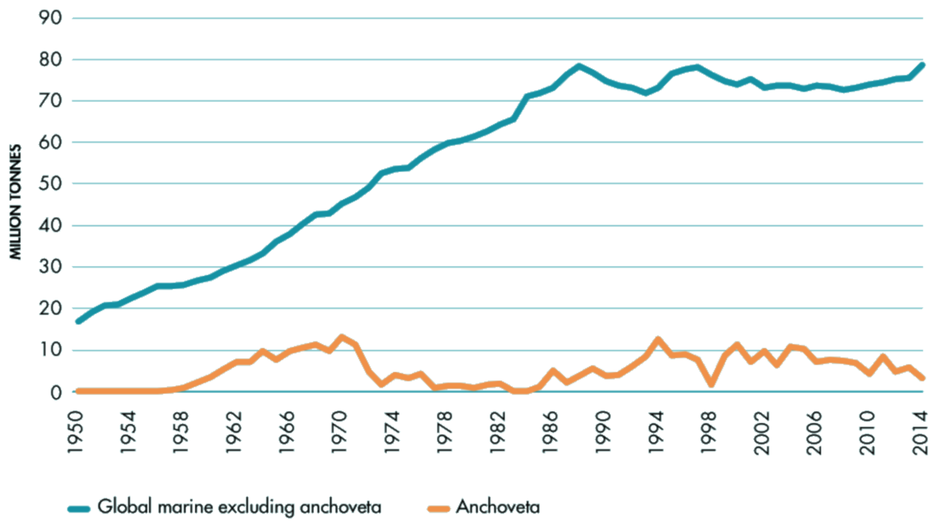

Figure 3: Global marine catches from 1950 to 2014 (source: FAO, 2016).

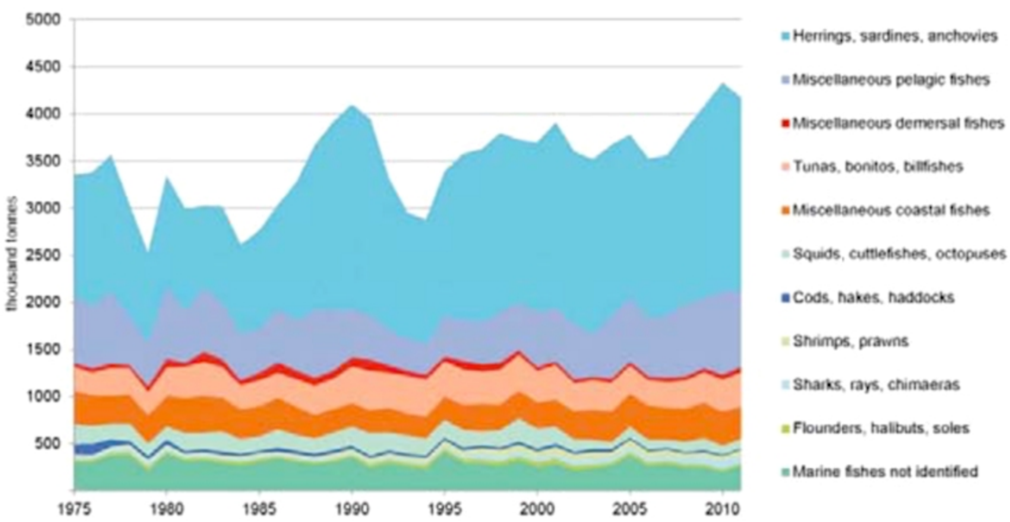

Figure 4: Landings of main fisheries in fishing area 34 (source: Carpenter & De Angelis, 2014).

Overall, approximately 300 species (or group of species) were reported in the catches of area 34 between 1975 and 2012 (Carpenter & De Angelis, 2014), with sardines, anchovies and herring, contributing more than 40% of the total. The species that dominate the catches are *Sardina pilchardus, Sardinella aurita, Ethmalosa fimbriata, Engraulis encrasicolus and Sardinella maderensis*. Species from the genus *Trachurus* are also important, accounting (from 2000 to 2009) to an average of 240,000 tonnes. Catches of *Scomber japonicus* collapsed in 1993 and recovered again in 1997, contributing ever since with an average of 190,000 tonnes every year. Regarding tunas (all species grouped), the majority of the catches come from *Katsuwonus pelamis* and *Thunnus albacares*, and since 1990, a reduction is observed in their annual catches. Target species of hakes are *Merluccius senegalensis* and *Merluccius merluccius*; both species are fished with similar rates, with an important exception being the 1970s, where *M. senegalensis* had annual catches that exceeded 100,000 tonnes (FAO, 2011).

From the order of decapoda, *P. notialis* and *Parapenaeus longirostris* hold the lead of the area's annual catches. The shrimp *P. notialis* began to show substantial catches since the 1960s, and gradually peaked in 1999 to 33,000 tonnes (Figure 5b). From that year, however, the annual production of *P. notialis* had a continuous reduction up until 2004, after which it apparently stabilized at 13,000–14,000 tonnes per year. Furthermore, from 2004 and onwards, the non nominal catches of the genus *Penaeus* are in between 3,000 and 5,000 thousand tonnes. *P. longirostris* first appear in the reported catches at 1972. The annual caught values of the species varied substantially throughout the years, with a peak of 19,000 tonnes in 1978 and a minimum of 500 tonnes in 2009 (FAO, 2011).

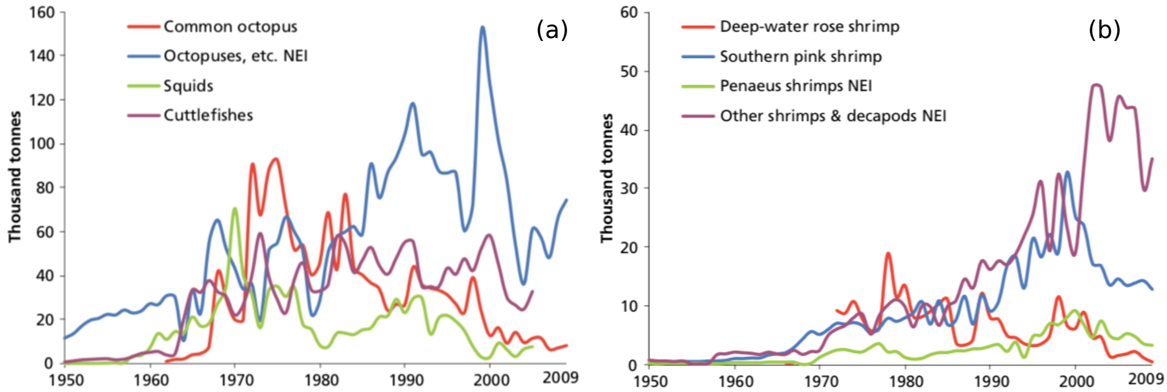

Figure 5: Annual catches of (a) cephalopods and (b) decapods in fishing area 34 (source: FAO, 2011).

Annual captures of cephalopods (according to FAO) are illustrated in Figure 5a. Note that even though the common octopus (*O. vulgaris*) was being captured since 1950, its reporting began in 1962. In 1975, the catches of the species peaked to 93,000 tonnes, but thenceforth an ongoing decrease of the quantities occurred, dropping to 8,000 tonnes in 2009. FAO notes that this reduction is very likely to originate from changes that occurred in the reporting methods of this species. Regarding the quantities reported as "octopus nei" (octopus non elsewhere included), the trend appears to be growing up until 1993. A small decrease was noted from 1993 to 1998, followed by the maximum value recorded for the group's captures, i.e. 150,000 tonnes in 1999. The catches of cuttlefishes from 1986 until 2004 had an average of 46,000 tonnes, while, in 2008, the annual quantities dropped to 25,000 tonnes. In the group of squids, a decrease of about 15,000 tonnes also occurred from the mid-1990s, but squid catches maintain a yearly average of 8,000 tonnes since 2000 (FAO, 2011).

1.1.4 Spatial distribution of main fisheries and the state of stocks

The CECAF committee is responsible for the assessment of the main fish stocks in fishing area 34. According to CECAF, area 34 is separated in two main sections, i.e. the north subarea (from Morocco to the south part of Senegal) and the south subarea that stretches from Guinea-Bissau to Angola (Table 1) (FAO, 2011; Carpenter & De Angelis, 2014).

Table 1: Stratification of FAO fishing area 34 in subareas, divisions and subdivisions, alongside CECAF subareas and corresponding counties.

Country	CECAF subarea	FAO subarea	FAO division	FAO subdivision
Morocco	North	34.1	34.1.1 34.1.3	34.1.11 34.1.12 34.1.13 34.1.31
Mauritania		34.1 34.3	34.1.3 34.3.1	34.1.32 34.1.11
Senegal		34.3	34.3.1	34.1.12
Gambia		34.3	34.3.1	34.1.12
Guinea-Bissau	South	34.3	34.3.1	34.3.13
Guinea		34.3	34.3.1	34.3.13
Sierra Leone		34.3	34.3.3	
Liberia		34.3	34.3.3	
Cote d' Ivoire		34.3	34.3.4	
Ghana		34.3	34.3.4	
Tongo		34.3	34.3.4	
Benin		34.3	34.3.4	
Nigeria		34.3	34.3.5	
Gabon		34.3	34.3.5	
Congo		34.3	34.3.5 34.3.6	
Democratic Republic of Congo		34.3	34.3.6	
Angola		34.3	34.3.6	

With respect to fish species, *S. pilchardus* dominates the catches in the north subarea. Its landings corresponded to 36% of the total pelagic fish caught in 2011, followed by *S. aurita* and *S. maderensis* with 26%. *Trachurus trecae* is an important species of horse mackerels, alongside *Trachurus trachurus.* Also significant are the species *S. japonicus*, *E. encrasicolus* and *E. fimbriata*. *Pagellus bellottii* is widely distributed in West Africa, and until 2003 it was the most important of the demersal fish (hake excluded), while, from 2003, catfishes of the genus *Arius* started to be also significant. In 2012, the hake species, *M. merluccius*, *M. senegalensis* and *Merluccius polli* had an average of 7% of the total demersal catches. The common octopus (*O. vulgaris*) is the predominant species from the group of cephalopods, and for the decapods, the shrimps *P. longirostris* and *P. notialis* contribute by 10% to the total demersal catches.

Generally, stocks of small pelagic fish in the north subarea are targeted with high exploitation demands during the last decades . Recent evaluations of *S. aurita* and *T. trecae* stocks showed that they are overexploited. Moreover, the stocks of *S. japonicus*, *E. encrasicolus* and *E. fimbriata* are fully exploited. Also, the stocks of the commercially important demersal species in this subarea are suffering from intense exploitation. Based on FAO's assessment for the demersal species resources, the stock of *Epinephelus aeneus* in Mauritania, Gambia and Senegal is overexploited, as well as the stocks of *O. vulgaris*, *P. longinostris* in Morocco and *P. notialis* in Senegal and Gambia.

In the southern subarea, the most significant pelagic species in terms of landings are *S. aurita* and *S. maderensis*. Both of them represented the 33% of group's total landings in 2007. Equally important are the species *E. encrasicolus*, *E. fimbriata* and *T. trecae*. For the demersal species, genus *Pseudotolithus* in between 2006 and 2010 had catches of approximately 37,000 tonnes, contributing 14% in total captures for the year 2010. Despite having low registered quantities of landings, the shrimps *P. longirostris* and *P. notialis* and cuttlefishes are considered important as well due to their high commercial value.

Stocks of small pelagic fish are also important, however, they show fluctuations because they are being intensively exploited from small and semi-industrialized fleets. The resources of demersal species in the south CECAF's subarea are considered highly exploited and nine of which have been characterized as overexploited (Carpenter & De Angelis, 2014)

A summary of the status of the fishery stocks in the north and south subarea is presented in Tables 2 and 3 , using data reported in CECAF's latest conference that took place in April 2016 (FAO-CECAF, 2016).

Table 2: State of the main stocks of small pelagic fish and demersal species in the north CECAF subarea (source: FAO-CECAF, 2016).

CECAF subarea	Category	Stock state	Species	Stock territory
North	Small pelagic	Overexploited	*S. aurita*	Entire subarea
			S. maderensis	Entire subarea
			Sardinella spp.	Entire subarea
			T. trecae	Entire subarea
			E. encrasicolus	Entire subarea
			E. fimbriata	Entire subarea
		Fully exploited	*S. pilchardus*	Zone A+B
			S. colias	Entire subarea
		Not fully exploited	*S. pilchardus*	Zone C
	Demersal	Overexploited	*M. merluccius*	Morocco
			E. aeneus	Mauritania, Senegal, Gambia
			Sparus spp.	Morocco
			P. mediterraneus	Morocco
			P. acarne	Morocco
			Pagellus spp.	Morocco
			P. longirostris	Morocco
			P. notialis	Senegal, Gambia
			O. vulgaris	Dakhla (26°N-20°50'N), Cap Blanc (20°N-16°N), Senegal, Gambia
		Not fully exploited	*Arius spp.*	Senegal, Gambia
			P. belottii	Mauritania, Senegal, Gambia
			Merluccius spp.	Mauritania
			P. notialis	Mauritania
			P. longirostris	Mauritania
			P. longirostris	Senegal, Gambia
			L. vulgaris	Cap Blanc (20°N-16°N)
			S. officinalis	Dakhla (26°N-20°50'N)
			S. officinalis	Cap Blanc (20°N-16°N)
			S. officinalis	Senegal, Gambia

Table 3: State of the main stocks of small pelagic fish and demersal species in the south CECAF subarea (source: FAO-CECAF, 2016).

CECAF subarea	Category	Stock state	Species	Stock territory
South	Small pelagic	Overexploited	*S. aurita*	Cote d' Ivoire, Ghana, Togo, Benin
			T. trecae	Guinea-Bissau, Guinea, Liberia, Gabon, Congo, Democratic Republic of Congo, Angola
			Decapterus spp.	Guinea
		Fully exploited	*S. maderensis*	Cote d' Ivoire, Ghana, Togo, Benin
			Sardinella spp.	Guinea-Bissau, Guinea, Sierra Leone, Liberia, Gabon, Congo, Democratic Republic of Congo, Angola
			E. fimbriata	Guinea, Gabon, Congo, Democratic Republic of Congo
			E. encrasicolus	Cote d' Ivoire, Ghana, Togo, Benin
		Not fully exploited	*E. encrasicolus*	Congo
	Demersal	Overexploited	*Pseudotolithus spp.*	Guinea, Guinea-Bissau
			B. auritus	Cote d' Ivoire, Ghana, Togo, Benin
			G. decadactylus	Cote d' Ivoire, Ghana, Togo, Benin
			P. bellottii	Cote d' Ivoire, Ghana, Togo, Benin
			Pseudotolithus spp.	Congo, Gabon, Angola
			G. decadactylus	Congo, Gabon, Angola
			Cynoglossus spp.	Angola
			B. auritus	Congo, Angola
			Sepia spp.	Ghana
		Not Fully exploited	*Pomadasys spp.*	Guinea, Guinea-Bissau
			Sparidae	Guinea, Guinea-Bissau
			P. notalis	Ghana
			P. notalis	Congo
			P. longirostris	Guinea-Bissau
			O. vulgaris	Guinea-Bissau

2 Methods

2.1 Description of fishing vessels and their fishing grounds

The catch and effort data analyzed in this study were collected during 2004–2012 from three industrialized bottom trawlers, hereafter referred to as T1, T2, and T3. The trawlers are active throughout the year in the study area, with the exception of short breaks for landing their monthly catch and their annual inspection for maintenance and repairs. Their main fishing grounds are located in the coastal areas of Mauritania, Guinea, Gambia and Senegal as presented on the heat-maps of Figure 6. The main targeted species are *P. notialis*, *O. vulgaris*, *M. surmuletus, Sepia officinalis, Pagellus erythrinus*, *Pagrus pagrus*, *E. aeneus* and various species of flatfish.

All three trawlers have similar characteristics regarding their fishing capacity. The overall length of the vessels is 32 m and the width is about 7.7 m. Horse power of the main engines differs from 500 hp in T1, to 800 hp in T2 and 1100 hp in T3. The hold capacity of each vessel is also different as T1 has 30 tonnes, T2 has 60 tonnes and T3 has 90 tonnes. They are all steel vessels constructed between 1990 and 2000, and employ 11 to 19 crew members. The trawlers are equipped with radars, echo-sounder, VHF and satellite navigation, and also with blast freezers for the preservation of catches.

During fishing operations, the vessels use bottom otter trawl nets and travel with a speed of 3 knots. The characteristics of the nets are harmonized with the type of fishing license and corresponding legislation. The length of nets is 35 m for crustaceans and 42 m for cephalopods and fish, while mesh dimensions range from 50 mm to 70 mm on the sac, and from 80 mm to 114 mm on the wings, respectively.

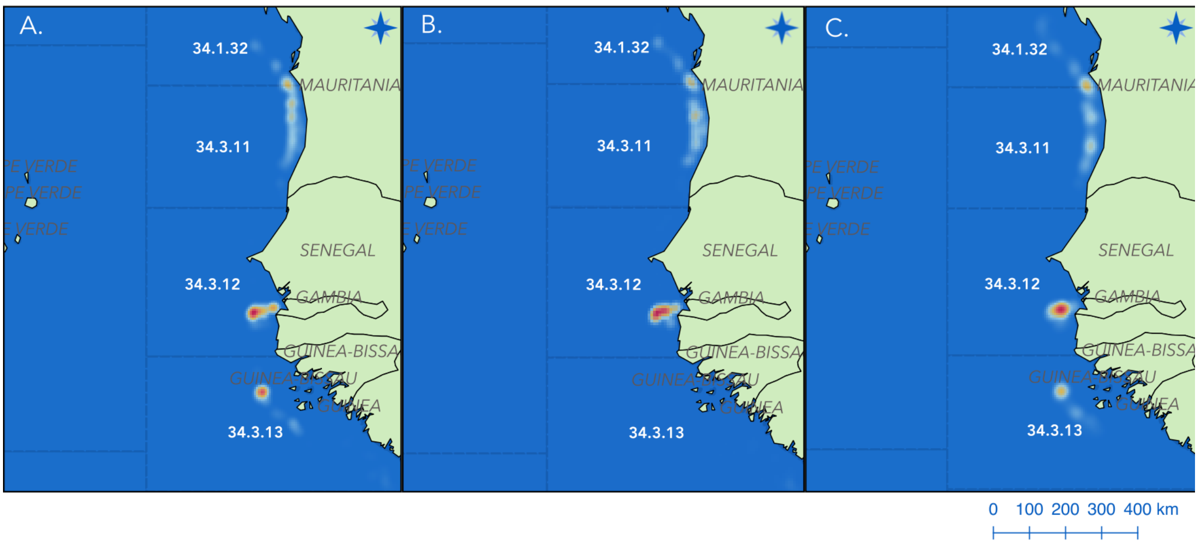

Figure 6: Heat-maps of the trawlers' main marine fishing grounds in FAO area 34. Maps A, B and C refer to the main fishing locations of bottom trawler T1, T2 and T3, respectively.

2.2 Data set description

The data set analyzed in this study covers exhaustively all catches acquired by the three trawlers during the time period 2004 to 2012, as well as detailed information regarding their activity in the ECA fishing grounds. Data from the three trawlers were maintained in a common database by the operating company, and included –per ship– the caught quantities (in kg) of all species captured (from 3 different categories, i.e., crustaceans, cephalopods, fish), alongside the corresponding fishing effort (measured in days), and the specific date/location where each catch took place. These data were aggregated into time periods that were typically 5–7 days long (e.g. catch per species per trawler for 05-Jan-2004 to 11-Jan-2004). For each time period, a species was listed only if it had been captured. Note that for each species, its catch in the database was already separated into predefined size classes (see column "Fcode" in Table 4), according to commercial standards.

In order to extract the needed information from the trawlers' database, a custom application was developed to facilitate the management and tabulation of the raw data (due to the nature of this software and its links to the proprietary database, the source code is not provided in the Appendix of this work). An example output of the final, tabulated data set is listed in Table 4.

Table 4: Excerpt of the final data set, listing the catch per species tabulated by date, fishing location and bottom trawler. The column "Fcode" denotes the commercial size group code (e.g. code 1M for *M. surmuletus* corresponds to 8–11 individuals per kg). "Days" correspond to the fishing effort spent to acquire each catch during the time period marked by the "From" / "To" columns.

Species	Fcode	kg	Month	Year	Days	From	To	Area	Ship
Pagrus pagrus	4G	23	1	2004	7	05/01/04	11/01/04	Mauritania	T2
Penaeus notialis	S0/2	6	1	2004	7	05/01/04	11/01/04	Mauritania	T2
Penaeus notialis	S1/2	2	1	2004	7	05/01/04	11/01/04	Mauritania	T2
Penaeus notialis	S2/2	2	1	2004	7	05/01/04	11/01/04	Mauritania	T2
Pagellus erythrinus	3G	69	1	2004	7	05/01/04	11/01/04	Mauritania	T2
Pagellus erythrinus	3M	46	1	2004	7	05/01/04	11/01/04	Mauritania	T2
Mullus surmuletus	1G	23	1	2004	7	05/01/04	11/01/04	Mauritania	T1
Mullus surmuletus	1M	23	1	2004	7	05/01/04	11/01/04	Mauritania	T1
Diplodus sargus	24M	115	1	2004	7	05/01/04	11/01/04	Mauritania	T1
Octopus vulgaris	TX3	156	1	2004	7	05/01/04	11/01/04	Mauritania	T3
Octopus vulgaris	TX4	416	1	2004	7	05/01/04	11/01/04	Mauritania	T3
Octopus vulgaris	TX5	494	1	2004	7	05/01/04	11/01/04	Mauritania	T3
Sepia officinalis	K6	253	1	2004	7	05/01/04	11/01/04	Mauritania	T3

2.3 Preliminary analysis of the entire data set

2.3.1 Documentation of catch composition

The entire (tabulated) data set of all three trawlers was scrutinized manually in order to produce a list of species that are being fished in the study area. A total number of 55 species was reported in the records, 15 of which were excluded from any further analysis due to undefined –or poorly reported– taxonomy (e.g. fish documented with only local designation and/or common names with negligible relative contribution to the total catch). This preliminary filtering resulted to 40 species total, 5 of which are crustaceans, 4 are cephalopods, and 31 are fish. The list of species and their relative contribution to the total catch is reported in detail in the respective Results (Section 3.1).

2.3.2 Trophic level of fished species

The trophic level (TL) of the catch composition was also investigated, using TL information per species acquired from FishBase (Froese & Pauly, 2018) and SeaLifeBase (Palomares & Pauly, 2018). An exception was the shrimp *P. notialis;* due to lack of information in the online databases, the TL reported by Meissa & Gascuel (2015) was used. Moreover, the TL of the crab *Portunus validus* could not be found in the literature, thus the species was not included in this part of the analysis.

The 40 species comprising the catch were categorized into four groups according to their TL, i.e. < 3; 3 – 3.5 (including TL = 3); 3.5 – 4 (including TL = 3.5); and ≥4. The total catch per trophic group was calculated, and the corresponding annual annual catch was computed. Note that not all species had a consistent presence throughout the entire study period.

2.4 Main analysis

From the total catch 3 species were selected for further analysis, due to their relative contribution and importance in the market. The selected species are *O. vulgaris*, *P. notialis* and *M. surmuletus.* A brief description of their biological characteristics, habitat and commercial importance is presented below.

2.4.1 Mullus surmuletus

Mullus surmuletus (Linnaeus, 1758) (striped red mullet) is commonly distributed in the Mediterranean Sea, the Black Sea, as well as from South Norway down to Senegal (Carpenter & De Angelis, 2016; Froese & Pauly, 2018) (Figure 7). The depth at which this mullet thrives is typically less than 100 m (maximum: 400 m), and prefers sandy habitats frequented by rocky patches and muddy substrates (Fisher et al., 1981a; Labropoulou et al., 1997; Carpenter & De Angelis, 2016). It mainly feeds on benthic crustaceans, worms and other invertebrates (Carpenter & De Angelis, 2016; Froese & Pauly, 2018). Spawning takes place from winter to summer, especially from February to May at depths from 30 to 70 m (Carpenter & De

Angelis, 2016; FAO, 2017a). Pajuelo et al. (2010) reports that, at the Canary Islands, the spawning of the species is temperature related and the optimum temperature is 19-22 ºC, which in this area occurs during spring. Furthermore, the species around this area reaches sexual maturity at the first year of its life, at an approximate length of 16.6 cm (Pajuelo et al., 2010).

M. surmuletus can be identified from its color pattern which seems to differ according to the habitat. In shallow waters with rocky substrates, the fish appears to have brown color on its back that turns into reddish brown near the ventral surface, combined with brown stripes. In deeper waters, the color is red with a pattern of several horizontal yellow stripes. In both cases, the first dorsal fin stands out with yellow or darker markings (Carpenter & De Angelis, 2016). Its body is moderately elongated and compressed, typically sized between 10 and 25 cm, while the snout is not very steep (Figure 8). The mouth is small and inferior in position with a pair of barbels, longer than the pectoral fin, distinguishing on the chin. The teeth are small and can be found only on the lower jaw and on the roof of the mouth, as the upper jaw is toothless. About the fins, the first dorsal has 7 to 8 spines and seldom 9, with the first spine very small. The second dorsal and the anal fin have 1 spine and 7 or 8 soft rays. The pectoral fin is structured from 15 to 17 soft rays and the lateral-line scales 33 to 37 rays. The gill rakers on *M. surmuletus* appear to be from 23 to 26 (Carpenter & De Angelis, 2016; FAO, 2017a).

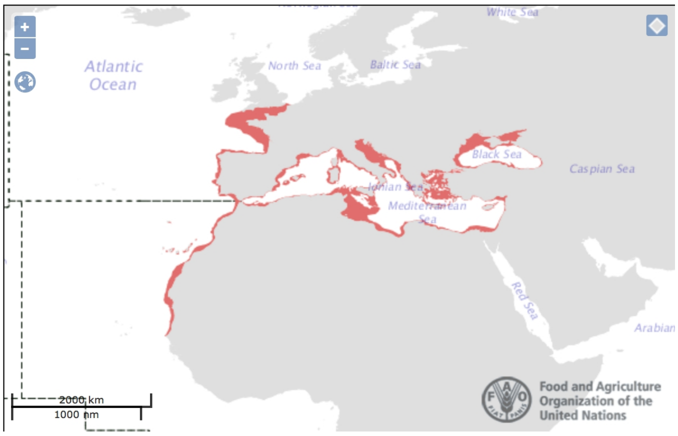

Figure 7: Global distribution of *M. surmuletus* (source: FAO, 2017a).

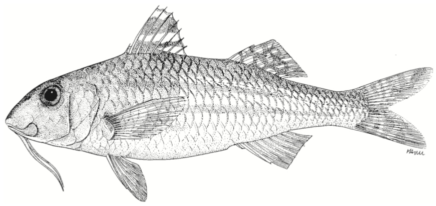

Figure 8: Illustration of *M. surmuletus* (source: Carpenter & De Angelis, 2016).

The striped red mullet is principally caught with gillnets, trammel nets or bottom trawls in coastal waters at depths from 20 to 200 m. It is distributed in the markets as fresh or frozen, and is widely appreciated for the quality and taste of its flesh. As Figure 9 illustrates, the global production of *M. surmuletus* global production has been substantial from the mid-80's and onwards, with the maximum appearing in 2007 with approximately 18,300 tonnes captured. As FAO reports, in 1999, the two countries with the largest value of catches were Libyan Arab Jamahiriya, with 4,000 tonnes, and France with 2,541 tonnes (Fisher et al., 1981a; Carpenter & De Angelis, 2016; FAO, 2017a; Froese & Pauly, 2018).

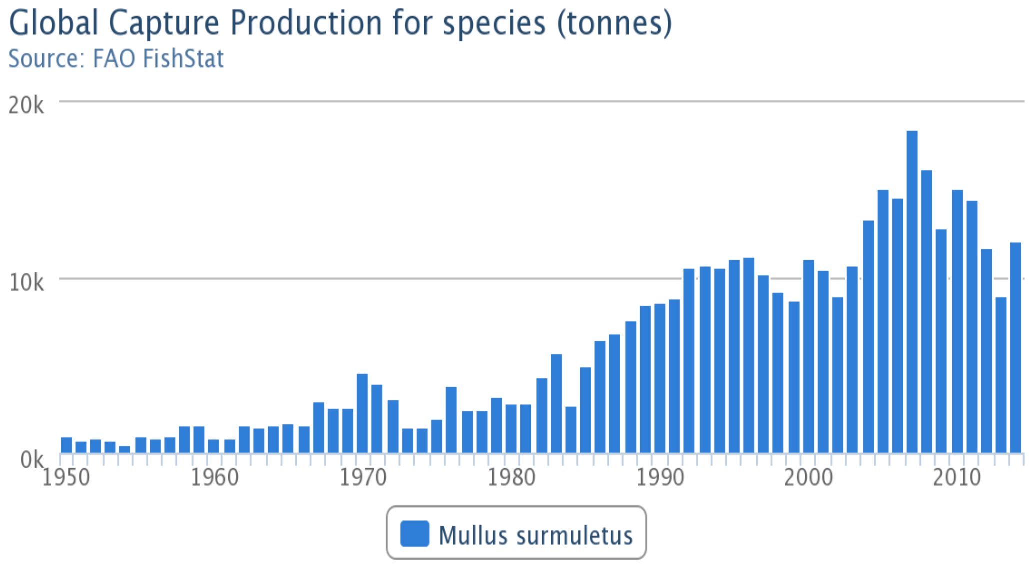

Figure 9: Global production in tonnes of *M. surmuletus* from 1950 to 2014 (source: FAO, 2017a).

2.4.2 Octopus vulgaris

Octopus vulgaris (Lamarck, 1798) (common octopus) has a typical flattened octopod appearance with a sac-shaped mantle (Figure 11). Its color varies from a spotted brown, to white and tan. The maximum size in females is 1.2 m, in males 1.3 m, but it is also mentioned that in the eastern Atlantic it can reach up to 1.8 m total length and 40 cm mantle length. The typical weight is 3 kg and the maximum published weight is 10 kg. The arms of the common octopus are strong and equally shaped, burly at the base with about the same length and thickness, except from the two dorsal arms which are slightly shorter. All arms have 2 rows of suckers, and arm II and III, in mature individuals, have the 15th and 17th sucker enlarged. On males, the right arm III is hectocotylized having a very small spoon-shaped tip (Fisher et al., 1981b; Carpenter & De Angelis, 2014; FAO, 2017b).

The common octopus is highly abundant in the Mediterranean and the eastern Atlantic Ocean. As Figure 10 displays, this species is reported from tropical to temperate waters and it is characterized as cosmopolitan, although its distribution is being reevaluated to new biogeographical boundaries. It occurs at depths up to 200 m, from the coastline to the edge of the continental shelf and in diverse habitats (Carpenter & De Angelis, 2014). *O. vulgaris* is a limited seasonal migratory species, ordinarily spending the winter in deeper waters and living closer to the coast in the warm months (FAO, 2017b).

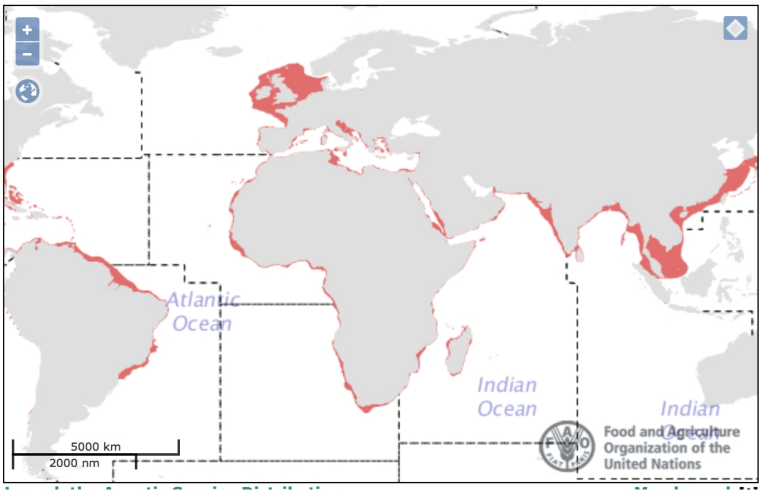

Figure 10: Global distribution of *O. vulgaris* (source: FAO, 2017b).

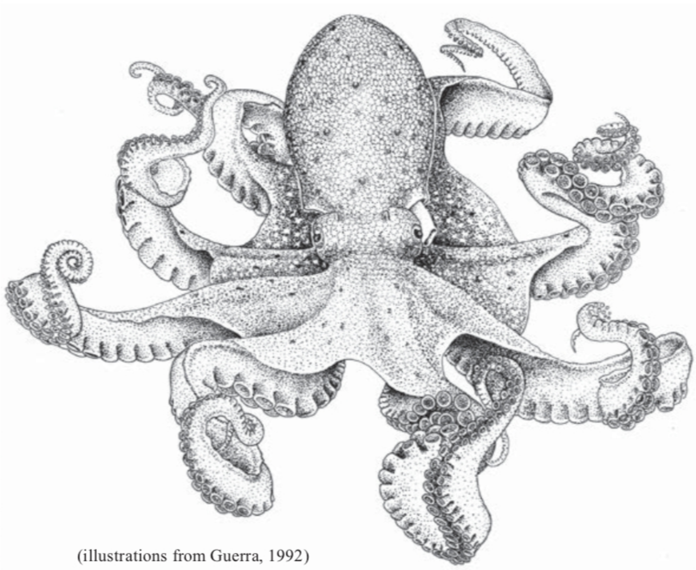

Figure 11: Illustration of *O. vulgaris* (source: Carpenter & De Angelis, 2014).

Spawning can last up to 1 month and occurs at depths from 15 to 100 m throughout the year, climaxing twice –in the Atlantic populations– in spring and in autumn (Fisher et al., 1981b; Carpenter & De Angelis, 2014; FAO, 2017b). Limited information about the species in Cape Blanc (West Africa) reports that the first spawning peak happens in May or June, while the second one, which is noted as more important, takes place in September (FAO, 2017b). Maturity is reached at a length of 8 to 11.3 cm. The life span of the species is estimated to be 2 years, but is typically lower, as individuals often die after spawning and brooding their descendants. The duration before the hatch of eggs depends on the temperature, and can last from 20 days at 25 ºC to 125 days at 13 ºC, with a minimum size of hatchlings at approximately 12 mm. After incubation, a planktonic stage occurs that lasts for about 2 to 3 months, after which the animal settles to its benthic habitat in the marine environment (Carpenter & De Angelis, 2014; FAO, 2017b).

The principal predators of the common octopus vary, and range from marine mammals, sharks, and several bony fish. *O. vulgaris,* as other cephalopods, suffers from high natural morality during the paralarva and settlement stages, and has great vulnerability against changes in environmental conditions. Hence, the abundance of food for the paralarva is controlled by environmental factors, and therefore population abundance often appears highly variable (Carpenter & De Angelis, 2014; FAO, 2017b). It is important to note that the Mauritania region is a primary area for the species recruitment, due to the coastal upwelling system (Carpenter & De Angelis, 2014).

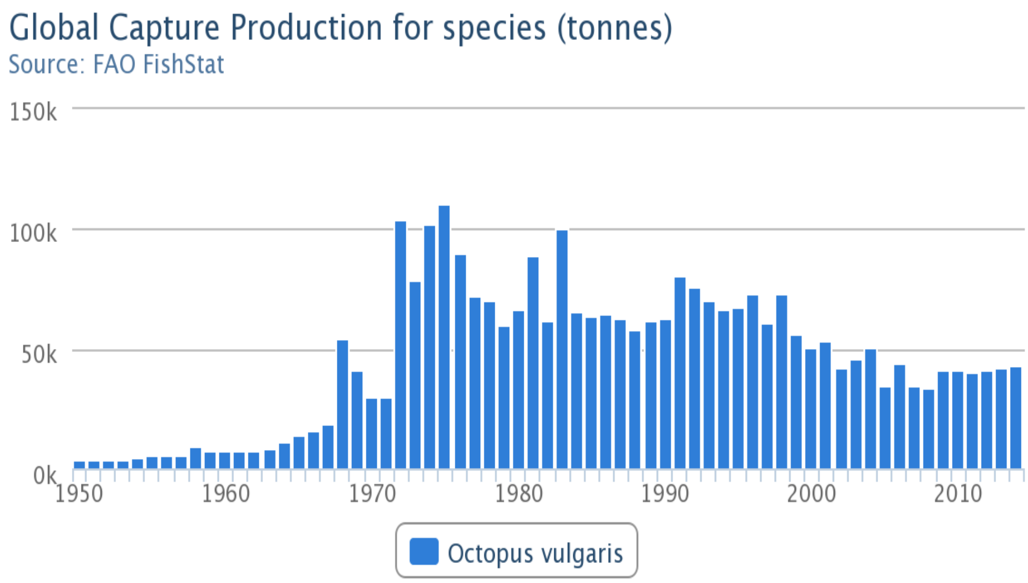

Figure 12: Global production in tonnes of *O. vulgaris* from 1950 to 2014 (source: FAO, 2017b).

The common octopus constitutes a high price target species throughout the year, both for bottom trawls and for artisanal coastal fisheries (Carpenter & De Angelis, 2014). There are many and diverse fishing methods for capturing it, such as lures, hooks and otter trawls, and is marketed as fresh, frozen or dried salted. The maximum yield was noted in 1975 with 109,000 tonnes, followed by a general decrease; in 2014, the global production was 43,000 tonnes (Figure 12) (Fisher et al., 1981b; FAO, 2017b). According to CECAF regarding fishing area 34, *O. vulgaris* stocks of Dakhla, Cap Blanc, Senegal and Gambia are characterized as overexploited (FAO-CECAF, 2016).

2.4.3 Penaeus notialis

Penaeus notials (Perez-Farfante, 1967), commonly named as southern pink shrimp, is distributed in the Eastern and Western Atlantic Ocean (Figure 13). The habitat for this species is mud or muddy sand substrates, and it prospers up to 100 m depth, although it is usually found from 10 to 75 m. It generally thrives in temperate waters of temperatures between 18 and 24 ºC, near river mouths and lagoons. The southern pink shrimp is considered nocturnal, particularly in warmer months, but can also be active during daylight in turbid waters (Carpenter & De Angelis, 2014).

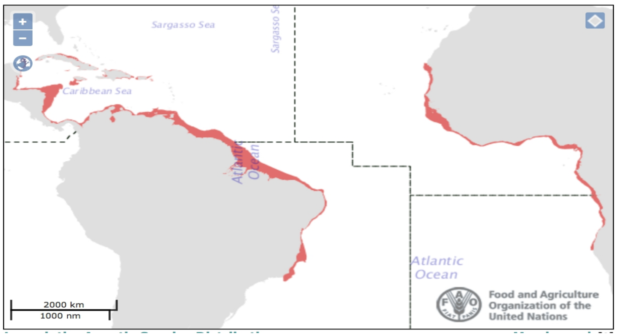

Figure 13: Global distribution of *P. notialis* (source: FAO, 2017c).

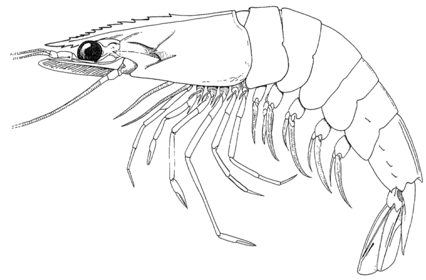

Figure 14: Illustration of *P. notialis* (source: Carpenter & De Angelis, 2014).

Body size differs between males and females, with a maximum total length of 17 cm and 23 cm, respectively (Carpenter & De Angelis, 2014). The integument of the species is thin (Lawal-Are & Akinjogunla, 2012) and smooth, while the coloration on individuals populating the West African coasts is uniformly blond and has a distinct dark spot on the dorsal area. However, color on shrimps resident in the western central Atlantic differentiates according to the habitat, and ranges from pink to brownish red or lemon yellow. On the rostrum, 8 to 11 teeth can be found on the dorsal margin and 2 teeth on the ventral margin (Figure 14) (Carpenter & De Angelis, 2014). The species has distinguishing long antennas on the carapace, which holds a medial carina expanding to its posterior end. The venter area is externally divided with 4 to 6 well defined segments that end to a spine (Lawal-Are & Akinjogunla, 2012; Carpenter & De Angelis, 2014).

Life expectancy for souther pink shrimp really expands over 20 months. Spawning occurs offshore, throughout the year, having two peaks correlated with the salinity of the nurseries. During the stages of metamorphosis, hatchlings are drifting towards the shore due to marine currents, thence, migrating to mangrove habitats for protection and feed (Le Reste & Diallo, 1994). When maturity is reached, after 4 to 6 months, shrimps migrate back offshore to spawning grounds (Ziegler et al., 2009; Carpenter & De Angelis, 2014; Eichelsheim, 2017), with estimated size between 10 to 17 g and total length ≥ 20 cm.

P. notialis is considered to be a very important species for local and foreign fishing fleets, owing to its very high prices in the market. It is distributed as fresh or frozen, cooked or raw and some times processed (e.g. smoked). It is caught with various fishing equipment that range from traps to mechanized bottom trawls, and some of the main fishing grounds in fishing area 34 are the coastal muddy bottoms in Senegal, Guinea, Gambia, Congo and Angola (Carpenter & De Angelis, 2014). In 2016, the stocks of Senegal and Gambia were classified by CECAF as overexploited, while the stocks of Mauritania, Ghana and Congo were characterized as not fully exploited (FAO-CECAF, 2016). Figure 15 illustrates the global quantities captured for this species, with 1999 being the year with the highest yield; in total, almost 33,000 tonnes were caught that year, with Nigeria and Senegal having the higher quantities of caches. Thereafter, global production had a gradual decrease, dropping to about 15,000 tonnes in 2014 (Carpenter & De Angelis, 2014; FAO, 2017c).

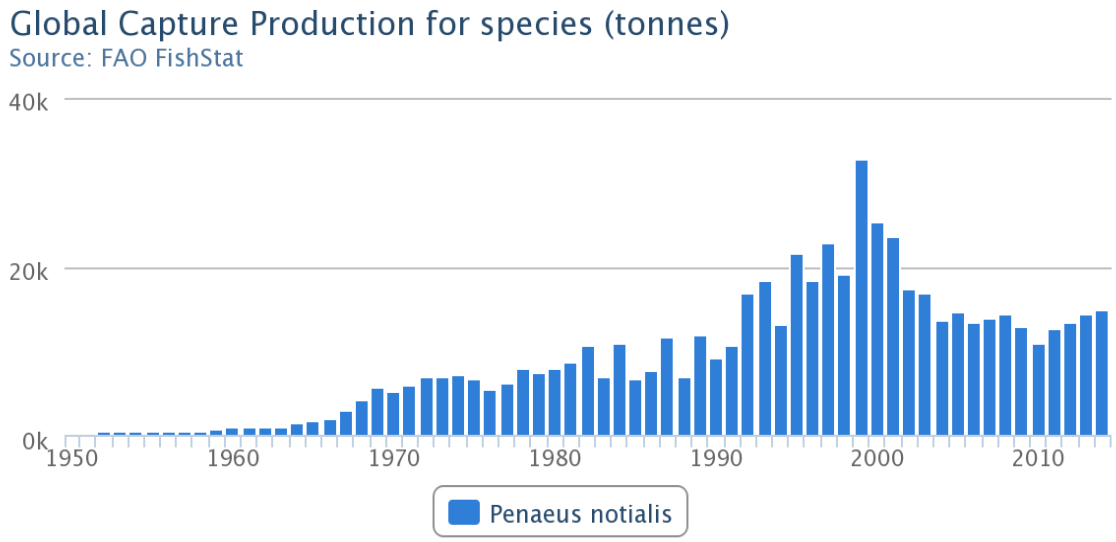

Figure 15: Global production in tonnes of *P. notialis* from 1950 to 2014 (source: FAO, 2017c).

2.4.4 Calculation of CPUE per species and size group

The tabulated data set was scrutinized with MATLAB scripts, in order to correct any potential minor discrepancies in the records, such as conflicts in the location of the trawlers or one day overlap in the dates of fishing trip (the respective code is presented in Appendix A). Subsequently, the CPUE was calculated per species total and by species size groups (Appendix B). This CPUE information was further processed with Generalized Additive Models (GAMs) analysis in R to inspect the time trends (see Section 2.4.5).

As mentioned above, the data were provided in commercial size categories. These categories were merged into size groups and renamed as shown on Tables 5, 6 and 7. Additionally, a size description of the commercial size categories is presented alongside with the calculated morphometric characteristics of each category. The the allometric, species-specific length-weight relationship was used to estimate the approximate size of the species. The related a and b parameters were found in SeaLifeBase (Palomares & Pauly, 2018), in Pajuelo's et al. (2010) and in Faye et al. (2015) studies for *O. vulgaris*, *M. surmuletus* and *P. notialis*, respectively.

$$W = a(L^b)$$

Table 5: Commercial size categories and corresponding size group codes of *O. vulgaris*, and their description regarding the weight of individuals and their approximate mantle length.

Species	Size group code	Commercial size category (kg)	Mantle length (cm)
Octopus vulgaris	O1	≥4.5	≥15.81
		3.0 - 4.5	15.81 - 13.87
	O2	2.0 - 3.0	13.87 - 12.16
		1.5 - 2.0	12.16 - 11.08
	O3	1.2 - 1.5	11.08 - 10.31
		0.8 - 1.2	10.31 - 9.05
	O4	0.5 - 0.8	9.05 - 7.77
		0.3 - 0.5	7.77 - 6.59

Table 6: Commercial size categories and corresponding size group codes of *P. notialis*, and their description regarding the weight of individuals along with the estimated cephalothorax length and their approximate total length.

Species	Size group code	Commercial size category (indiv./kg)	Weight (g)	Cephalothorax length (cm)	Approximate total length (cm)
Penaeus notialis	P1	1 - 15	≥66	≥4.76	≥20.3
		15 - 20	50 - 66	4.3 - 4.76	19.7 - 20.3
	P2	20 - 30	33 - 50	3.70 - 4.31	16.3 - 19.7
		30 - 40	25 - 33	3.34 - 3.70	14.9 - 16.3
	P3	40 - 60	17 - 25	2.91 - 3.34	13.7 - 14.9
	P4	60 - 80	13 - 17	2.64 - 2.91	12.7 - 13.7
	P5	80 - 100	10 - 13	2.40 - 2.64	11.7 - 12.7
	P6	100 - 120	8 - 10	2.21 - 2.40	10.3 - 11.7

Table 7: Commercial size categories and corresponding size group codes of *M. surmuletus*, and their description regarding the weight of individuals and their calculated length.

Species	Size group code	Commercial size category (indiv./kg)	Weight (g)	Length (cm)
Mullus surmuletus	M1	≤7	≥143	≥22.21
	M2	8 - 11	91 - 125	19.27 - 21.29
	M3	12 - 16	62.51 - 83	17.13 - 18.72
	M4	>16	<62.5	<17.13

2.4.5 Generalized additive models

Generalized additive models (GAMs) are practically an extension of generalized linear models (Hastie & Tibshirani, 1990) in which the linear relationship between the predictors and the response is replaced by multiple non-linear smooth functions. They are widely applied in order to identify and model potential trends in time series data (Wood et al., 2016). In our case, GAMs were used for detecting the time trends of the CPUE. The models were developed in R with the use of "mgcv" package (see Appendix C). The dependent variable was either the species CPUE or the CPUE of the size groups, while time (i.e. years) was used as the predicting factor.

3 Results

3.1 Catch composition

The list of species composing the catch is presented in Table 8, along with the contribution of the 3 fisheries groups in Figure 16. Examining each fisheries group separately, specific species appear to contribute most to the group's total catch. Specifically, in the crustaceans group, *P. notialis* holds the 98.2% (6.6% of the total catch) of all 5 species, while *Penaeus monodon* comes second with 1.1% (Figure 17a). From the cephalopods, *O. vulgaris* has the 78.2% of group's captures (39.7% of the total catch), *S. officinalis* has 19.1% and the remaining 2.7% concern *Loligo vulgaris* and *Todarodes sagittatus* (Figure 17b). In the fish category, *M. surmuletus* and *P. pagrus* differentiate from the rest of 29 species as they have 34% and 20% of the total catch, respectively. Catches of the remaining fish species are generally similar, ranging between 1% and 8% (Figure 17c).

Table 8: Species synthesizing the catch, listed according to the fisheries group.

Fish	Crustaceans	Cephalopods
Lithognathus mormyrus	*Penaeus notialis*	*Octopus vulgaris*
Epinephelus fasciatus	*Palinurus regius*	*Loligo vulgaris*
Seriola dymerili	*Portunus validus*	*Todarodes sagittatus*
Merlucciuc senegalensis	*Penaeus monodon*	*Sepia officinalis*
Sebastes mentella	*Scyllarides sp.*	
Spondyliosoma cantharus		
Mullus surmuletus		
Umbrina cirrosa		
Serranus scriba		
Epinephelus aeneus		
Sparisoma cretense		
Scorpaena scrofa		
Arnoglossus kessleri		
Pomadasys jubelini		
Cynoglossus senegalensis		
Pagellus erythrinus		
Galeorhinus galeus		
Dentex dentex		
Dentex macropthalmus		
Serranus cabrilla		
Diplodus sargus		
Acanthurus monroviae		
Epinephelus marginatus		
Zeus faber		
Sciaena umbra		
Pagrus pagrus		
Lophius sp.		
Sphyraena sphyraena		
Solea cuneata		
Dicologlossa hexophthalma		
Pagellus acarne		

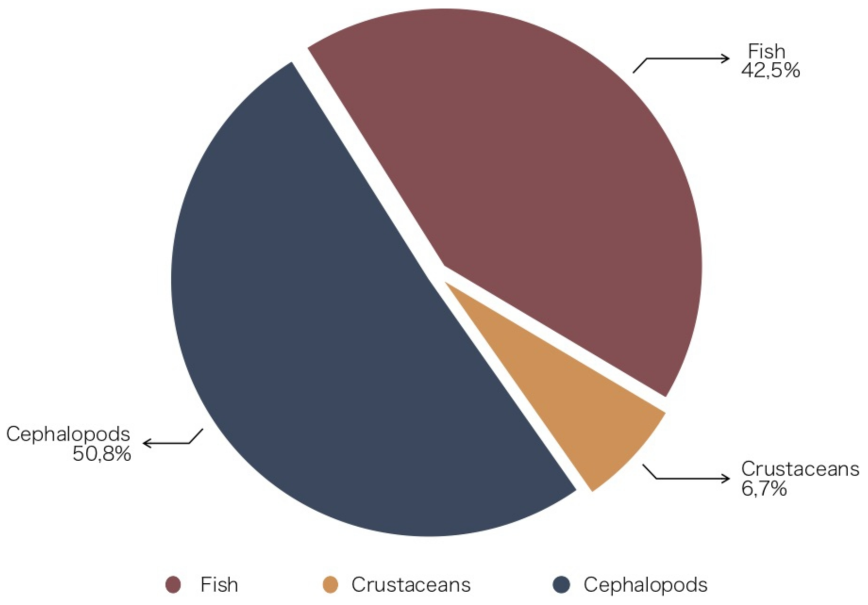

Figure 16: Proportion of fisheries in the total catch grouped into three main categories, cephalopodes (blue), fish (red) and crustaceans (orange).

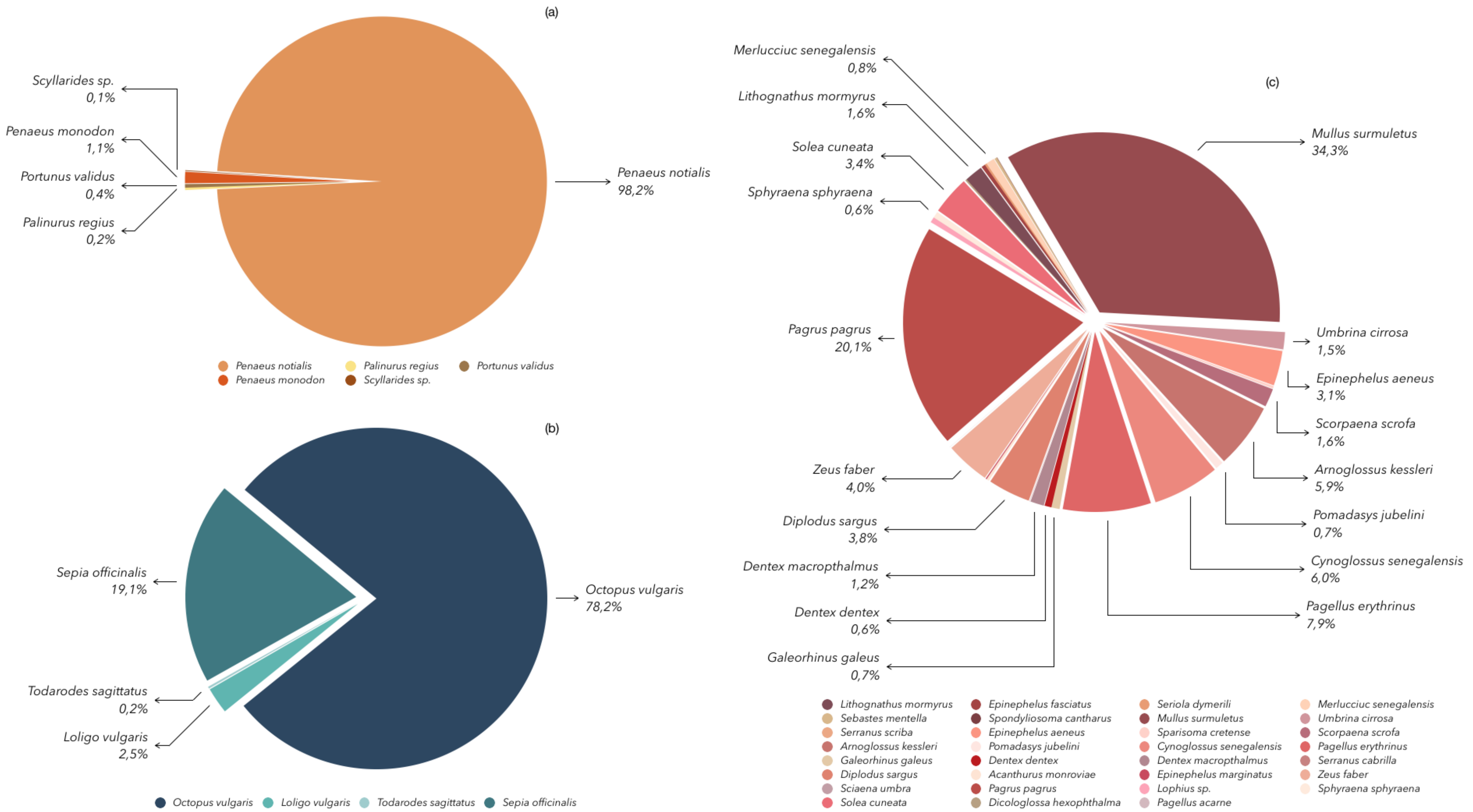

Figure 17: Proportions of the caught species according to their fisheries group. Figures (a), (b) and (c) refer to crustaceans, cephalopodes and fish, respectively.

3.2 Trophic levels of the catch

Species included in the TL analysis are listed on Table 9 according to their TL category. Additionally, the annual catch of the four TL categories is presented in Figure 18. The group of species with TL ≥4 had the lowest quantities, not exceeding the 43,772 kg in the period of 2004-2006. In 2007, the quantities rose up to 83,856 kg and then decrease again until 2010. The maximum of 164,938 kg occurred in 2011. Species that have the grater values in this category are *L. vulgaris*, *Zeus faber* and *E. aeneus.* Also, *Arnoglossus kessleri*, even though is not present every year, in 2011 and 2012 showed significantly high values (Figure 19a).

Species of TL 4 > 3.5 are fluctuating for year to year, but still have remarkably higher values. The minimum of this category was 402,988 kg in 2010. After that the values climaxed again reaching the maximum of 651,187 kg in 2012. As expected, *O. vulgaris* dominates this category, followed by the species of *S. officinalis* and *P. pagrus* (Figure 19b).

The category of species with TL 3.5 > 3 had the minimum value of 60,946 kg in 2007. This category peaked three times in 2006, 2009 and in 2011 with 279,257 kg, 248,566 kg and 343,580 kg, respectively. In this TL category *M. surmuletus* stands out from the other species, especially in 2011, where its quantities reached the 231.056 kg (Figure 19c).

The group of TL <3, had the first three years notable values with the maximum of 133,204 kg in 2005. Since then, the values are generally decreasing, reaching the minimum of 4,941 kg in 2012. Only three species are classified in this category (*P. notialis*, *Acanthurus monroviae* and *Sparisoma cretense*) and *P. notialis* is dominating while the other two species have minor presence (Figure 19d).

Table 9: List of species and their division to the corresponding TL categories.

	Trophic level category			
	≥4	**4 > 3.5**	**3.5 > 3**	**<3**
Species	*E. aeneus*	*P. pagrus*	*D. sargus*	*P. notialis*
	S. sphyraena	*S. scriba*	*S. cantharus*	*A. monroviae*
	A. kessleri	*C. senegalensis*	*S. cuneata*	*S. cretense*
	S. dymerili	*S. cabrilla*	*P. jubelini*	
	E. marginatus	*S. officinalis*	*P. regius*	
	S. mentella	*P. acarne*	*P. monodon*	
	Z. faber	*O. vulgaris*	*D. hexophthalma*	
	G. galeus	*S. umbra*	*U. cirrosa*	
	T. sagittatus	*E. fasciatus*	*L. mormyrus*	
	L. vulgaris	*Scyllarides sp.*	*D. macropthalmus*	
	M. senegalensis	*S. scrofa*	*P. erythrinus*	
	D. dentex		*M. surmuletus*	
	Lophius sp.			

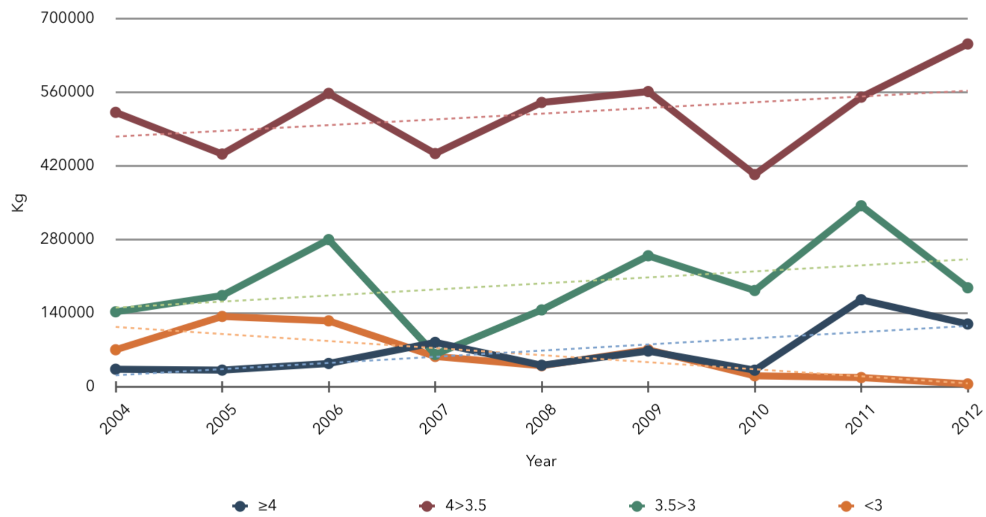

Figure 18: Summarized total catch of all species (excluding *P. validus*) in each of the four TL categories from 2004 until 2012. Linear trend lines are fitted, presented in a similar color to each one of the TL categories.

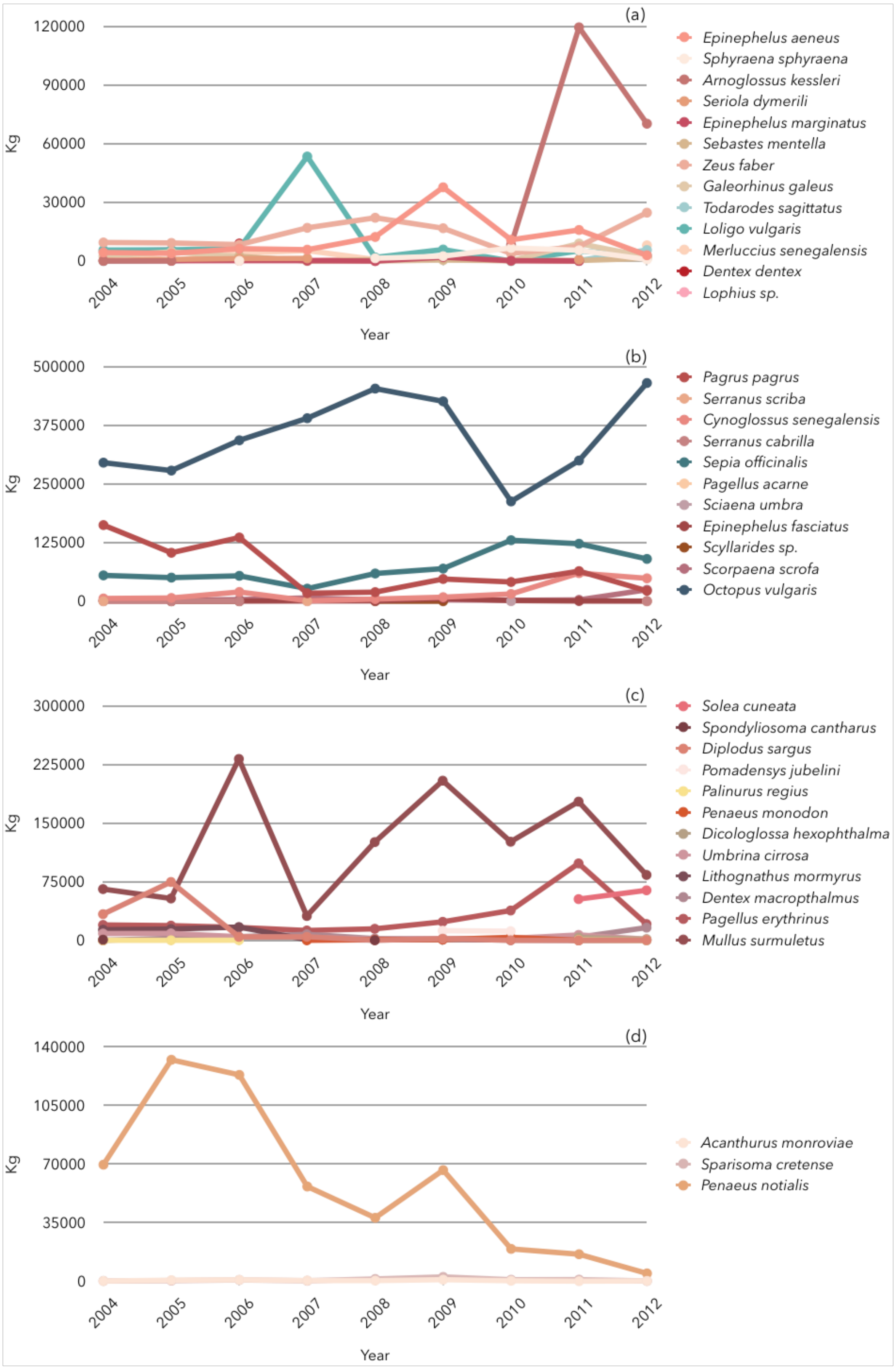

Figure 19: Total catch of species in the TL categories (a) ≥4, (b) 4 > 3.5, (c) 3.5 > 3 and (d) <3.

In order to detect any shift of the species inside the TL categories, Figures 20 to 21 were created excluding the dominant species of *O.vulgaris*, *M. surmuletus* and *P. notialis*. In the category of TL<3, *S. cretense* shows an increase after 2007 (Figure 20). Also, *A. monroviae* seems to be fluctuating, but still not exceeding the 920 kg of annual catch. In general, most of the species of the category TL 3 < 3.5 have values no grater than 25,000 kg (Figure 21). The species of *Diplodus sargus* and *P. erythrinus* are the only species in this group with consistent presence that created a notable peak. Furthermore, in 2011 the flatfish *Solea cuneata* was introduced in the catch with the annual value of 52,716 kg. In the category of TL 3.5 < 4, the species *P. pagrus* presents a significant decline of its catch in 2007 (Figure 22). After that downfall the values of *P. pagrus* appear to stay low while the catch of *S. officinalis* starts to increase. Besides the above mentioned species, *Cynoglossus senegalensis* has also notable presence overcoming the catch of *P. pagrus* the last couple of years.

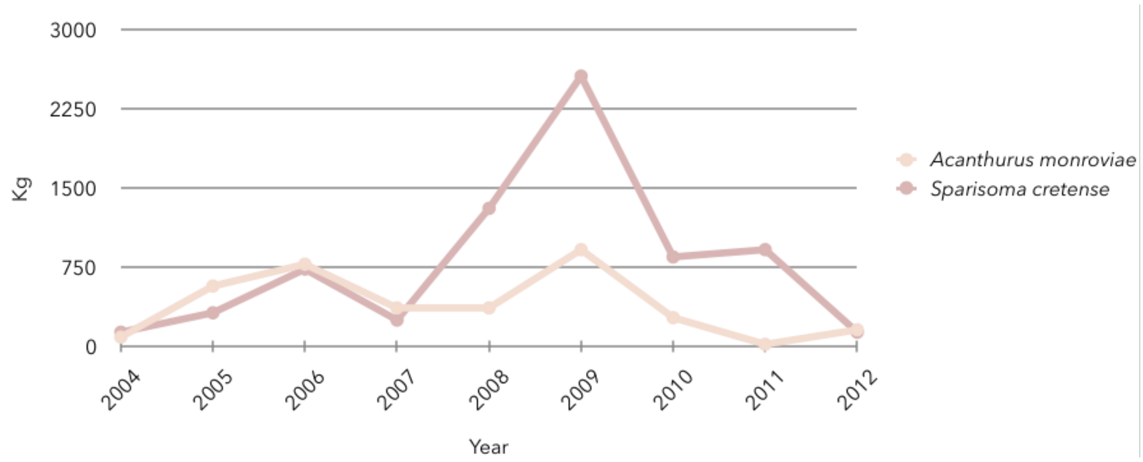

Figure 20: Total catch of the species in TL category <3, excluding *P. notialis*.

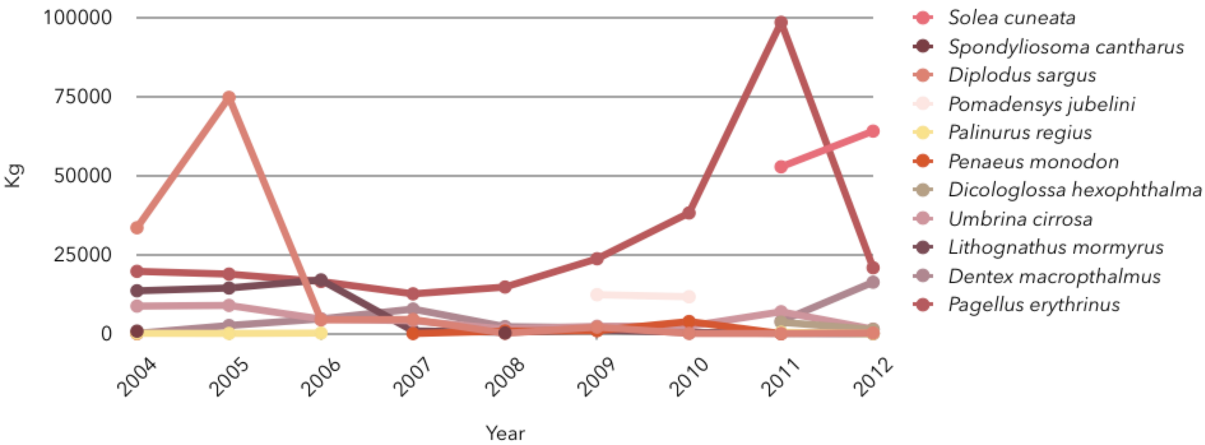

Figure 21: Total catch of the species in TL category 3.5 > 3, excluding *M. surmuletus*.

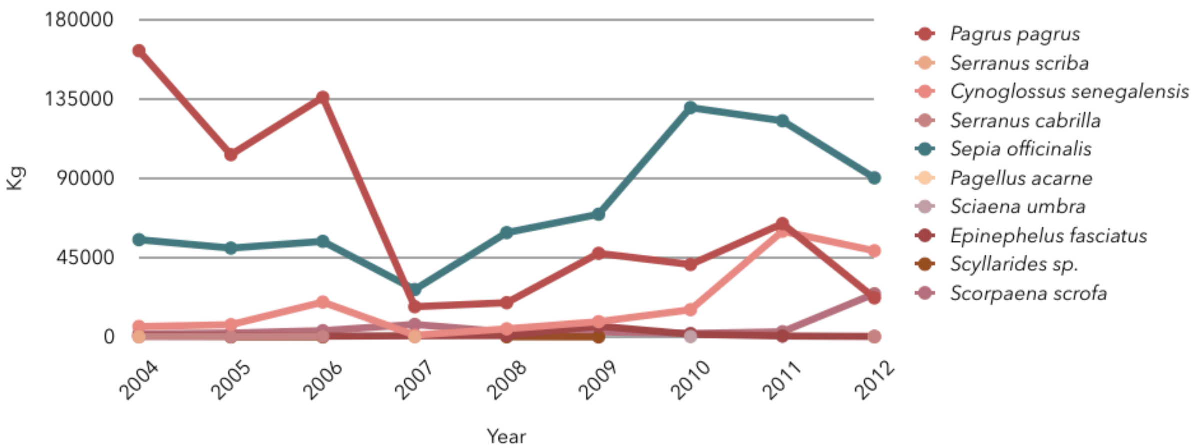

Figure 22: Total catch of the species in TL category 4 > 3.5, excluding *O. vulgaris*.

3.3 Species CPUE

The initial results of the main analysis consist of the CPUE of the selected species, during the time period 2004-2012 (Figure 23). Additionally, in order to view in detail the activity of each surveyed trawler Figure 25 was created, presenting the annual CPUE of the vessels regarding *O. vulgaris*, *M. surmuletus* and *P. notialis*.

Throughout the years, *O. vulgaris* owns the majority of the catch with at least 50% of the total (Figure 24). The minimum CPUE of 347.28 kg/day occurred in 2005. Until 2008 the values increased up to 536.38 kg/day. From 2008 to 2011, a decease appeared, followed by a great rise reaching from 371.14 kg/day (2011), the maximum of 587.33 kg/day in 2012 (Figure 23). For *O. vulgaris* the trends of the vessels seem to follow the same pattern. An exception occurred in 2011 from trawler T2, where its CPUE was 205.66 kg/day, unlike the other two trawlers which had at least the double values (Figure 25a).

According to Figure 23, *M. surmuletus* CPUE values fluctuate over the years. An intense rise of the catch took place in 2006, causing the maximum of 164.97 kg/day. In 2007, the minimum value of 36.14 kg/day is displayed, while after 2007 the numbers begin to elevate. The first three years (i.e. 2004 - 2006), the majority of *M. surmuletus* captures came from T1 contributing in total 163.3 tonnes. In addition, since 2007 there is no appearance of a plain motif differentiating a specific vessel according to its CPUE (Figure 25b).

P. notialis, has a distinct decreasing trend with even smaller values of CPUE every year. In 2004, the CPUE of *P. notialis* was 82.49 kg/day. Moreover, the maximum value of the species was estimated at 164.97 kg/day in 2005. Since then, the values are steadily reducing, reaching the 5.86 kg/day in 2012. The above discussed decrease of *P. notialis* occurred in all the surveyed trawlers (Figure 25c). From 2004 to 2007, trawler T3 catches the greater part of 40%, followed by T2 and T3. After 2007, the pattern changes and all trawlers have very close CPUE values.

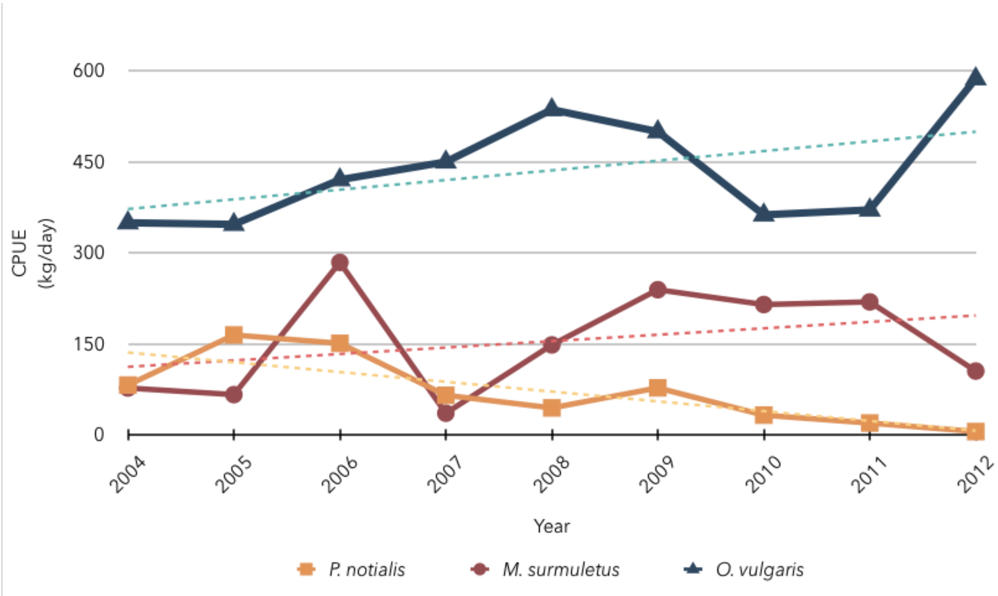

Figure 23: Total annual CPUE of *O. vulgaris* (blue), *M. surmuletus* (red) and *P. notialis* (orange). Linear trend lines are fitted, presented in a similar color to each one of the species.

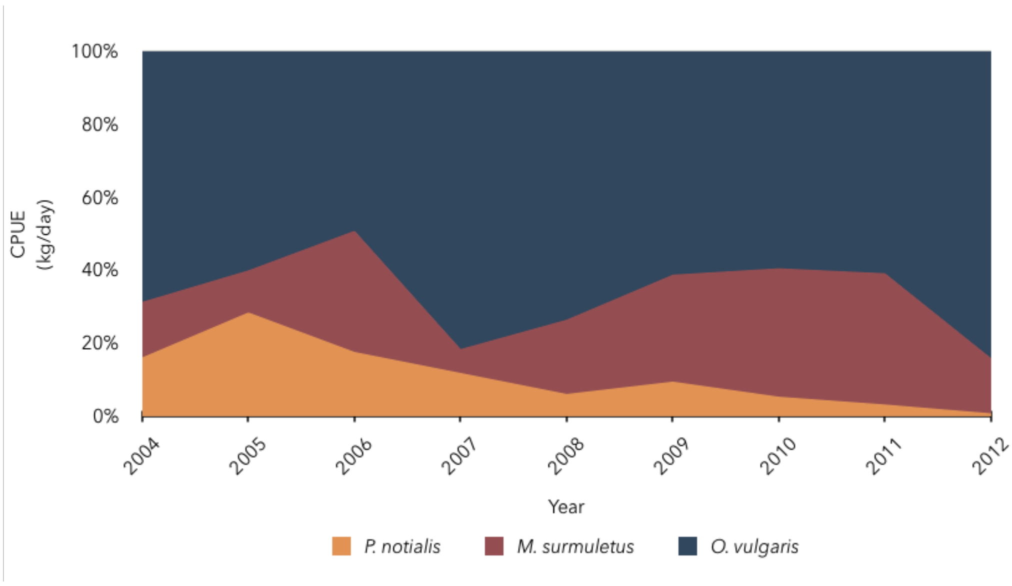

Figure 24: Relative contribution of the analyzed species, *O. vulgaris* (blue), *M. surmuletus* (red) and *P. notialis* (orange), throughout the 2004-2012 period.

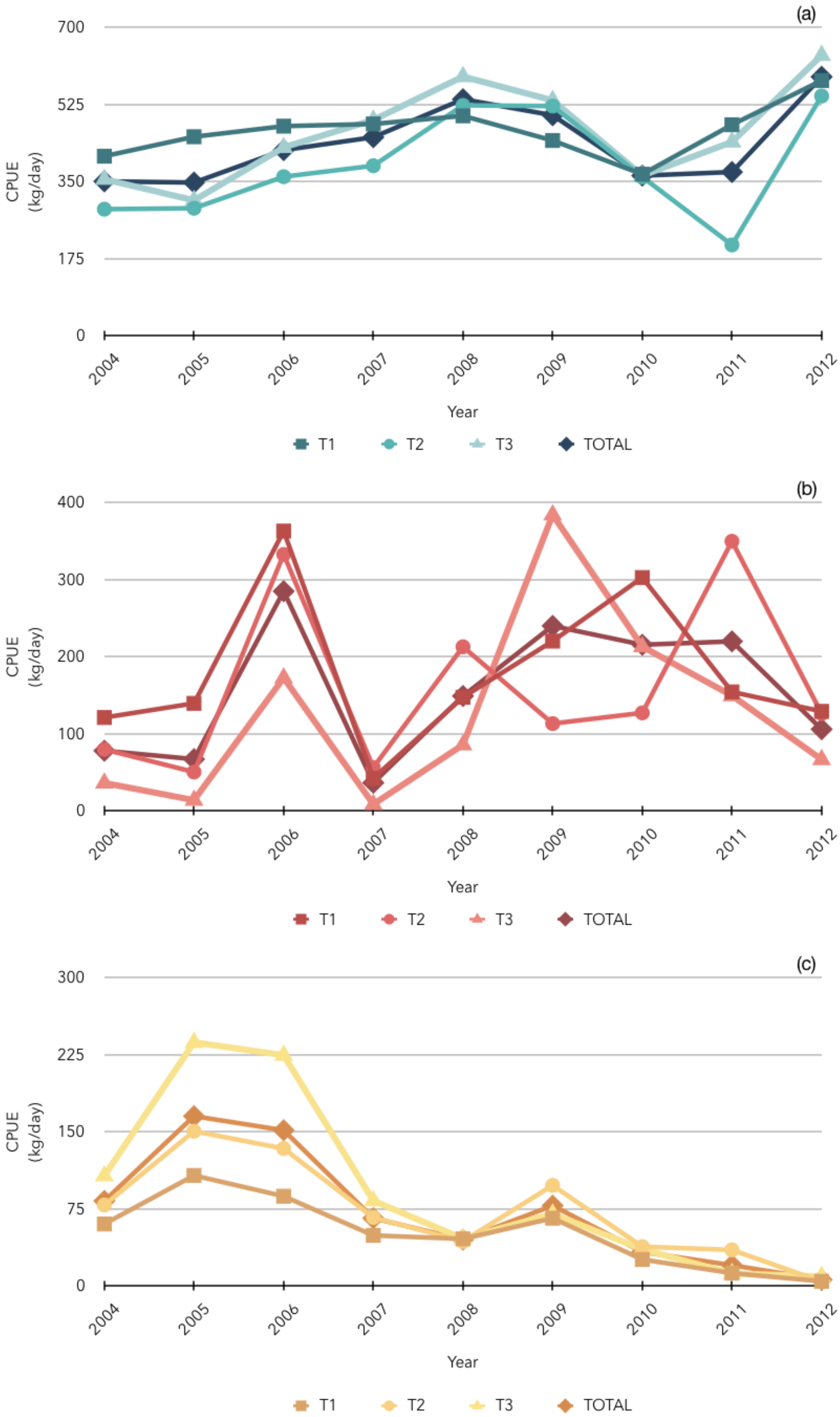

Figure 25: Annual CPUE of the surveyed trawlers (T1, T2, T3), along with the total species annual CPUE regarding (a) *O. vulgaris*, (b) *M. surmuletus* and (c) *P. notialis*.

3.4 Size groups CPUE

Examining the species size structure in the catch, the annual CPUE of the size groups is presented in the time series below (Figures 26-28). Regarding *O. vulgaris*, size group O1 shows stability during this time period without any extreme variations (Figure 26a). The group's maximum of 17.31 kg/day was in 2009, followed by the minimum of 4.17 kg/day in 2010. Size group O2 had the maximum of 116.74 kg/day also in 2009. The size group O3 has significantly bigger values than the two later categories, offering an approximate 35% (Figure 26b). This group exceeded with 190.88 kg/day in 2009. Unlike the other groups, O4 follows a different pattern with distinct fluctuations. Undoubtedly, the majority of the octopus catches originate from this size group (i.e. O4), having the maximum of 379.49 kg/day in 2012, providing that year the 75% of this species captures.

As presented in Figure 27b , *M. surmuletus* size group M1, constantly has the higher quantities compared to the other size groups of the species. The minimum value of the group appeared in 2007 with 17.79 kg/day. Also, the maximum of 91.98 kg/day was in 2011. Size groups M2 and M3 follow similar trends. The size group M4, was introduced in the catch in 2006, and as it is shown in Figure 27 it distinctly fluctuates from year to year, not always following the same pattern as the bigger size groups.

From Figure 28 *P. notialis* appears to have the higher caught quantities from 2004 until 2006. Moreover, from 2007 to 2012 the quantities are notably reduced for all the size groups. Overall, the groups of medium and small sized shrimp (i.e. P3, P4, P5) have bigger CPUE values, in contrast to the groups of the larger sizes (i.e. P1 and P2). The size group with the higher values is P5, with the maximum of 51.82 kg/day in 2005. Also, an obvious exception of this size group took place in 2009, with a distinct increase of 27.37 kg/day from the previous year. In addition, group P6 steadily contributes the smallest part with values from 6.92 kg/day (2004) to 11.38 kg/day (2006) the first three years, and since 2007 it appears that only quantities less than a kg total per day are captured.

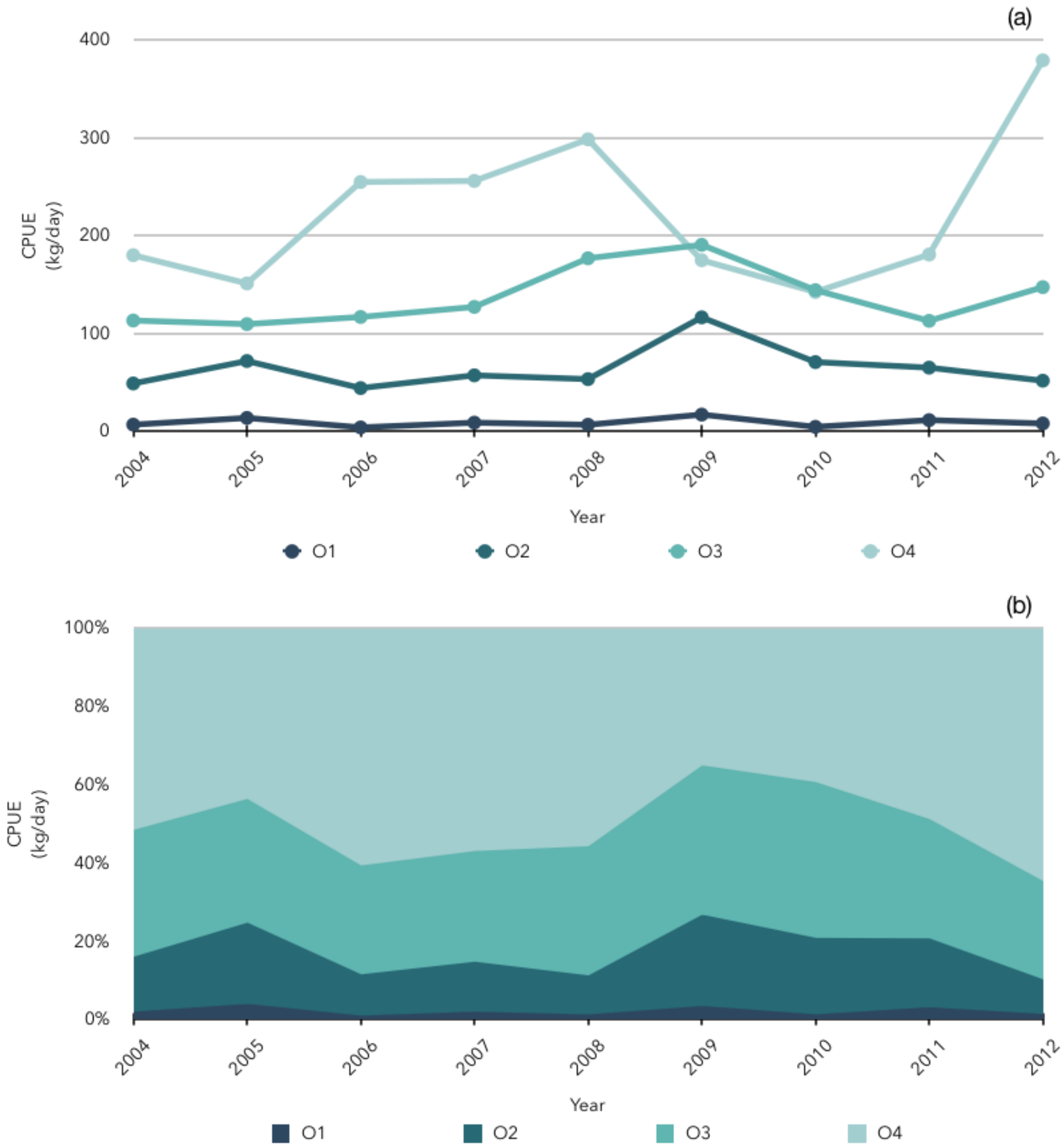

Figure 26: Annual CPUE of *O. vulgaris* size groups in the period of 2004-2012, expressed in (a) absolute values and in (b) relative contribution.

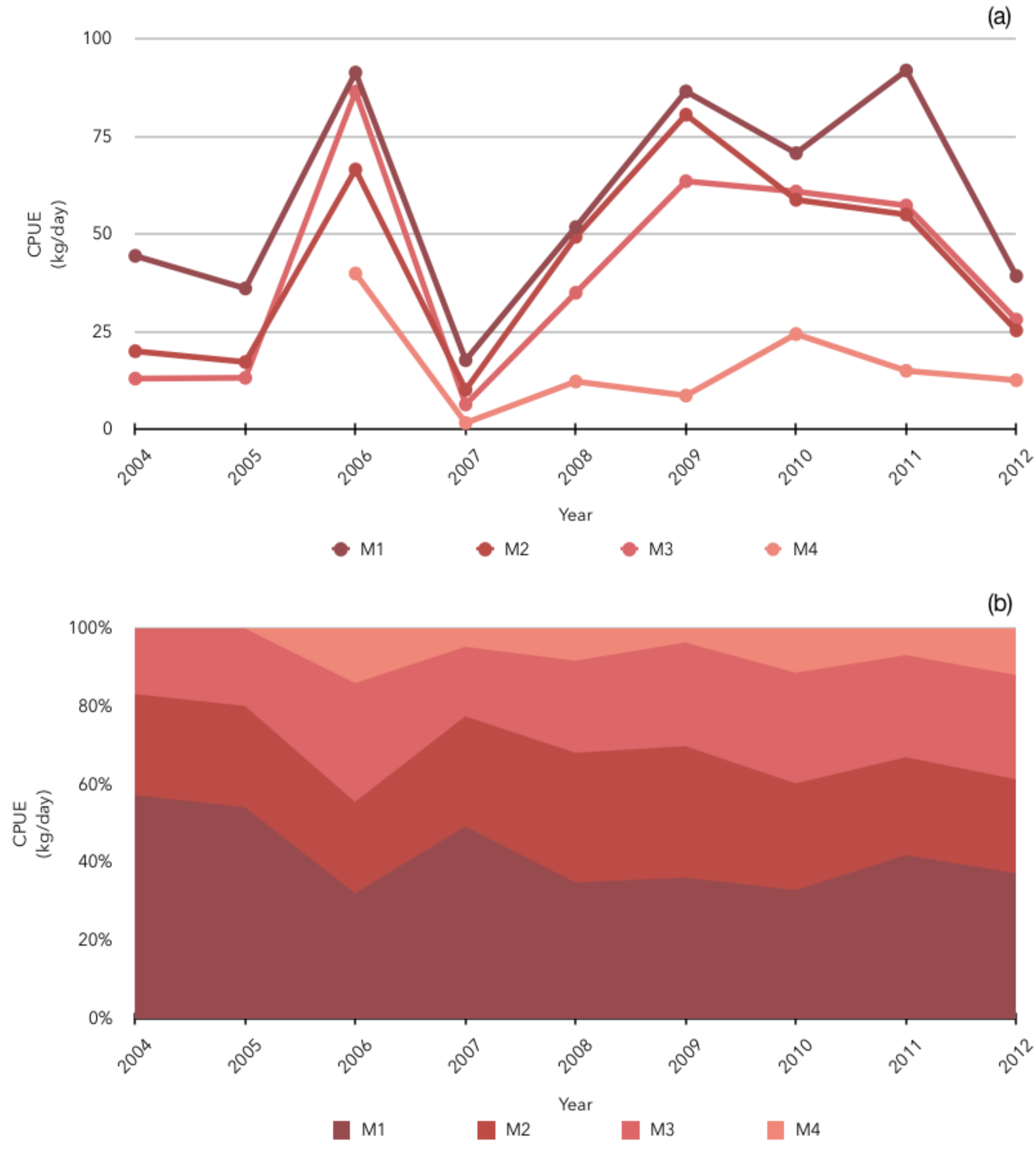

Figure 27: Annual CPUE of *M.surmuletus* size groups in the period of 2004-2012, expressed in (a) absolute values and in (b) relative contribution.

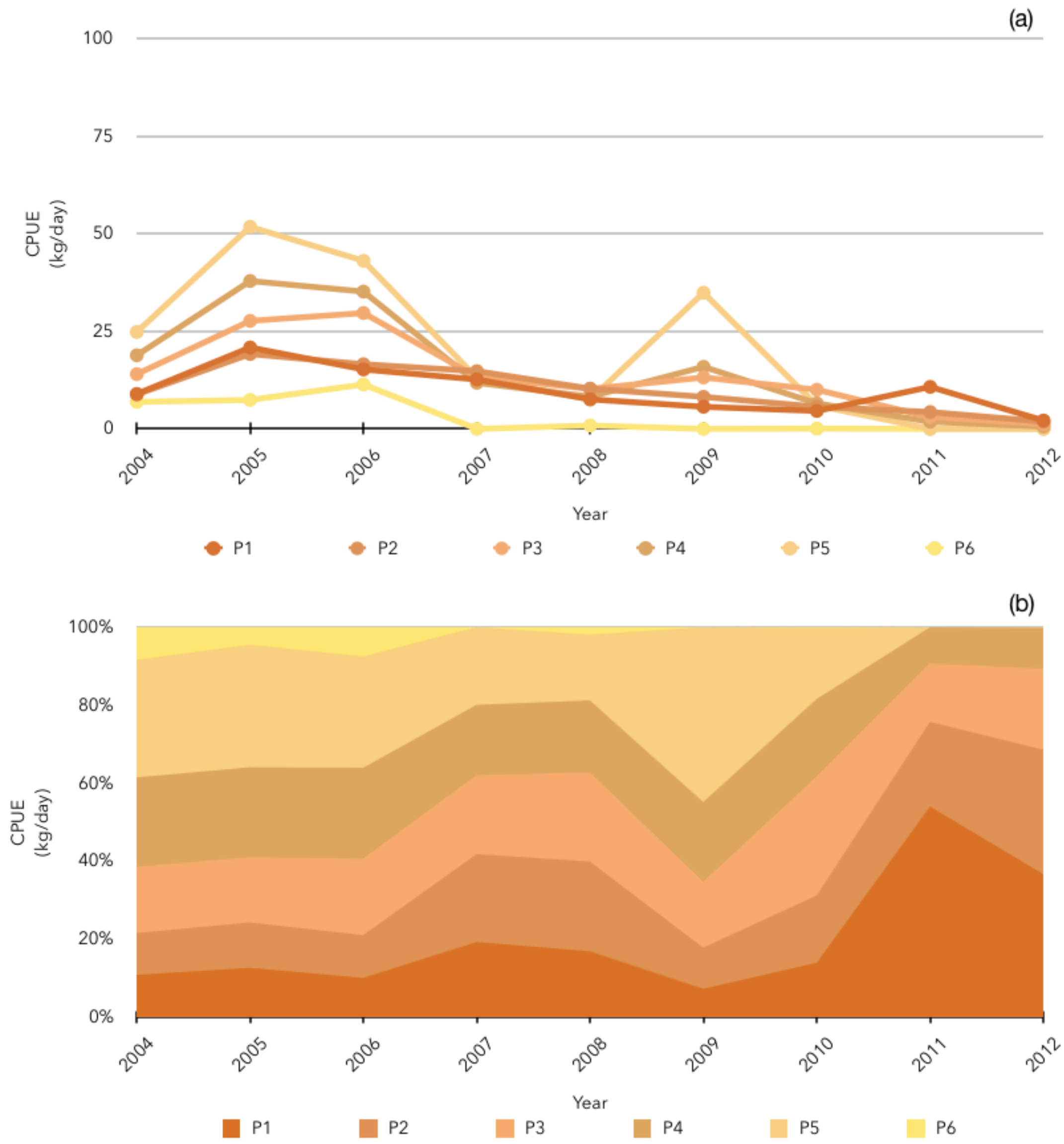

Figure 28: Annual CPUE of *P. notialis* size groups in the period of 2004-2012, expressed in (a) absolute values and in (b) relative contribution.

3.5 CPUE GAMs and years with statistically significant changes in the time-series

GAM analysis was applied on the species CPUE, as also on the CPUE of the species size groups. These results are presented in Figures Error: Reference source not found to 32, where the additive models are illustrated along with the first derivative of the fitted trends of the model.

From the additive model of *O. vulgaris* CPUE, the fitted values show an increasing trend from 2004 to 2008 (Error: Reference source not founda), with significant change presented from 2006 to 2008 (Error: Reference source not foundb). The trend of the model changes to negative after 2008, while the model displays once more a significant increase in 2011 and 2012. Regarding the *O. vulgaris* size groups, GAMs had poor fitting of the groups O1 (Figure 30a) and O2 (Figure 30c) with no important changes in the time series (Figures 30b and d). On the other hand, size groups O3 (Figure 30e) and O4 (Figure 30g) had a better fit. Size group O3 displayed a notable increase after 2006 and until 2009 (Figure 30f). From 2009, the trend shifts and until 2011 the values are decreasing. Size group O4 did not have major fluctuations (Figure 30g), but the trend alters significantly in 2009 and in 2011 as shown in Figure 30h.

The GAM of *M. surmuletus* had a poor fitting of the species CPUE values (Error: Reference source not foundc). Probably there are other predicting factors needed (excluding time) in order to produce a better model. In addition, all of the size groups showed the same non significant shifts of the trends (Figure 31).

The applied model on *P. notialis* CPUE has a noteworthy continuous decrease, especially after 2006 (Error: Reference source not founde). The first two years of the time series a significant rise is presented, while after 2005 the values begin to decline creating important trends in the period of 2005-2007, as also in 2010 and 2011(Error: Reference source not foundf). The GAMs of the species size groups show the same overall trend occurring in all classes (Figure 32). Size groups P1 did not have a good fit of the model, and the decrease of this group happened without any particular significance (Figure 32a and k). Furthermore, the most intense shifts were presented in the size groups P4 and P5 in the period of 2005-2007 (Figure 32h and j). As for the rest of the groups, period of notable decrease is marked between 2006 and 2008 (Figure 32d, f and l).

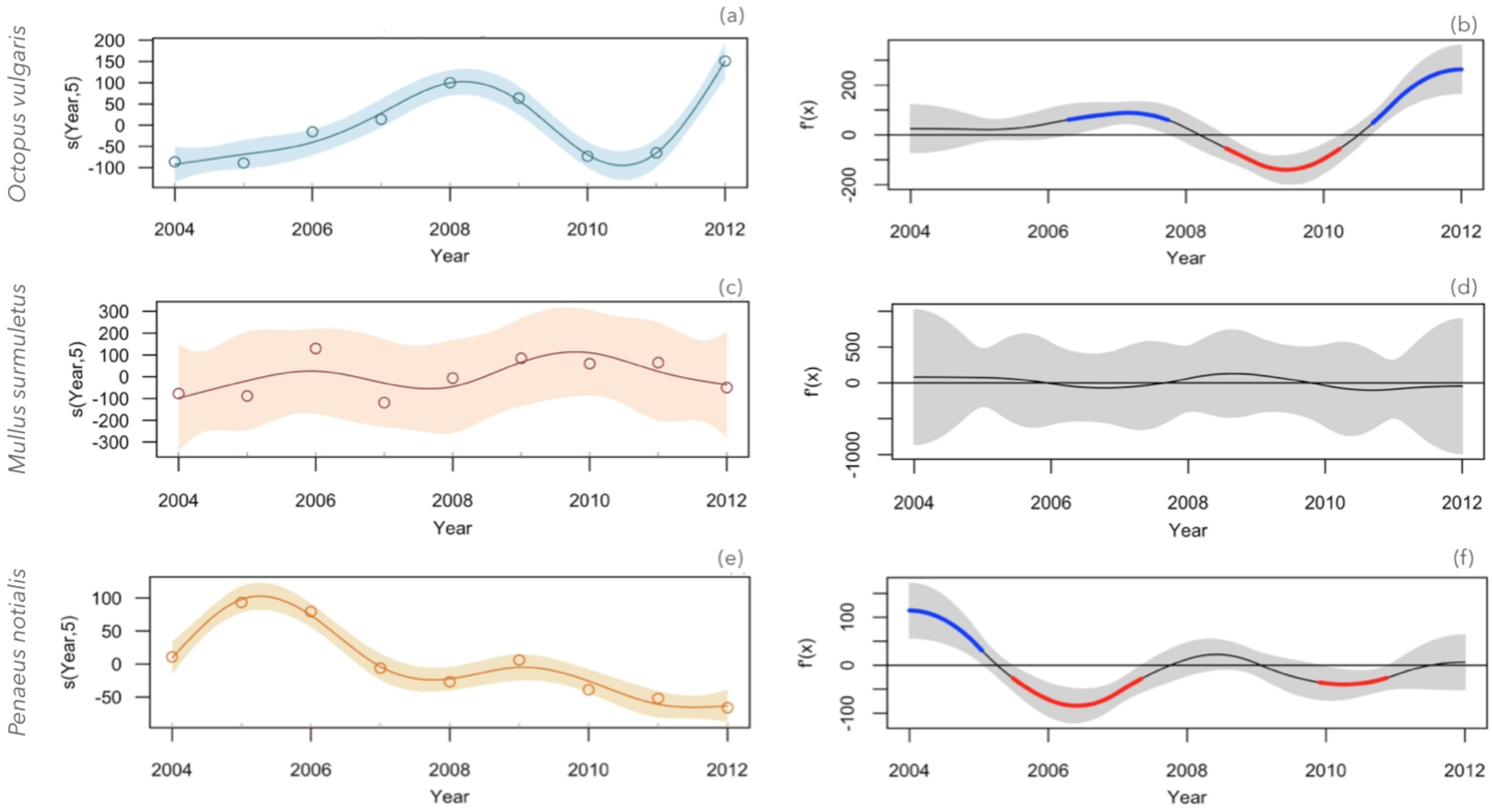

Figure 29: Illustrations of the GAMs applied on species CPUE presented on panels (a), (c) and (e), as also the first derivative of the models in panels (b), (d) and (f), for *O. vulgaris*, *M. sumuletus* and *P. notialis*, respectively.

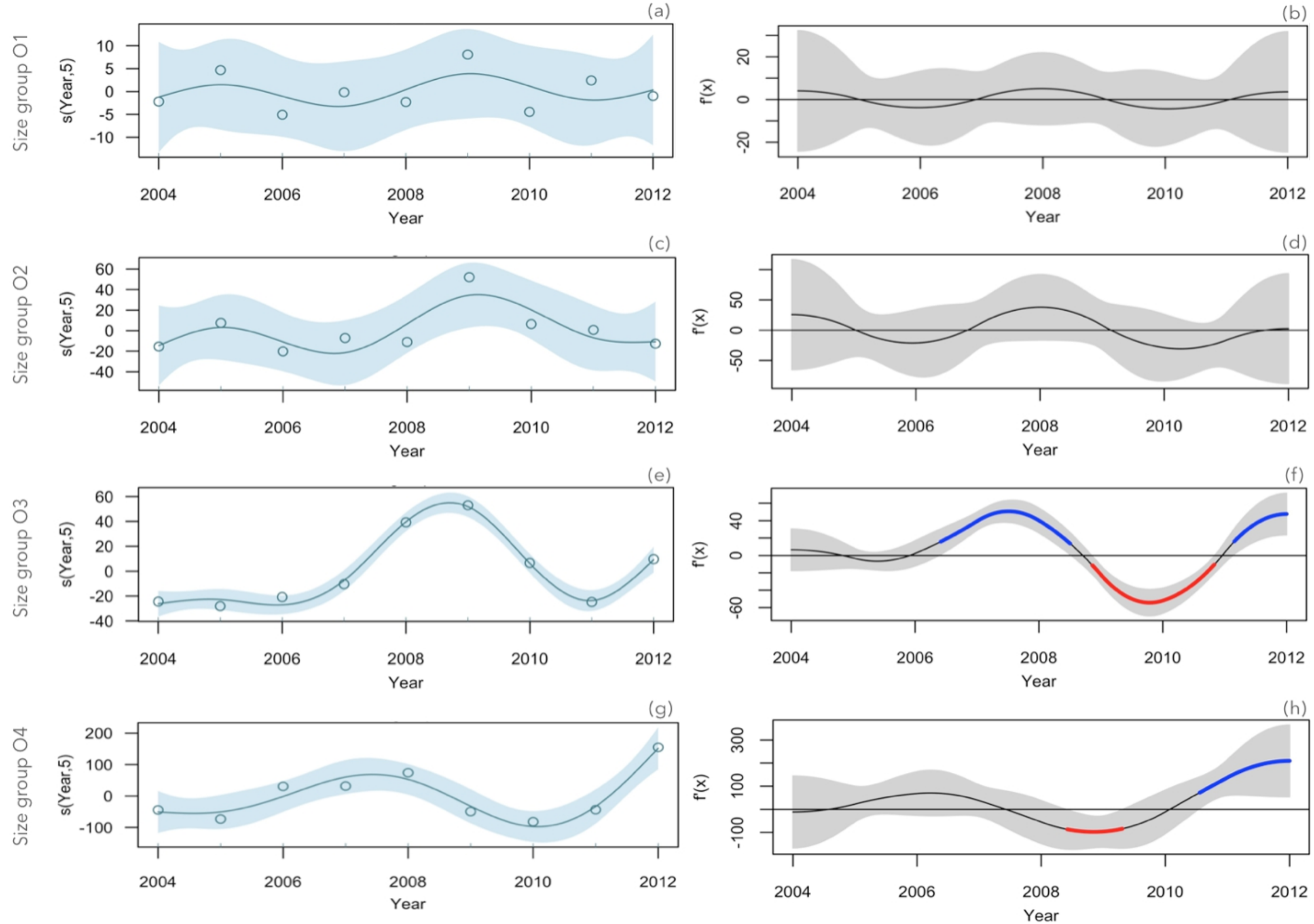

Figure 30: GAMs of *O. vulgaris* size groups (panels a, c, e and g) and the first derivative of each model (panels b, d, f and h).

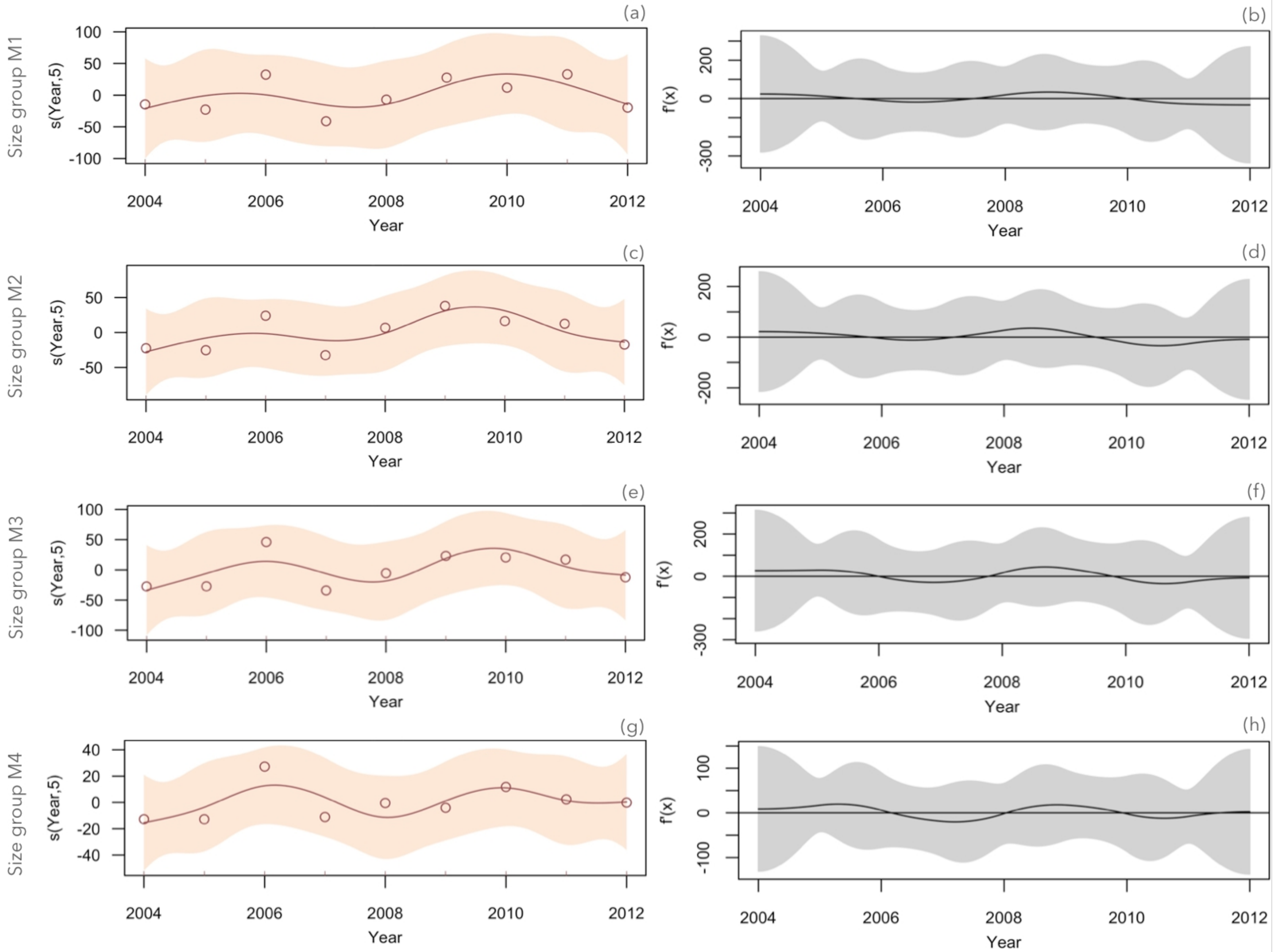

Figure 31: GAMs of *M. surmuletus* size groups (panels a, c, e and g) and the first derivative of each model (panels b, d, f and h).

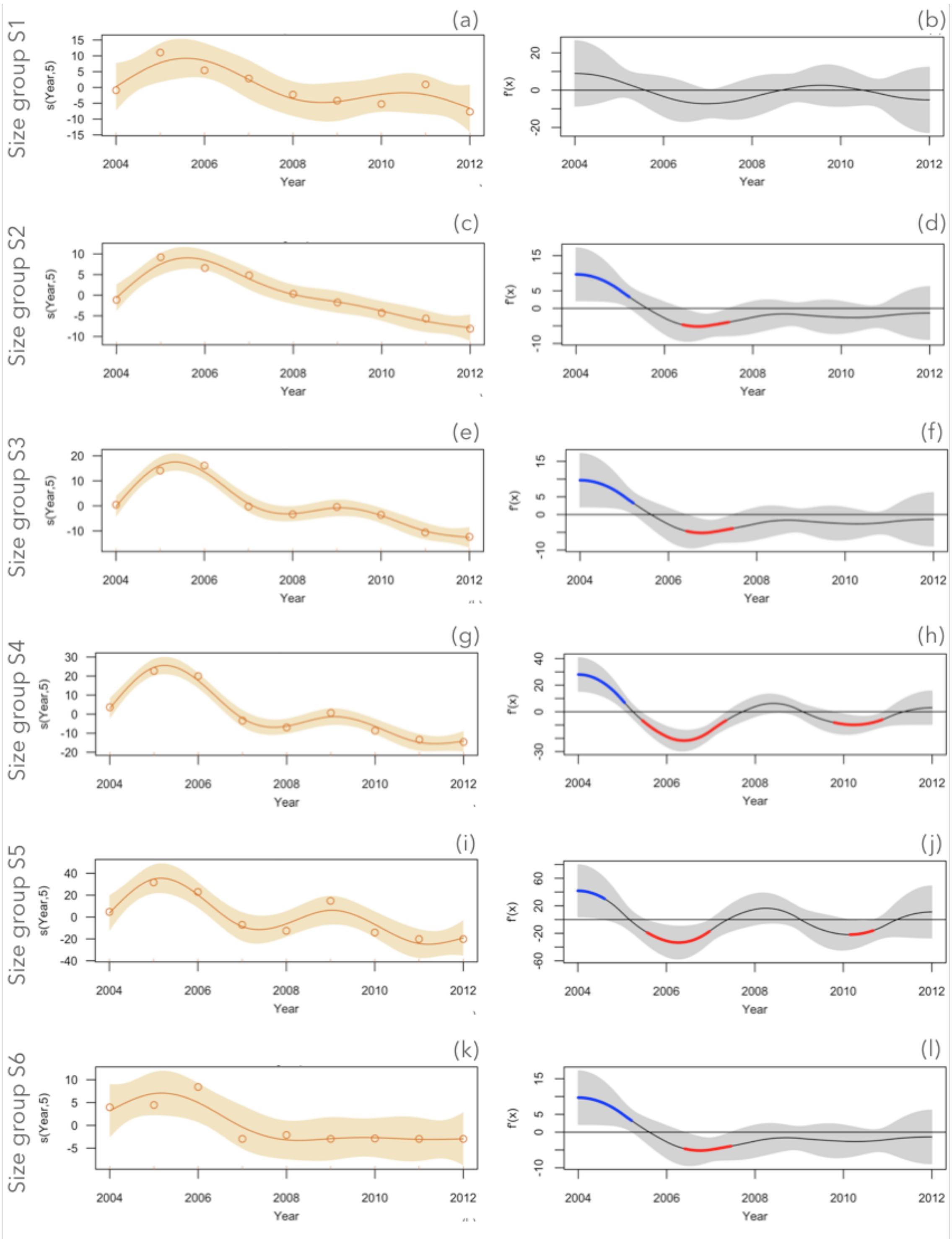

Figure 32: GAMs of *P. notialis* size groups (panels a, c, e, g, i and k) and the first derivative of each model (panels b, d, f, h, j and l).

4 Discussion

Catch data derived from official databases such as those maintained by FAO or regional fisheries management organizations (e.g. CECAF) are a valuable source of information regarding the status of fisheries across the globe. However, such aggregated data may not always accurately reflect the actual fishing status in particular areas, or may suffer from severe inaccuracies/uncertainties due to (deliberate or not) data miss-reporting, gaps in the available catch time-series, lack of actual fishing effort information or other discrepancies. Long-term information from fishery-independent surveys (e.g. Bell et al., 2018) or studies that elaborate on accurate and reliable raw catch and effort data from a commercial fleet can provide very useful insights into the status of commercial stocks, and the potential structural changes that occur to a fishery regarding targeted fish and their abundance or size composition through time.

Using the rare opportunity of having access to the data describing the fishing activities of three industrial trawlers during 2004-2012 , this study analyzed their catch composition in the ECA region, where historically-important demersal stocks have been reported as decreasing by multiple CECAF reports (FAO-CECAF, 2016b; FAO-CECAF, 2016c). The data were interpreted and analyzed in several stages, in the effort to provide a comprehensive view into the actual structure of the catch and its trends over the course of almost a decade. To this end, the species composition of the total catch was initially documented, reporting the list of species that were being fished in ECA. Analyzing their relative contribution to the total catch helped identify the species that systematically contributed the most in terms of landed quantities and (thereby) commercial interest. The trophic level of the total catch was also analyzed, and then particular focus was given into three commercially important species (*O. vulgaris, M. surmuletus*, and *P. notialis*) whose CPUE trends in time where investigated via GAMs, both in terms of total catch and in terms of size group categories.

The analysis of the total catch showed that some specific species characterize the long-term data, while few others have a limited and/or not consistent presence in the records. Species with the most notable values are *O. vulgaris*, *M. surmuletus*, *S. officianalis*, *P. pagus* and *P. notialis*; interest was also found in the shifts of catch of *P. erythrinus*, *D. sargus*, *L. vulgaris* and *E. aeneus*. Among these species, various stocks are declared either overexploited or fully exploited in this fishing area (for example, the stocks of *Pagellus acarne* in Morocco and *E. aeneus* in Mauritania, Gambia and Senegal, (FAO-CECAF, 2016c).

Regarding the trophic level of the catch, the preliminary assessment conducted in this study examined 39 species in total, grouped in 4 TL categories using their summed annual catch. All categories displayed fluctuations in time, nevertheless, the edge categories (lowest and highest TL) showed some significant alterations. Moreover, the species category of higher TLs (TL ≥4) present an generally increasing trend, especially after 2010 (Figure 18). This category is mainly affected from four species; *L. vulgaris*, *E. aeneus*, *Z. faber* and *A. kessleri*. The later (i.e. *A. kessleri*) was present in the catch in 2004 and 2005 with very small quantities, then again from 2010 until 2012 with significantly raised values, causing the aforementioned positive trend. The rest of the not mentioned species in this category did not show any noteworthy shifts. On the other hand, the smallest TLs of the corresponding category (i.e. TL <3), display a notable decrease. This category, consisting from three species only, is monopolized by the targeted catch of *P. notialis*. Hence, the decreasing trend is a reflection of the species catch. Regarding the two middle categories, from 2005 until 2011, both seem to fluctuate with a similar pattern. The category of TLs between 3.5 and 4, is mainly driven by the catch *O. vulgaris,* which is the most abundant species. Furthermore, the trends of the category with TLs from 3 to 3.5 is dominated by the catch of *M. surmuletus*.

An older study (Laurans et al., 2004) investigating the changes in the trophic structure of demersal communities in Senegal and Guinea, concluded that the biomass of higher TLs declined, while the biomass of lower TLs ether decreased or remained unchanged. In the study of Camara et al. (2016) about the demersal fish-stocks in Guinea, the TL was found to be deceasing in the period of 1985-2012. This result was attributed to the fishing pressure forced in Guineas continental shelf over the years. Furthermore, the assessment of Meissa and Gascuel (2015) regarding the demersal stocks of Mauritania, presented that the 66.6% of the stocks are overexploited or fully exploited. Their results showed that the total demersal biomass reduced since the 1982, and that the mean trophic level also declined in their 20 years period of examination.

With respect to the three main commercially important species examined, the overall finding was that *O. vulgaris* systematically dominates the catch, while at the same time, the other two species have a mutually-reversed pattern; specifically, *P. notialis* has a higher percentage than *M. surmuletus* during the first years of this study, and as the CPUE of the shrimp gradually decreases through time, the contribution of *M. surmuletus* increases.

O. vulgaris data analyzed in this study showed that is CPUE was increasing, and this result is in good agreement with the corresponding (aggregated) data of maintained by CECAF (Figure 33). A reduction of its CPUE began in 2009, but then again the values rose to the maximum in 2012. The group size analysis conducted in this study showed that what apparently causes this growing trend are mainly the smallest individuals of size group O4. This size class has almost every year the highest amount of CPUE. An exception was the year 2009 where the size group O3 had bigger daily catch with a difference of 15.74 kg/day. Also the next year both size groups had a slightly difference. Moreover, in terms of proportions the O1 category had persistent small values of CPUE, never exceeding the 4%. The category O2 provides a percentage in between 9 and 23% in the examined period, while the other two categories fluctuate with higher CPUE values.

Since octopus is highly affected by the environmental factors at its early life stages (Diankha & Thiaw, 2016), the showcased intense fluctuations of the O4 size group, could be a reflection of an influenced recruitment. A s Otero et al. (2008) mentions in their research, upwelling events contributes to the larva survival via indirect processes, while having also a positive effect on their CPUE. Regarding predators of *O. vulgaris* such as *Epinephelus marginatus* and *L. vulgaris*, both presented an increase of their catch in 2009, where *O. vulgaris* had a significant decrease especially in the smaller size groups (O3 and O4). Further, the reduction of the CPUE values in 2010 could also be related with the lessened overall days of effort. From the one hand the catch data are standardized by effort, but still the vessels might occur only in a low productive period. As an outcome, it can be said that none of the size groups displayed any dramatic or not recovering decrease in the analyzed data.

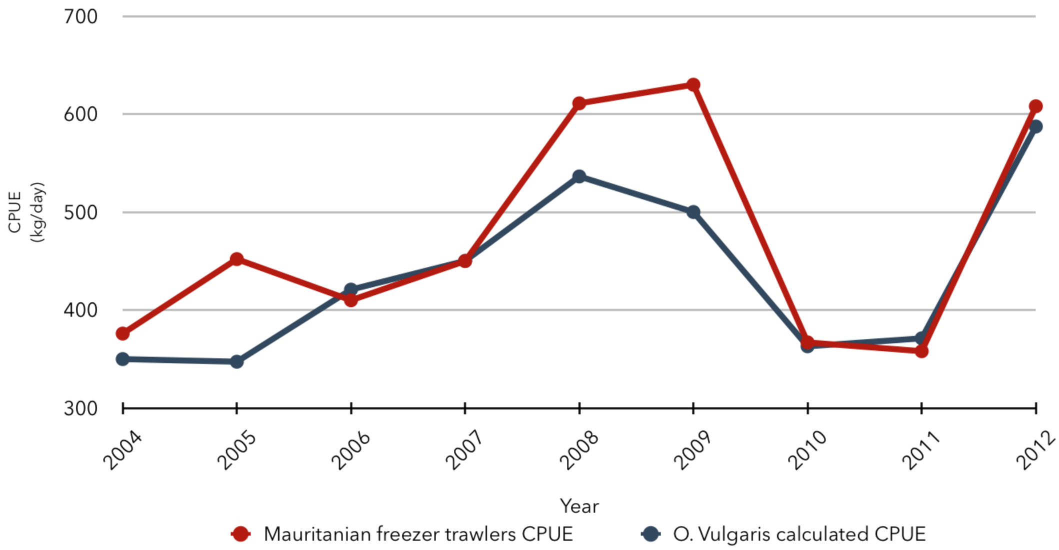

Figure 33: CPUE for *O. vulgaris* according to data of the present study and the official CECAF (FAO-CECAF, 2016b) records.

Contrary to *O. vulgaris*, the results of our analysis showed that *P. notialis* suffers from a clear decrease. The total CPUE of the species, after the peak of 2005, began to reduce dropping even more every year. This not growing trend could be a result of a change in the fishing agreements, but as far as we are aware the species never stopped of being a target. At this point, probably the single analysis of by-catch data would indicate a more compete explanation of this reduction. The results of the size group analysis for this species showed that the mentioned trend appears in all *P. notialis* size groups. From 2004 until 2006, the size groups have more or less a fix shareholding of the CPUE values. Since 2007, alterations began to occur in the size structure of the catch, along with the evident overall decreasing trend. More specifically, the smallest size shrimps (i.e. size group P6) are practically absent in the catch, especially after 2008. Furthermore, group P5 had a distinct increase in 2009 with the 45% of the annual CPUE. Finally, from 2010 until 2012 the bigger size groups present higher values contradicting the previous years of the time-series.

Several assumptions can be made in order to attribute the spoken reduction. Relative rises of the bigger shrimp may be related to the change of fishing gear, targeting other larger species due to the general reduction of the shrimp. Also, the disappearance of the smallest shrimp might be related to the other catchability factors (Walker et al., 2017). Additionally, the fact that the reduction of the values in 2010 and 2011 appeared also on *O. vulgaris* time-series could indicate environmental factors affecting the abundance of both species. Moreover, Caveriviere and Rabarison Andriamirado (1997) mention in their study that the predation of *P. notialis* in the open sea is low, as in its marine phase the species has a big size while its large predators are limited. Nevertheless, the only predator of *P. notialis* found in the catch in significant quantities and consistent presence, is *E. aeneus*. The catch of *E. aeneus* showcased an increase in 2009 where also the catch of *P. notialis* rouse, after both of their values decreased. With that been said and along with the fact that the artisanal fleet in FAO fishing area 34 is constantly growing, it can be assumed that the species is retained and caught in the estuaries were the artisanal fleet operates. As a result, the species would never progress to its marine phase, thus its overall abundance in the open sea would be affected as also the smaller size groups would present significant reductions.

Overall, the shrimp *P. notialis* is one of the two most targeted species of crustaceans in the ECA region (FAO-CECAF, 2016c). The general trend of our catch data is in concordance to those reported by FIRMS (FAO-CECAF, 2017) for the same period (Figure 34), however the comparison of corresponding CPUEs was troublesome and often, contradictory. Specifically, while the CPUE data reported by CECAF (FAO-CECAF, 2016a) for *P. notialis* Mauritanian stock indicate a rise of the values, our analysis showcased an opposing trend. In the report, it is also stated that the fleet reduced from 8 to 4 vessels in 2012, due to reduction of *P. notialis* abundance, nevertheless the CPUE values increased to 794 kg/day. This discrepancy of the values creates a need for future research in order to interpret the incompatibilities.

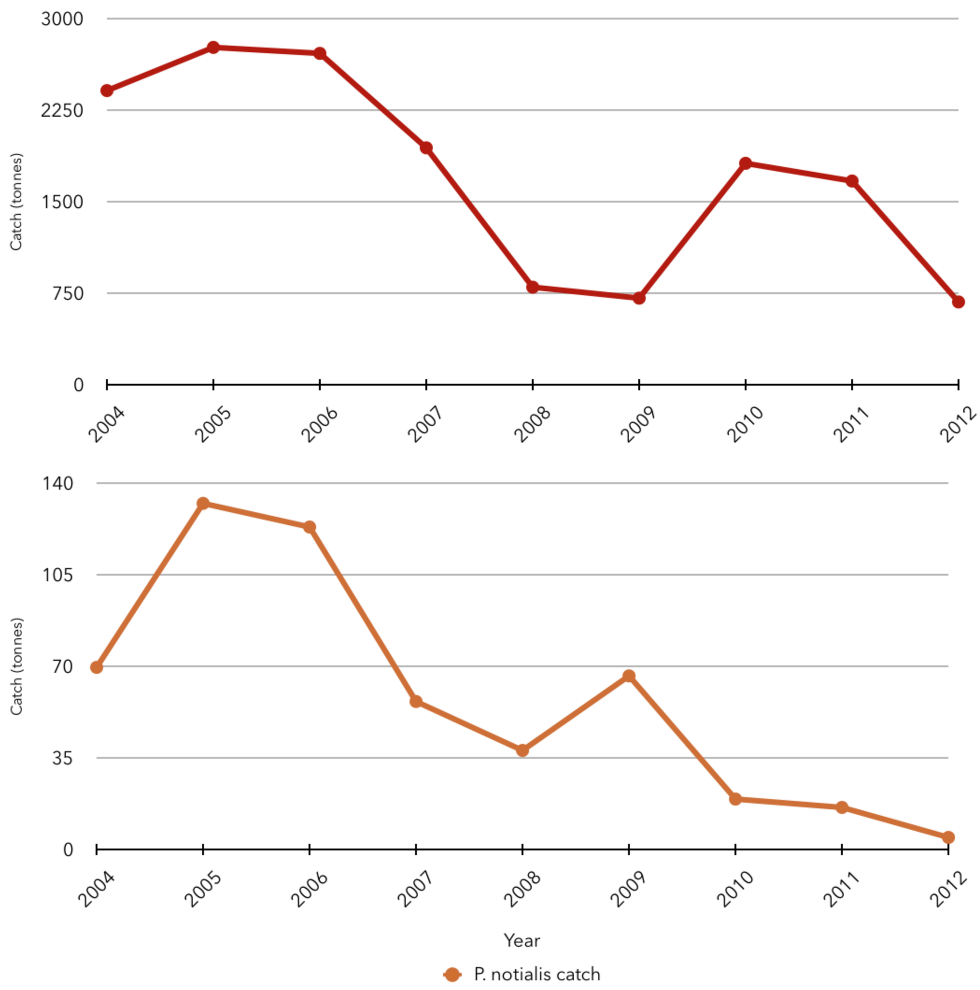

Figure 34: Catch for *P. notialis* according to data of the present study and the official CECAF (FAO-CECAF, 2016b) records.

For the species of *M. surmuletus,* informations according to the state of its stocks in this FAO fishing area were not found. Hence, our results were not compared to any official reports. The analysis of *M. surmuletus* data includes the total CPUE analysis and the size spectra analysis for the four commercial size categories that were used as given. From the general scheme of *M. surmuletus* total CPUE, intense fluctuation are displayed from 2004 until 2007. After 2007 the values are increased and the fluctuations seems to be smoothened. In 2012, the CPUE was again decreased nearly reaching the values of 2004 and 2005. Focusing on the size structure of the species catch, a stable pattern is observed throughout this period of time. The larger fish of size group O1 have the greatest amount followed respectively by the rest of the categories. Small alterations of proportions have occurred in the size groups of O2 and O3, but none of them is highly significant. Also, the size group O4, corresponding to the smallest fish, was introduced in the catch the year 2006, thus for the first two years of the time-series its values are null. From 2006 and after, its CPUE has the lowest values, providing in the species catch an amount from 4% to 14%.

In terms of alterations in the size structure of the *M. surmuletus* catch, from the seven years that all four size groups have data, not any significant shifts were detected in order to conclude that the species could be affected by intense fishing activity. Regarding its predators, *E. marginatus* and *Serranus cabrilla* have very low quantities compared to *M. surmuletus* for a comparison. Furthermore, it would be only appropriate to make also a size analysis of the predator species before making any abundance correlations. Moreover, Levi et al. (2003) researching the relationship between *Mullus barbatus* recruitment and the sea surface temperature (SST) in the Mediterranean, concluded that higher than average SST corresponds to increased recruitment. Hence, variations appearing in our data need to be compared with parameters like SST and upwelling events so shifting trends can be explained. Overall the proportions of the size groups remained varying in a range, but in order to detect the existence of any significant shifts a longer time series is needed.

In terms of fisheries management, there are several actions recommended for the species of *O. vulgaris* and *P. notialis*. In the northern area of CECAF, the recommendations about *P. notialis* are the restriction or the decrease of fishing mortality to the levels of 2011. For *O. vulgaris*, the main management proposals are the limitation of fishing effort in the Dakhla stock to the levels of 2012, the confinement of fishing mortality in Cape Blanc, Senegal and Gambia, and also the empowerment of their controlling measures (FAO-CECAF, 2016c). Combining our results to the management recommendations, for sure the species of *P. notialis* needs to be treated in order to increase into grater values. The assessment of *O. vulgaris* from our dataset did not show any worrying alterations. The size spectra revealed fluctuations in the concentration of the smaller individuals, but the rest of the size groups did not show any reduction. Hence, management measures are needed in order to at least maintain the existing status. Regarding *M. surmuletus*, only mentions were found about the management planning on mullet fishery, and the stated status of those plans was ether “under preparation” or “awaiting validation” (FAO-CECAF, 2016d). From our assessment this species did not show any trends such as the *P. notialis*, but fluctuations were still presented.

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6 Appendix

Appendix A: fix_source_file.m

```
% Run this script before running calc_cpue.
% It will scan the input file for 'From-To' date conflicts, and fix
% dates and effort accordingly. The fixed file is saved at OUTPATH,
% appending the '_fixed' suffix, e.g.
%
% SRCFILE     : '/path/to/sourcefile/data.csv'
% output saved: '/path/to/fixedfile/data_fixed.csv'
%
% If no conflicts are found, no file is saved.
%
% Normally, data entry changes should be like:
%   -----------------------------------------
%             Row    'From'       'To'
%   (prev)    i-1    '01-OCT-09'  '04-OCT-09'
%   (curr)    i      '05-OCT-09'  '11-OCT-09'
%   -----------------------------------------
%   which means that i-1 'To' should be different than i 'From'
%
% Conflicts occur if curr_From is the same with prev_To, e.g.:
%   -----------------------------------------
%             Row    'From'       'To'
%   (prev)    i-1    '01-OCT-09'  '04-OCT-09'
%   (curr)    i      '04-OCT-09'  '11-OCT-09'
%   -----------------------------------------
%   In this case, curr_From is incremented by +1, and effort is reduced by -1.
%   If effort is <=3, both curr_From and curr_To are incremented by +1 and
%   effort is left as is, to avoid zero effort.
%
% ------------------------------------
% Additional check, without auto-fixes
% ------------------------------------
% In addition to the aforementioned 'From'-'To' conflicts (which are
% automatically fixed by this script and saved as "_fixed.csv"), the source
% data also had some rare occurences in which a specific boat had overlapping
% days, e.g. boat T2 seemed as if it was at two different places during the
% same time period.
%  Original file (T2):
%     05-APR-04 to 11-APR-04
%     11-APR-04 to 14-APR-04
%     12-APR-04 to 18-APR-0
%  "_fixed.csv" (T2):
%     12-APR-04 to 14-APR-04
%     12-APR-04 to 18-APR-04
%
% This script also checks for these overlaps, *after* the "_fixed.csv" has been
% saved on disk. Corrections are not automatically applied, and the user is
% prompted to manually fix these problems in the "_fixed.csv" output file.

% programming: V.Trygonis, I.Anastasaki
% version:     1.1


clear,clc

% ===== config ======
SRCFILE   = '/path/to/data/raw_data_final.csv';
delimiter = ';';
suffix    = '_fixed';
OUTPATH   = '/path/to/data';
% ===== config ======

RAW = read_dlm_file(SRCFILE,delimiter); % class: cell
```

```
% -------------------------------------------------------
% separate header from data
% -------------------------------------------------------
header = RAW(1,:);
       % 1.  'Species'
       % 2.  'Fcode'
       % 3.  'Kgrs'
       % 4.  'Month'
       % 5.  'Year'
       % 6.  'Days'
       % 7.  'From'
       % 8.  'To'
       % 9.  'Area'
       % 10. 'Ship'
DATA = RAW(2:end,:);

% -------------------------------------------------------
% count unique Ships
% -------------------------------------------------------
uniqShips   = unique(DATA(:,10));
nShips      = numel(uniqShips);
            % 'T1'
            % 'T2'
            % 'T3'

% -------------------------------------------------------
% Isolate each Ship, and check for From/To overlaps
% -------------------------------------------------------
countFromToConflicts = 0;
for tt = 1:nShips
    tShip = uniqShips{tt};             % T1, or T2, or T3, ...
    idx   = strcmp(DATA(:,10),tShip);  % idx points to all lines with tShip
    tDATA = DATA(idx,:);               % isolate them to tDATA
    %
    % Scan each tDATA line and check for From/To conflicts.
    % Normally, data entry changes should be like:
    %             Row    'From'        'To'
    %   (prev)    i-1    '01-OCT-09'   '04-OCT-09'
    %   (curr)    i      '05-OCT-09'   '11-OCT-09'
    %
    % which means that i-1 'To' should be different than i 'From'
    %
    for ii = 2:size(tDATA,1)
        curr_From = tDATA(ii   ,7);      % i,   'From'
        prev_From = tDATA(ii-1 ,7);      % i-1, 'From'
        curr_To   = tDATA(ii   ,8);      % i,   'To'
        prev_To   = tDATA(ii-1 ,8);      % i-1, 'To'

        % If curr_From is different from prev_From,
        % i.e. we are at a data entry change row,
        if ~strcmp(curr_From,prev_From)
           % Check if curr_From is the same with prev_To, e.g.:
           %             Row    'From'        'To'
           %   (prev)    i-1    '01-OCT-09'   '04-OCT-09'
           %   (curr)    i      '04-OCT-09'   '11-OCT-09'
           if strcmp(curr_From,prev_To)
              % ---- conflict found !!!
              fprintf(...
               '\nFrom-To overlap at ''%s'', ship %s.\n',...
                curr_From{1},tShip)

              % get current effort
              curr_Effort = str2double(tDATA(ii,6));
              % fix curr_From, by always incrementing it by +1
              curr_From_fixed = upper(datestr(datenum(curr_From) + 1,'dd-mmm-yy'));
              %
              if curr_Effort >= 4
                 % When curr_Effort is "large", keep curr_To as is, but reduce
                 % curr_Effort by -1
                 curr_To_fixed     = curr_To{1};
```

```
                 curr_Effort_fixed = curr_Effort - 1;
                 asterisk = '';
              else
                 % When curr_Effort is "small", keep curr_Effort as is, and
                 % increment also curr_To* by +1.
                 % *reminder: curr_From_fixed has already been incremented by +1
                 curr_To_fixed = upper(datestr(datenum(curr_To) + 1,'dd-mmm-yy'));
                 curr_Effort_fixed = curr_Effort;
                 asterisk = '*';
              end

              fprintf('\twas        ''%s'' to ''%s'', effort %g%s\n',...
                      curr_From{1},curr_To{1},curr_Effort,asterisk)
              fprintf('\tfixed as   ''%s'' to ''%s'', effort %g\n',...
                      curr_From_fixed,curr_To_fixed,curr_Effort_fixed)

              % ---------------------------------------------
              % apply fix to the (original) DATA array
              % ---------------------------------------------
              for gg = 1:size(DATA,1)
                  if all(strcmp(DATA(gg,4:end),tDATA(ii,4:end)))
                     DATA{gg,6} = num2str(curr_Effort_fixed);
                     DATA{gg,7} = curr_From_fixed;
                     DATA{gg,8} = curr_To_fixed;
                  end
              end

              % increment conflict counter
              countFromToConflicts = countFromToConflicts + 1;
           end
        end
    end
end

if countFromToConflicts == 0
   % ---------------------------------------------
   % no conflicts, do not save fixed
   % ---------------------------------------------
   fprintf('Source file is OK (no From-To conflicts found).\n')
   fprintf('Nothing was saved to disk.\n')
else
   fprintf('\nFixed %g From-To conflicts total.\n',countFromToConflicts)
   % ---------------------------------------------
   % save fixed copy
   % ---------------------------------------------
   %
   % break SRCFILE into path,filename, and file extension
   [src_path,src_filename,src_fex] = fileparts(SRCFILE);
   % make output filename
   outfilename = [src_filename,suffix,src_fex]; % e.g. raw_data_final_fixed.csv
   % make outpath
   OUTPATHfull = fullfile(OUTPATH,outfilename);
   % notify
   fprintf('\nSaving fixed file: ''%s'' ...\n',OUTPATHfull)
   % merge output array
   OUT = [header;DATA];

   % make fprintf instruction:
   nColsOut = size(OUT,2);
   finst = [repmat('%s;',1,nColsOut-1), '%s\r\n'];

   % open (initilize) file with 'w'rite permission
   fid = fopen(OUTPATHfull,'w');
   for gg = 1:size(OUT,1)
       fprintf(fid,finst, OUT{gg,:});
   end
   fclose(fid);

   fprintf('Done.\n')
end
```

```
fprintf('\nWill now check for v1.1 conflicts (time overlaps).\n')

% ================================================================
% Boat location conflict check and reporting (without auto-fix)
% ================================================================
fprintf('\n----------------------\nv1.1 time overlap check\n')

% -------------------------------------------------------
% Isolate each Ship, and check for conflicts
% -------------------------------------------------------
countOverlapDateConflicts = 0;
for tt = 1:nShips
    tShip = uniqShips{tt};             % T1, or T2, or T3, ...
    idx   = strcmp(DATA(:,10),tShip);  % idx points to all lines with tShip
    tDATA = DATA(idx,:);               % isolate them to tDATA
    %
    % Scan each tDATA line and check for From/To conflicts.
    % Normally, data entry changes should be like:
    %            Row    'From'      'To'
    %   (prev)   i-1    '12-APR-04'  '14-APR-04'
    %   (curr)   i      '12-APR-04'  '18-APR-04'
    %
    % which means that i-1 period should *never* overlap i period
    %
    for ii = 2:size(tDATA,1)
        curr_From = tDATA(ii   ,7);      % i,   'From'
        prev_From = tDATA(ii-1 ,7);      % i-1, 'From'
        curr_To   = tDATA(ii   ,8);      % i,   'To'
        prev_To   = tDATA(ii-1 ,8);      % i-1, 'To'
        %
        % convert to serial date (e.g. datenum('24-DEC-12') = 735227
        % and check overlap
        curr_From_serial = datenum(curr_From);
        curr_To_serial   = datenum(curr_To);
        prev_From_serial = datenum(prev_From);
        prev_To_serial   = datenum(prev_To);

        currFromTo_serial = curr_From_serial:curr_To_serial; % vector of linear dates
        prevFromTo_serial = prev_From_serial:prev_To_serial; % vector of linear dates

        % If currFromTo_serial is in anyway different from prevFromTo_serial
        % we are at a data entry change row
        stx = setxor(currFromTo_serial,prevFromTo_serial); % [] if they are identical
        if ~isempty(stx)
           % data entry change row
           % If they are completely different, stx should have as many
           % elements as currFromTo_serial + prevFromTo_serial combined
           checkN = numel(stx) == (numel(currFromTo_serial) + numel(prevFromTo_serial));
           if checkN == false
              % overlap conflict!
              countOverlapDateConflicts = countOverlapDateConflicts + 1;
              fprintf('\nTime overlap found, ship %s:\n',tShip)
              fprintf('   From         To            Area\n')
              fprintf('   %s     %s     %s\n',prev_From{1},prev_To{1},tDATA{ii-1,9})
              fprintf('   %s     %s     %s\n',curr_From{1},curr_To{1},tDATA{ii,9})
           end
        end
    end
end
if countOverlapDateConflicts==0
   fprintf('\nNo v1.1 overlap conflicts were found.\n')
else
   fprintf('\nNote:\n')
   fprintf('  No edits were applied to _fixed output file.\n')
   fprintf('  Manually fix these %g v1.1 overlap conflicts.\n',countOverlapDateConflicts)
   fprintf('\nv1.1 time overlap check\n')
   fprintf('----------------------\n')
end
fprintf('\n\nWill now halt.\n')
```

Appendix B: calc_cpue.m

```
% Read fixed raw data and calculate CPUE by boat, species and fcode.
%
%   Input: The "fixed" raw data file produced by fix_source_file.m, *after*
%          the boat location conflicts are manually corrected.
%
%   Output: Two csv files, saved at the same directory as the input file.
%           [1]. Yearly CPUE by species
%           [1]. Yearly CPUE by species by fcode

% programming: V.Trygonis, I.Anastasaki
% version:     1.2

clear,clc

SRCFILE = '/path/to/data/raw_data_final_fixed.csv'; % with manual boat location fixes
delim   = ';';

RAW = read_dlm_file(SRCFILE,delim); % class: cell

format bank
% --------------------------------------------------------
% separate header from data
% --------------------------------------------------------
header = RAW(1,:);
       % 1.  'Species'
       % 2.  'Fcode'
       % 3.  'Kgrs'
       % 4.  'Month'
       % 5.  'Year'
       % 6.  'Days'
       % 7.  'From'
       % 8.  'To'
       % 9.  'Area'
       % 10. 'Ship'
DATA = RAW(2:end,:);

% --------------------------------------------------------
% get basic info on unique years, species, Fcodes, etc.
% --------------------------------------------------------
uniqSpecies = unique(DATA(:,1));
nSpecies    = numel(uniqSpecies);
            % 'ΓΑΡΙΔΑ'
            % 'ΜΠΑΡΜΠΟΥΝΙ'
            % 'ΧΤΑΠΟΔΙ'

uniqShips   = unique(DATA(:,10));
nShips      = numel(uniqShips);
            % 'T1'
            % 'T2'
            % 'T3'

uniqYears   = unique(DATA(:,5)); % for double: str2num(char(unique(DATA(:,5))))
nYears      = numel(uniqYears);
            % '2004'
            % '2005'
            %  ...
            % '2012'

% store Fcodes next to species
uniqFcodes = [uniqSpecies, cell(nSpecies,1)];
           % nSpecies x 2 cell, 1st column species, 2nd column its Fcodes
           % 'ΓΑΡΙΔΑ'        {8x1 cell}
           % 'ΜΠΑΡΜΠΟΥΝΙ'    {4x1 cell}
           % 'ΧΤΑΠΟΔΙ'       {8x1 cell}
           %
```

```
           % uniqFcodes{2,1}
           % >> ΜΠΑΡΜΠΟΥΝΙ
           % uniqFcodes{2,2}
           % >> '1G'
           %    '1M'
           %    '1P'
           %    '1PP'
for ii=1:nSpecies
    iSpecies = uniqSpecies{ii};
    idx = strcmp(DATA(:,1),iSpecies);
    uniqFcodes{ii,2} = unique(DATA(idx,2));
end


% --------------------------------------------------------
% make month-year time vectors
% --------------------------------------------------------
monthVector = repmat([1:12]',nYears,1);
yearVector  = zeros(size(monthVector));
c = 1;
for ii = 1:(12*nYears)
    yearVector(ii) = str2double(uniqYears{c});
    if monthVector(ii)==12 % if December,
       c = c + 1;       % go forward one year
    end
end
monthyearVector = [monthVector, yearVector]; % class:double
                %       1          2004
                %       2          2004
                %       3          2004
                %       ....
                %       11         2004
                %       12         2004
                %       1          2005
                %       2          2005
                %       3          2005
                %       ...
                %       10         2012
                %       11         2012
                %       12         2012

serial_date   = datenum(yearVector,monthVector,1);    % year, month, day=1
              % 731947 ~ 1/1/2004
              % 731978 ~ 1/2/2004
              % 732007 ~ 1/3/2004
string_mmyyyy = datestr(serial_date,'mmm-yyyy'); % 'Oct-2009'
              % 'Jan-2004'
              % 'Feb-2004'
              % 'Mar-2004'
string_yyyy   = num2str(yearVector);
              % '2004'
              % '2004'
              % '2004'


% --------------------------------------------------------
% yearly effort (days) by ship
% --------------------------------------------------------
fprintf('Calculating YEARLY_EFFORT (days) by ship...\n')
YEARLY_effort_by_ship = zeros(nYears,nShips); % rows:year, columns:ship

for ii = 1:nYears
    iYear  = uniqYears{ii};
    for jj = 1:nShips
        jShip = uniqShips{jj};
        % get index of all lines with
        % - year = iYear(e.g. 2004) and
        % - ship = iShip(e.g. T1)
        idx = (strcmp(DATA(:,5),iYear)) & (strcmp(DATA(:,10),jShip));
        % and isolate them as "localDATA"
```

```
        localDATA = DATA(idx,:);
        % within localDATA, get unique From dates, and their index I
        [localFrom,I] = unique(localDATA(:,7));
        % sum their effort
        YEARLY_effort_by_ship(ii,jj) = sum(str2num(char(localDATA(I,6))));
    end
end
fprintf('Done.\n')
% [str2num(char(uniqYears)) , YEARLY_effort_by_ship]
% >>
%     2004    ,    276         272         296
%     2005    ,    259         278         265
%     2006    ,    259         264         292
%     2007    ,    289         299         273
%     2008    ,    279         285         281
%     2009    ,    275         287         290
%     2010    ,    197         189         200
%     2011    ,    251         278         279
%     2012    ,    243         267         282


% -------------------------------------------------------
% yearly catch by species, by ship, and total | and cpue
% -------------------------------------------------------
% e.g.
% ΓΑΡΙΔΑ catch T1 | ΓΑΡΙΔΑ catch T2 | ΓΑΡΙΔΑ catch T3 | ΓΑΡΙΔΑ catch total
%
fprintf('Calculating YEARLY_CATCH by species by ship...\n')

YEARLY_catch_by_spp_by_ship = zeros(nYears,(nShips*2 + 2),nSpecies);
HeaderCatch_tmp = cell(1,(nShips*2 + 2),nSpecies);
      % Multi-dim array:
      % --- page 1:
      %     1. ΓΑΡΙΔΑ catch T1 (kg)
      %     2. ΓΑΡΙΔΑ T2 (kg)
      %     3. ΓΑΡΙΔΑ T3 (kg)
      %     4. ΓΑΡΙΔΑ catch total (kg)
      %     5. ΓΑΡΙΔΑ cpue T1
      %     6. ΓΑΡΙΔΑ cpue T2
      %     7. ΓΑΡΙΔΑ cpue T3
      %     8. ΓΑΡΙΔΑ cpue total
      % --- page 2: next species
for ii = 1:nYears
    iYear  = uniqYears{ii};
    fprintf(' %s\n',iYear)
    for kk = 1:nSpecies
        kSpecies = uniqSpecies{kk};
        for jj = 1:nShips
            jShip = uniqShips{jj};
            % get index of all lines with
            % - year = iYear(e.g. 2004) and
            % - species = kSpecies (e.g. ΓΑΡΙΔΑ)
            % - ship = iShip(e.g. T1)
            idx = (strcmp(DATA(:,5),iYear)) &...
                  (strcmp(DATA(:,1),kSpecies)) &...
                  (strcmp(DATA(:,10),jShip));
            % and isolate them as "localDATA"
            localDATA = DATA(idx,:);

            % CATCH!
            % -------
            c0 = sum(str2num(char(localDATA(:,3))));

            % catch
            % ---------
            % columns 1:3
            YEARLY_catch_by_spp_by_ship(ii,jj,kk) = c0; % T1, T2, T2 catch
            % column 4
            YEARLY_catch_by_spp_by_ship(ii,nShips+1 ,kk) =...
               sum(YEARLY_catch_by_spp_by_ship(ii,1:nShips,kk)); % catch total
```

```
            % columns 5:7
            YEARLY_catch_by_spp_by_ship(ii,nShips+1+jj,kk) =...
               YEARLY_catch_by_spp_by_ship(ii,jj,kk)/...
               YEARLY_effort_by_ship(ii,jj); % T1, T2, T2 cpue
            % column 8
            YEARLY_catch_by_spp_by_ship(ii,end,kk) =...
               YEARLY_catch_by_spp_by_ship(ii,nShips+1 ,kk)/...
               sum(YEARLY_effort_by_ship(ii,:)); % cpue total

            % header, since we have the info
            % -------
            % columns 1:3
            HeaderCatch_tmp{1,jj,kk} = [kSpecies ' catch ' jShip ' (kg)'];
            % column 4
            HeaderCatch_tmp{1,nShips+1,kk} =[kSpecies ' catch total (kg)'];
            % columns 5:7
            HeaderCatch_tmp{1,nShips+1+jj,kk} =[kSpecies ' cpue ' jShip];
            % column 8
            HeaderCatch_tmp{1,end,kk} =[kSpecies ' cpue total'];
        end
    end
end
fprintf('Done.\n')

% ---------------------------------------------------------
% make header,flatten multi-dim, attach effort, and export...
% ---------------------------------------------------------
HeaderYear{1} = 'Year';
for ii=1:nShips
    HeaderEffort{1,ii} = [uniqShips{ii} ' effort (days)'];
end
HeaderCatch = [];
for ii=1:size(HeaderCatch_tmp,3)
    HeaderCatch = [HeaderCatch, HeaderCatch_tmp(:,:,ii)];
end
HEAD = [HeaderYear,HeaderEffort,HeaderCatch];

% flatten CATCH
YEARLY_catch_by_spp_by_ship_FLAT = [];
for ii=1:size(YEARLY_catch_by_spp_by_ship,3)
    YEARLY_catch_by_spp_by_ship_FLAT = ...
       [YEARLY_catch_by_spp_by_ship_FLAT, YEARLY_catch_by_spp_by_ship(:,:,ii)];
end

% effort to string
YEARLY_effort_by_ship_str = cell(size(YEARLY_effort_by_ship));
for ii = 1:size(YEARLY_effort_by_ship,1)
   for jj = 1:size(YEARLY_effort_by_ship,2);
       YEARLY_effort_by_ship_str{ii,jj} = num2str(YEARLY_effort_by_ship(ii,jj));
   end
end

% catch flat to string
YEARLY_catch_by_spp_by_ship_FLAT_str = cell(size(YEARLY_catch_by_spp_by_ship_FLAT));
for ii = 1:size(YEARLY_catch_by_spp_by_ship_FLAT,1)
   for jj = 1:size(YEARLY_catch_by_spp_by_ship_FLAT,2);
       YEARLY_catch_by_spp_by_ship_FLAT_str{ii,jj} =...
          num2str(YEARLY_catch_by_spp_by_ship_FLAT(ii,jj));
   end
end

OUT = [HEAD;...
   uniqYears,...
   YEARLY_effort_by_ship_str,...
   YEARLY_catch_by_spp_by_ship_FLAT_str]; % EXPORT THIS


if 1
% ---------------------------------------------------------
% save YEARLY_CATCH_by_species
```

```
% -------------------------------------------------------
% make filename, splitting source file:
[OUTPATH,f2,f3] = fileparts(SRCFILE);
fnameOUT = [f2,'_YEARLY_CATCH_by_species.csv'];

fprintf('\nSaving _YEARLY_CATCH_by_species file ''%s''\n at ''%s'' ...\n',...
   fnameOUT,OUTPATH)

% make fprintf instruction:
nCols = size(OUT,2);
finst = [repmat('%s;',1,nCols-1), '%s\r\n'];
% open (initilize) file with 'w'rite permission
fid = fopen(fullfile(OUTPATH,fnameOUT),'w');
for gg = 1:size(OUT,1)
    fprintf(fid,finst, OUT{gg,:});
end
fclose(fid); % close (release) file
fprintf('Done.\n\n')
% -------------------------------------------------------
% -------------------------------------------------------
end




% -------------------------------------------------------
% yearly catch by species, by Fcode, by ship | and cpue
% -------------------------------------------------------
% see "sizing_vt_FINAL.xlsx" for Fcode groupings
%
% Reminder: uniqFcodes =
% nSpecies x 2 cell, 1st column species, 2nd column its Fcodes
% 'ΓΑΡΙΔΑ'        {8x1 cell}
% 'ΜΠΑΡΜΠΟΥΝΙ'    {4x1 cell}
% 'ΧΤΑΠΟΔΙ'       {8x1 cell}
%
% uniqFcodes{2,1}
% >> ΜΠΑΡΜΠΟΥΝΙ
% uniqFcodes{2,2}
% >> '1G'
%    '1M'
%    '1P'
%    '1PP'

% print Species and Fcodes
cmdthis = [];
for ii=1:nSpecies
    cmdthis = [cmdthis;uniqFcodes(ii,1)];
end
disp(cmdthis)
cmdthis = [];
for ii=1:nSpecies
    cmdthis = [cmdthis;uniqFcodes{ii,2}];
end
disp(cmdthis)


% ============================================
% Manually set Fcode groups here, size should equal nSpecies, and
%  the order of species should match that in the uniqFcodes array.
%
% GROUPING ID's MUST BE CONSECUTIVE PER GROUP, I.E. 1,2,3,...      !!!
% ============================================
Fgroup{1} = [...     % 'ΓΑΡΙΔΑ'
   1   % 'S0/2'
   1   % 'S1/2'
   2   % 'S2/2'
   2   % 'S3/2'
   3   % 'S4/2'
   4   % 'S5/2'
```

```
   5   % 'S5B/2'
   6   % 'S6/2'
       ];

Fgroup{2} = [...     % 'ΜΠΑΡΜΠΟΥΝΙ'
   1   % '1G'
   2   % '1M'
   3   % '1P'
   4   % '1PP'
       ];

Fgroup{3} = [...     % 'ΧΤΑΠΟΔΙ'
   1   % 'TX1'
   1   % 'TX2'
   2   % 'TX3'
   2   % 'TX4'
   3   % 'TX5'
   3   % 'TX6'
   4   % 'TX7'
   4   % 'TX8'
       ];

% check that user's grouping matches nSpecies
if numel(Fgroup)~=nSpecies
   error(['The number of cells in the manually-entered Fgroup array ',...
          'must be equal to number of Species.'])
end

fprintf('Calculating YEARLY_CATCH by Fcode(group) by ship...\n')

% count num of groups per species
for ii=1:numel(Fgroup)
    nGroups(ii) = numel(unique(Fgroup{ii})); %#ok
end

% preallocate output array, each species one cell (nGroups do not necessarily
% match between species, so this can't be a rectangular "normal" double array.
% So, cell:
for ii=1:nSpecies
    % for data
    FC{ii}  = nan(nYears,(nShips*nGroups(ii)*2 + nGroups(ii)*2)); % each species one cell
    % header
    H{ii} = cell(1,(nShips*nGroups(ii)*2 + nGroups(ii)*2));
          % FC =
          %      [9x48 double]    [9x32 double]    [9x32 double]
          % H =
          %      {1x48 cell}    {1x32 cell}    {1x32 cell}
end

% --- FC cell 1:
%     1.  ΓΑΡΙΔΑ group1 catch T1 (kg)
%     2.  ΓΑΡΙΔΑ group2 catch T1 (kg)
%     3.  ΓΑΡΙΔΑ group3 catch T1 (kg)
%     4.  ΓΑΡΙΔΑ group1 catch T2 (kg)
%     5.  ΓΑΡΙΔΑ group2 catch T2 (kg)
%     6.  ΓΑΡΙΔΑ group3 catch T2 (kg)
%     7.  ΓΑΡΙΔΑ group1 catch T3 (kg)
%     8.  ΓΑΡΙΔΑ group2 catch T3 (kg)
%     9.  ΓΑΡΙΔΑ group3 catch T3 (kg)
%     10. ΓΑΡΙΔΑ group1 catch total (kg)
%     11. ΓΑΡΙΔΑ group2 catch total (kg)
%     12. ΓΑΡΙΔΑ group3 catch total (kg)
%     13. ΓΑΡΙΔΑ group1 cpue T1
%     14. ΓΑΡΙΔΑ group2 cpue T1
%     15. ΓΑΡΙΔΑ group3 cpue T1
%     16. ΓΑΡΙΔΑ group1 cpue T2
%     17. ΓΑΡΙΔΑ group2 cpue T2
%     18. ΓΑΡΙΔΑ group3 cpue T2
%     19. ΓΑΡΙΔΑ group1 cpue T3
%     20. ΓΑΡΙΔΑ group2 cpue T3
```

```
%     21. ΓΑΡΙΔΑ group3 cpue T3
%     22. ΓΑΡΙΔΑ group1 cpue total
%     23. ΓΑΡΙΔΑ group2 cpue total
%     24. ΓΑΡΙΔΑ group3 cpue total
% --- FC cell 2: next species
for ii = 1:nYears
    iYear  = uniqYears{ii};
    fprintf(' %s\n',iYear)
    for kk = 1:nSpecies
        kSpecies = uniqSpecies{kk};
        for ff = 1:nGroups(kk)
            % since grouping ID's are consecutive per group, ff *is* the group ID
            %
            % find rows in Fgroup(user) that match this ff loop
            II = Fgroup{kk}==ff;
            % and get their actual Fcode ('TX1-TX2', etc...)
            fcodestr = uniqFcodes{kk,2}(II); % Nx1 cell
                     % 'TX1'
                     % 'Tx2'
            headstr=[];
            for pp = 1:numel(fcodestr)
                headstr = [headstr,fcodestr{pp},'-'];
            end
            % 'TX7-TX8-'
            headstr(end)=[]; % 'TX7-TX8'

            for jj = 1:nShips
                jShip = uniqShips{jj};
                % get index of all lines with
                % - year = iYear(e.g. 2004) and
                % - species = kSpecies (e.g. ΓΑΡΙΔΑ)
                % - ship = iShip(e.g. T1)
                idx = (strcmp(DATA(:,5),iYear)) &...
                      (strcmp(DATA(:,1),kSpecies)) &...
                      (strcmp(DATA(:,10),jShip));
                % and isolate them as "tmpDATA"
                tmpDATA = DATA(idx,:);
                % Now keep only fcode strings (your ff group).
                % Problem is that fcode is not necessarily 1x1 (most ussually
                % is Nx1), so "strcmp(tmpDATA(:,2),fcode)" errors-out. Must
                % separately str_compare tmpDATA(:,2) with each element of fcode...
                III = false(size(tmpDATA,1),1);
                for rr = 1:size(tmpDATA,1)
                    for ss = 1:numel(fcodestr)
                        if strcmp(tmpDATA(rr,2),fcodestr(ss)) == 1
                           III(rr) = true;
                        end
                    end
                end
                % here we are:
                localDATA = tmpDATA(III,:);

                % CATCH!
                % -------
                c00 = sum(str2num(char(localDATA(:,3))));

                % group catch per ship
                % ---------
                % data
                FC{kk}(ii, ff + nGroups(kk)*(jj-1) ) = c00;
                  % where c00: year ii, species kk, group ff, vessel jj | catch

                % header
                H{kk}{1, ff + nGroups(kk)*(jj-1) } =...
                   [kSpecies ' ' headstr ' catch ' jShip ' (kg)'];
                  % 'ΧΤΑΠΟΔΙ     TX7-TX8    catch     T3    (kg)'

                % group catch total per ship
                % ---------
                % data
```

```
                cc = 1:nGroups(kk):(nShips*nGroups(kk));
                FC{kk}(ii, nShips*nGroups(kk) + ff) = sum(FC{kk}(ii,cc + ff-1));
                % header
                H{kk}{1, nShips*nGroups(kk) + ff} =...
                   [kSpecies ' ' headstr ' catch total (kg)'];

                % group cpue per ship
                % ---------
                cccI = [1:nGroups(kk)] + [nGroups(kk)*jj - nGroups(kk)];
                       %1:4 | 5:8 | 9:12, column indices for catch
                cpuI = cccI + (nShips*nGroups(kk)) + nGroups(kk); %column indices for cpue
                % data
                FC{kk}(ii, cpuI) = FC{kk}(ii, cccI) / YEARLY_effort_by_ship(ii,jj);
                % header
                % it's complex here, because we assign all values in a vector (cccI-cpuI),
                % which tranverses groups, but the entire loop is built on a specific
                % group (i.e., headstr does not contain all group strings to deal them
                % accross cccI-cpuI)
                %
                % An ugly hack is to repeat the headstr loop locally:
                for ff_ = 1:nGroups(kk)
                    II_ = Fgroup{kk}==ff_;
                    fcodestr_ = uniqFcodes{kk,2}(II_);
                    headstr_=[];
                    for pp_ = 1:numel(fcodestr_)
                        headstr_ = [headstr_,fcodestr_{pp_},'-'];
                    end
                    % 'TX7-TX8-'
                    headstr_(end)=[]; % 'TX7-TX8'
                    H{kk}{1, cpuI(ff_)} = [kSpecies ' ' headstr_ ' cpue ' jShip];

                end

                % group cpue total
                % ---------
                % data
                FC{kk}(ii,nShips*nGroups(kk)*2 + nGroups(kk) + ff) =...
                   FC{kk}(ii, nShips*nGroups(kk) + ff) / sum(YEARLY_effort_by_ship(ii,:));
                % header
                H{kk}{1,nShips*nGroups(kk)*2 + nGroups(kk) + ff} =...
                   [kSpecies ' ' headstr ' cpue total'];
           end
        end
    end
end

% --------------------------------------------------------
% flatten header and data arrays, convert data to strings
% --------------------------------------------------------
HEADD = [];
DATT = [];
for ii=1:numel(H)
    HEADD = [HEADD, H{ii}];
    DATT = [DATT, FC{ii}];
end
HEADD = [HeaderYear, HeaderEffort, HEADD];

DATT_str = cell(size(DATT));
for ii = 1:size(DATT,1)
   for jj = 1:size(DATT,2);
       DATT_str{ii,jj} = num2str(DATT(ii,jj));
   end
end

% merge
OUTT = [HEADD; uniqYears, YEARLY_effort_by_ship_str, DATT_str];

if 1
% --------------------------------------------------------
% save FC/H = _YEARLY_CATCH_by_fcode
```

```
% ---------------------------------------------------------
% make filename, splitting source file:
[OUTPATH,f2,f3] = fileparts(SRCFILE);
fnameOUTT = [f2,'_YEARLY_CATCH_by_fcode.csv'];

fprintf('\nSaving YEARLY_CATCH_by_fcode file ''%s''\n at ''%s'' ...\n',...
   fnameOUTT,OUTPATH)

% make fprintf instruction:
nCols = size(OUTT,2);
finst = [repmat('%s;',1,nCols-1), '%s\r\n'];
% open (initilize) file with 'w'rite permission
fid = fopen(fullfile(OUTPATH,fnameOUTT),'w');
for gg = 1:size(OUTT,1)
    fprintf(fid,finst, OUTT{gg,:});
end
fclose(fid); % close (release) file
fprintf('Done.\n\n')
% ---------------------------------------------------------
end
```

Appendix C: read_dlm_file.m

```
function out = read_dlm_file(srcfile,varargin)
%READ_DLM_FILE Read plain text file using custom delimiter.
%
% READ_DLM_FILE reads a delimited (plain text) file SRCFILE, using the custom
% delimiter specified in the 2nd input argument. If no delimiter is supplied,
% it defaults to comma. File contents are returned to OUT as cellstrings.
%
% Syntax
%   OUT = READ_DLM_FILE(SRCFILE)
%   OUT = READ_DLM_FILE(SRCFILE,DELIMITER)
%
% Input
%   SRCFILE   : String with absolute path to source file.
%   DELIMITER : String with an appropriate field delimiter.
%               Standard delimiters are:
%               ','  Comma
%               '\b' Backspace
%               '\n' New line
%               '\r' Carriage return
%               '\t' Tab
%               but can use any arbitrary string, e.g. '?'.
%
% Output
%   OUT       : MxN cellstring array, holding the SRCFILE contents.
%               All cells are strings.
%
% Examples
%   out = read_dlm_file('/path/to/file/rawdata.txt')
%   out = read_dlm_file('/path/to/file/rawdata.csv')
%   out = read_dlm_file('/path/to/file/rawdata.csv',',')
%   out = read_dlm_file('/path/to/file/rawdata.xyz','\t')

% programming: V.Trygonis
% version:     1.0

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% --------------------------
% error checks
% --------------------------
% more than 2 input arguments?
if numel(varargin)>1
   error('Too many input arguments.')
end

% is 1st argument a string?
if ~ischar(srcfile) || size(srcfile,1) ~=1 || isempty(strtrim(srcfile))
   error('First input argument must be a filename string.')
end

% does input file exist?
if exist(srcfile,'file') ~= 2
   error('Input file ''%s'' does not exist.',srcfile)
end

% parse optional delimiter argin, default to comma if not provided
if isempty(varargin)
   % delimiter not specified, use default
   delim = ',';
else
   if ~ischar(varargin{1}) || size(varargin{1},1) ~=1 || isempty(strtrim(varargin{1}))
      % delimiter specified, but is not a string
      error('Second input argument must be a string that specifies a file delimiter.')
   else
      % user-input delimiter, e.g. '\t' or ';'
      delim = varargin{1};
   end
end


% --------------------------
% read file
% --------------------------
% open file, read-only mode
  fid = fopen(srcfile,'r');
% read <formatted> data including whitespace ('%c' flag)
  oneLiner = fscanf(fid,'%c');
% close file
  fclose(fid);
% scan "oneLiner" as plain string ('%s') and parse end of line ('\n')
  M = strread(oneLiner,'%s','delimiter','\n');  % {nRows x 1} CELL
  % M holds the entire file data, with each file row in a separate line

% scan each row of M and separate cell entries
```

```
for iRow = 1:length(M)
    tempLine  = strread(M{iRow},'%s','delimiter',delim); % {nCols x 1}, CELL

    % scan each tempLine cell and put it to its proper place in the output aray
    for jj = 1:length(tempLine)
        out{iRow,jj} = tempLine{jj};        %#ok OUT, cell of strings
    end
end
```

Appendix D: GAMs script

```
# Apply GAM models to CPUE per species and Fcode
#
# programming: I.Anastasaki
# version: 1.0
# R package dependencies: mgcv



setwd("/Users/maria-ioanastasaki-lampsakinou/Desktop/GAM")
data= read.table("Rdata_all.csv", head=TRUE, sep = ";")
str(data)

library(mgcv)
library(RColorBrewer)
library(extrafont)

#download derivatives

tmpf <- tempfile()
download.file("https://gist.github.com/gavinsimpson/e73f011fdaaab4bb5a30/raw/82118ee30c9ef1254
795d2ec6d356a664cc138ab/Deriv.R",
              tmpf, method="auto")
source(tmpf)
ls()

#set alpha as value

a= 0.5

#peneus notialis

#gam
gam1= gam(P~s(Year, fx = TRUE, k=6), data = data)
summary (gam1)
AIC (gam1)

par(mar=c(5,5,5,4))
gam.check (gam1)


gam1.d<- Deriv(gam1, n=200)
pdat1<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot  (gam1,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,  shade.col="#F2E5C0",  col="#DB720F",
seWithMean = TRUE, scale = 0)

CI1 <- confint(gam1.d, alpha = a)
S1 <- signifD(gam1, gam1.d$Year$deriv, CI1$Year$upper, CI1$Year$lower, eval = 0)

plot(gam1.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Penaeus notialis GAM", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam1,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#F2E5C0", col="#DB720F", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Penaeus notialis", font=3, cex=0.8)

par(mar=c(6,7,12,5))
```

```
par(new=T)
plot(gam1.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()


## GAM by Fcode

#P1
gam1_1= gam(P1~s(Year, fx = TRUE, k=6), data = data)
summary (gam1_1)
AIC (gam1_1)

par(mar=c(5,5,5,4))
gam.check (gam1_1)


gam1_1.d<- Deriv(gam1_1, n=200)
pdat1_1<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam1_1, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#F2E5C0", col="#DB720F",
seWithMean = TRUE, scale = 0)

CI1_1 <- confint(gam1_1.d, alpha = a)
S1_1 <- signifD(gam1_1, gam1_1.d$Year$deriv, CI1_1$Year$upper, CI1_1$Year$lower, eval = 0)

plot(gam1_1.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group P1", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam1_1, ylab="", xlab="", cex.axis= 0.8, residuals=TRUE, pch=1, las=1, shade=TRUE,
shade.col="#F2E5C0", col="#DB720F", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group P1", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam1_1.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#P2
gam1_2= gam(P2~s(Year, fx = TRUE, k=6), data = data)
summary (gam1_2)
AIC (gam1_2)

par(mar=c(5,5,5,4))
gam.check (gam1_2)


gam1_2.d<- Deriv(gam1_2, n=200)
pdat1_2<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam1_2, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#F2E5C0", col="#DB720F",
seWithMean = TRUE, scale = 0)

CI1_2 <- confint(gam1_2.d, alpha = a)
S1_2 <- signifD(gam1_2, gam1_2.d$Year$deriv, CI1_2$Year$upper, CI1_2$Year$lower, eval = 0)
```

```
plot(gam1_2.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group P2", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam1_2,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#F2E5C0", col="#DB720F", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group P2", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam1_2.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#P3

gam1_3= gam(P3~s(Year, fx = TRUE, k=6), data = data)
summary (gam1_3)
AIC (gam1_3)

par(mar=c(5,5,5,4))
gam.check (gam1_3)


gam1_3.d<- Deriv(gam1_2, n=200)
pdat1_3<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot  (gam1_3,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,  shade.col="#F2E5C0",  col="#DB720F",
seWithMean = TRUE, scale = 0)

CI1_3 <- confint(gam1_3.d, alpha = a)
S1_3 <- signifD(gam1_3, gam1_3.d$Year$deriv, CI1_3$Year$upper, CI1_3$Year$lower, eval = 0)

plot(gam1_3.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group P3", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam1_3,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#F2E5C0", col="#DB720F", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group P3", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam1_3.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#P4
gam1_4= gam(P4~s(Year, fx = TRUE, k=6), data = data)
summary (gam1_4)
AIC (gam1_4)

par(mar=c(5,5,5,4))
gam.check (gam1_4)


gam1_4.d<- Deriv(gam1_4, n=200)
```

```
pdat1_4<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam1_4, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#F2E5C0", col="#DB720F",
seWithMean = TRUE, scale = 0)

CI1_4 <- confint(gam1_4.d, alpha = a)
S1_4 <- signifD(gam1_4, gam1_4.d$Year$deriv, CI1_4$Year$upper, CI1_4$Year$lower, eval = 0)

plot(gam1_4.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group P4", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam1_4, ylab="", xlab="", cex.axis= 0.8, residuals=TRUE, pch=1, las=1, shade=TRUE,
shade.col="#F2E5C0", col="#DB720F", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group P4", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam1_4.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#P5
gam1_5= gam(P5~s(Year, fx = TRUE, k=6), data = data)
summary (gam1_5)
AIC (gam1_5)

par(mar=c(5,5,5,4))
gam.check (gam1_5)


gam1_5.d<- Deriv(gam1_5, n=200)
pdat1_5<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam1_5, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#F2E5C0", col="#DB720F",
seWithMean = TRUE, scale = 0)

CI1_5 <- confint(gam1_5.d, alpha = a)
S1_5 <- signifD(gam1_5, gam1_5.d$Year$deriv, CI1_5$Year$upper, CI1_5$Year$lower, eval = 0)

plot(gam1_5.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group P5", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam1_5, ylab="", xlab="", cex.axis= 0.8, residuals=TRUE, pch=1, las=1, shade=TRUE,
shade.col="#F2E5C0", col="#DB720F", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group P5", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam1_5.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()
```

```
#P6
gam1_6= gam(P6~s(Year, fx = TRUE, k=6), data = data)
summary (gam1_6)
AIC (gam1_6)

par(mar=c(5,5,5,4))
gam.check (gam1_6)


gam1_6.d<- Deriv(gam1_2, n=200)
pdat1_6<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam1_6, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#F2E5C0", col="#DB720F",
seWithMean = TRUE, scale = 0)

CI1_6 <- confint(gam1_6.d, alpha = a)
S1_6 <- signifD(gam1_6, gam1_6.d$Year$deriv, CI1_6$Year$upper, CI1_6$Year$lower, eval = 0)

plot(gam1_6.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group P6", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam1_6, ylab="", xlab="", cex.axis= 0.8, residuals=TRUE, pch=1, las=1, shade=TRUE,
shade.col="#F2E5C0", col="#DB720F", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group P6", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam1_6.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

##########################################


#mullus surmuletus
gam2= gam(M ~ s(Year, fx = TRUE, k=7), data = data)
summary (gam2)
AIC (gam2)

par(mar=c(5,5,5,4))
gam.check (gam2)


gam2.d<- Deriv(gam2, n=200)
pdat2<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam2, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#FEE8D6", col="#984A4E",
seWithMean = TRUE, scale = 0)

CI2 <- confint(gam2.d, alpha = a)
S2 <- signifD(gam2, gam2.d$Year$deriv, CI2$Year$upper, CI2$Year$lower, eval = 0)

plot(gam2.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Mullus surmuletus GAM", height = 12, width = 17, units = 'cm', res = 600)
```

```
par(mar=c(15,7,3,5))
plot(gam2,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#FEE8D6", col="#984A4E", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Mullus surmuletus", font=3, cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam2.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

## GAM by Fcode

#M1

gam2_1= gam(M1 ~ s(Year, fx = TRUE, k=7), data = data)
summary (gam2_1)
AIC (gam2_1)

par(mar=c(5,5,5,4))
gam.check (gam2_1)


gam2_1.d<- Deriv(gam2_1, n=200)
pdat2_1<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot  (gam2_1,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,  shade.col="#FEE8D6",  col="#984A4E",
seWithMean = TRUE, scale = 0)

CI2_1 <- confint(gam2_1.d, alpha = a)
S2_1 <- signifD(gam2_1, gam2_1.d$Year$deriv, CI2_1$Year$upper, CI2_1$Year$lower, eval = 0)

plot(gam2_1.d, sizer = TRUE, alpha = a)

#both plots

jpeg("Size group M1", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam2_1,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#FEE8D6", col="#984A4E", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group M1", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam2_1.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#M2

gam2_2= gam(M2 ~ s(Year, fx = TRUE, k=7), data = data)
summary (gam2_2)
AIC (gam2_2)

par(mar=c(5,5,5,4))
gam.check (gam2_2)


gam2_2.d<- Deriv(gam2_2, n=200)
pdat2_2<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))
```

```
#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam2_2, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#FEE8D6", col="#984A4E",
seWithMean = TRUE, scale = 0)

CI2_2 <- confint(gam2_2.d, alpha = a)
S2_2 <- signifD(gam2_2, gam2_2.d$Year$deriv, CI2_2$Year$upper, CI2_2$Year$lower, eval = 0)

plot(gam2_2.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group M2", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam2_2, ylab="", xlab="", cex.axis= 0.8, residuals=TRUE, pch=1, las=1, shade=TRUE,
shade.col="#FEE8D6", col="#984A4E", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group M2", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam2_2.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()


#M3

gam2_3= gam(M3 ~ s(Year, fx = TRUE, k=7), data = data)
summary (gam2_3)
AIC (gam2_3)

par(mar=c(5,5,5,4))
gam.check (gam2_3)


gam2_3.d<- Deriv(gam2_3, n=200)
pdat2_3<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam2_3, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#FEE8D6", col="#984A4E",
seWithMean = TRUE, scale = 0)

CI2_3 <- confint(gam2_3.d, alpha = a)
S2_3 <- signifD(gam2_3, gam2_3.d$Year$deriv, CI2_3$Year$upper, CI2_3$Year$lower, eval = 0)

plot(gam2_3.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group M3", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam2_3, ylab="", xlab="", cex.axis= 0.8, residuals=TRUE, pch=1, las=1, shade=TRUE,
shade.col="#FEE8D6", col="#984A4E", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group M3", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam2_3.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()
```

```
#M4

gam2_4= gam(M4 ~ s(Year, fx = TRUE, k=7), data = data)
summary (gam2_4)
AIC (gam2_4)

par(mar=c(5,5,5,4))
gam.check (gam2_4)


gam2_4.d<- Deriv(gam2_4, n=200)
pdat2_4<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam2_4, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#FEE8D6", col="#984A4E",
seWithMean = TRUE, scale = 0)

CI2_4 <- confint(gam2_4.d, alpha = a)
S2_4 <- signifD(gam2_4, gam2_4.d$Year$deriv, CI2_4$Year$upper, CI2_4$Year$lower, eval = 0)

plot(gam2_4.d, sizer = TRUE, alpha = a)

#both plots
jpeg("Size group M4", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam2_4, ylab="", xlab="", cex.axis= 0.8, residuals=TRUE, pch=1, las=1, shade=TRUE,
shade.col="#FEE8D6", col="#984A4E", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group M4", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam2_4.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()


###########################################

#octopus vulgaris
gam3= gam(O ~ s(Year, fx = TRUE, k=6), data = data)
summary (gam3)
AIC (gam3)

par(mar=c(5,5,5,4))
gam.check (gam3)


gam3.d<- Deriv(gam3, n=200)
pdat3<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot (gam3, residuals=TRUE, pch=1, las=1, shade=TRUE, shade.col="#D1E7F2", col="#397883",
seWithMean = TRUE, scale = 0)

CI3 <- confint(gam3.d, alpha = a)
S3 <- signifD(gam3, gam3.d$Year$deriv, CI3$Year$upper, CI3$Year$lower, eval = 0)

plot(gam3.d, sizer = TRUE, alpha = a)
```

```
#both plots
jpeg("Octopus vulgaris GAM", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam3,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#D1E7F2", col="#397883", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Octopus vulgaris", font= 3, cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam3.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

# GAM by Fcode

#O1

gam3_1= gam(O1 ~ s(Year, fx = TRUE, k=6), data = data)
summary (gam3_1)
AIC (gam3_1)

par(mar=c(5,5,5,4))
gam.check (gam3_1)


gam3_1.d<- Deriv(gam3_1, n=200)
pdat3_1<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot  (gam3_1,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,  shade.col="#D1E7F2",  col="#397883",
seWithMean = TRUE, scale = 0)

CI3_1 <- confint(gam3_1.d, alpha = a)
S3_1 <- signifD(gam3_1, gam3_1.d$Year$deriv, CI3_1$Year$upper, CI3_1$Year$lower, eval = 0)

plot(gam3_1.d, sizer = TRUE, alpha = a)


#both plots
jpeg("Size group O1", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam3_1,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#D1E7F2", col="#397883", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group O1", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam3_1.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#O2

gam3_2= gam(O2 ~ s(Year, fx = TRUE, k=6), data = data)
summary (gam3_2)
AIC (gam3_2)

par(mar=c(5,5,5,4))
gam.check (gam3_2)
```

```
gam3_2.d<- Deriv(gam3_2, n=200)
pdat3_2<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot  (gam3_2,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,  shade.col="#D1E7F2",  col="#397883",
seWithMean = TRUE, scale = 0)

CI3_2 <- confint(gam3_2.d, alpha = a)
S3_2 <- signifD(gam3_2, gam3_2.d$Year$deriv, CI3_2$Year$upper, CI3_2$Year$lower, eval = 0)

plot(gam3_2.d, sizer = TRUE, alpha = a)


#both plots
jpeg("Size group O2", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam3_2,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#D1E7F2", col="#397883", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group O2", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam3_2.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#O3

gam3_3= gam(O3 ~ s(Year, fx = TRUE, k=6), data = data)
summary (gam3_3)
AIC (gam3_3)

par(mar=c(5,5,5,4))
gam.check (gam3_3)


gam3_3.d<- Deriv(gam3_3, n=200)
pdat3_3<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot  (gam3_3,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,  shade.col="#D1E7F2",  col="#397883",
seWithMean = TRUE, scale = 0)

CI3_3 <- confint(gam3_3.d, alpha = a)
S3_3 <- signifD(gam3_3, gam3_3.d$Year$deriv, CI3_3$Year$upper, CI3_3$Year$lower, eval = 0)

plot(gam3_3.d, sizer = TRUE, alpha = a)


#both plots
jpeg("Size group O3", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam3_3,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#D1E7F2", col="#397883", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group O3", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
```

```
plot(gam3_3.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()

#O4

gam3_4= gam(O4 ~ s(Year, fx = TRUE, k=6), data = data)
summary (gam3_4)
AIC (gam3_4)

par(mar=c(5,5,5,4))
gam.check (gam3_4)


gam3_4.d<- Deriv(gam3_4, n=200)
pdat3_4<- with(data, data.frame(Year = seq(min(Year), max(Year), length = 200)))

#plots

#individual plots
par(mar=c(5,5,5,4))
plot  (gam3_4,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,  shade.col="#D1E7F2",  col="#397883",
seWithMean = TRUE, scale = 0)

CI3_4 <- confint(gam3_4.d, alpha = a)
S3_4 <- signifD(gam3_4, gam3_4.d$Year$deriv, CI3_4$Year$upper, CI3_4$Year$lower, eval = 0)

plot(gam3_4.d, sizer = TRUE, alpha = a)


#both plots
jpeg("Size group O4", height = 12, width = 17, units = 'cm', res = 600)
par(mar=c(15,7,3,5))
plot(gam3_4,  ylab="",  xlab="",  cex.axis=  0.8,  residuals=TRUE,  pch=1,  las=1,  shade=TRUE,
shade.col="#D1E7F2", col="#397883", seWithMean = TRUE, scale = 0)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "s(Year,5)", line=2.5, cex=0.8)
mtext(side=3, "Size group O4", cex=0.8)

par(mar=c(6,7,12,5))
par(new=T)
plot(gam3_4.d, ylab="", xlab="", cex.axis= 0.8, main= NULL, sizer = TRUE, alpha = a)
mtext(side=1, "Year", line=2, cex=0.8)
mtext(side=2, "f'(x)", line=2.5, cex=0.8)
dev.off()


################################################
```