



NAFO Scientific Council (SC) Working Group on Ecosystem Science and Assessment (WGESA)  
18-27 November 2014

Spatial and seasonal fleet activity and cod distribution in Flemish Cap

by

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**Abstract**

The aim of this analysis is to describe the spatial and seasonal fleet activity and cod distribution in the Flemish Cap area in the period 2008-2013. Especial attention is paid to the relative distribution of mature and immature sub-stocks, as well as individuals bellow 41 cm size (Minimum Landing Size, MLS). The following data sources were analyzed for different periods depending on the data availability and the aim followed: Daily Catch Reports (DCR), Vessel Monitoring System (VMS), Spanish Scientific Observers, EU Flemish Cap surveys.

In relation to spatial and seasonal fishing activity the results shows that the effort was very low in the period 2008-2009. In these years as the cod fishery was closed, the main fisheries were shrimp and redfish and were carried out in the western part of the bank. The shrimp fishery in depth more than 300 meters and redfish in depth less than 300 meters. When cod fishery was re-opened in 2010, a significant increase of fishing activity in deeper areas of the East and West of Flemish Cap was observed.

Regarding the spatial and seasonal distribution of catches, in 2012-2013 the highest cod CPUE based on DCR data were found in the south-west area of Flemish Cap. However, in the same period, the Spanish fleet activity showed a displacement from south-west in 2012 to eastern and shallower waters in 2013 (200-300 m). This change in distribution was associated with a change in size distribution of catches to smaller individuals, from around 60 cm in 2012 to 40 cm in 2013. However, the EU survey showed in these years a constant pattern in distribution of cod in the bank, with fishes being distributed evenly around the center of the bank.

The spatial distribution of mature and immature cod female individuals did not exhibit any specific spatial area where spawners or juveniles are more abundant. Results show that despite the length 50% maturity changes over time, the sampled population maintains the same proportion of mature and immature individuals in the time series.

The proportion of cod below the MLS (41 cm) has shown a peak in year 2011 due to the good recruitments in the period 2009-2012, but the number of bigger individuals is stable in the time series. Concerning the spatial distribution of concentration of cod below the MLS, as in the case of mature and immature individuals, there is not a clear spatial pattern but the cod distribution by depth seems to have a general pattern with fish less than 50 cm are at less than 400 m depth and fish with more than 50 cm are at depth more than 400 m.

**Introduction**

The Flemish Cap (NAFO Division 3M) is a continental fragment that is separated from the Grand Banks of Newfoundland by a rift zone known as Flemish Pass (Figure 1). It is about 200 km in radius with the shallow parts

being situated at 47° N, 45° W. The Flemish Cap Bank is located about 600 km to the East of Newfoundland within international waters (NAFO Division 3M). Depths range is between 125 m and 700 m. At the Southern rim of the bank there is a steep slope. To the West, water depth gradually increases to about 350 m, before the 1100 m deep Flemish Pass is reached. Flemish Cap is an oceanic bank area which comprises 4870 km<sup>2</sup> within the bathymetric contours of 200 m depth (Stein, 2007).

The waters of the Flemish Cap have been noted as excellent fishing waters from many decades ago; cod, redfish and American plaice have traditionally been fished in this area and, more recently, Greenland halibut, grenadiers and shrimp. Species in Flemish Cap underwent deep changes in abundance in the last twenty years (Pérez-Rodríguez *et al.*, 2012), as recorded by the EU bottom trawl survey of Flemish Cap and confirmed for the main commercial species by the NAFO Scientific Council (SC). Vazquez (2012) point it out that the most visible changes were the collapse of cod and American plaice stocks in 1993, the increase of the shrimp abundance that allowed an intense fishery between 1993-2004, the spread of Greenland halibut over the bank to occupy zones left by cod when restricted to shallowest part of the bank, and the remarkable increase of redfish. Since 2005, most of these species have reverted to their former abundance; only American plaice has remained in the same state. In 2010 the cod fishery was reopened and in 2011 the shrimp fishery was closed.

Northwest Atlantic Fisheries Organization (NAFO) regulates all marine fisheries resources, except salmon, tunas, marlins, whales and sedentary species (e.g. certain species of shellfish except shrimp) in the NAFO Regulatory Area (NRA). The NRA is that part of the Convention Area which lies beyond the areas in which Coastal States exercise fisheries jurisdiction (Figure 1).

Within the NAFO Regulatory Area (NRA) there are three main fisheries: the groundfish (GRO - primarily in Div. 3KLMNO), shrimp (PRA - primarily in Div. 3LM) and pelagic redfish fisheries (REB - primarily in Div. 1F and 2J). The shrimp fishery in Div. 3M has been under moratorium since 2011. The shrimp fishery in Div. 3L will be under no directed fishery in 2015. And in the last years the pelagic redfish fishery (Div 1F and 2J) was closed. The groundfish fishery should be divided into different fisheries depending on the target species, area, depth and gear (mesh size). Based on these aspects there are in the NRA the following groundfish fisheries:

- Greenland halibut (*Reinhardtius hippoglossoides*) fishery in Divisions 3LMNO at more than 600 m depth with demersal bottom trawl 130 mm mesh size gear.
- Redfish (*Sebastes spp*) fishery in Divisions 3LMNO with demersal bottom trawl 130 mm mesh size gear in the 200-600 m depth strata.
- Cod (*Gadus morhua*) fishery in Division 3M at depths between 150-550 m with 130 mm mesh size bottom trawl gear.
- Skates (*Raja spp*) fishery in Divisions 3NO with demersal bottom trawl 280 mm mesh size gear at less than 200 m depth.

At present, three different fisheries are being carried out in Flemish Cap: the Greenland halibut, the redfish and the cod fisheries. The first one is carried out at more than 600 m depth while the last two are carrying out at 200-600 m deep. Focusing on cod fishery, in the early sixteenth century, fishermen from England, France, Spain and Portugal discovered the Grand Banks waters to fish for cod. The cod fishery on Flemish Cap has traditionally been a directed fishery by Portuguese trawlers and gillnetters, Spanish pair trawlers and Faroese longliners in the second half of the twentieth century. Since 1974, when a TAC was established for the first time, estimated catches ranged from 48000 tons in 1989 to a minimum value of 5 tons in 2004. Annual catches were about 30000 tons in the late 1980's (notwithstanding the fact that the fishery was under moratorium in 1988-1990) and diminished since then as a consequence of the stock decline. The fishery was closed in 1999 and this stock had been on fishing moratorium since 1999 to 2009 following its collapse, which has been attributed to three simultaneous circumstances: a stock decline due to overfishing, an increase in catchability at low abundance levels and a series of very poor recruitments starting in 1993. The good shape of the stock led to a reopening of the fishery with 5500 tons of catch in 2010. The actual fishery is composed mainly by trawlers from Faroe Islands (Denmark), Portugal, Spain, Russia, Estonia, United Kingdom and Norway. TACs of 10000 tons in 2011, 9280 tons in 2012, 14113 tons in 2013 and 14521 tons in 2014 were established (González-Troncoso *et al.* 2014).

The NAFO Conservation and Enforcement Measure (NAFO, 2014) collects all management measures for NAFO fisheries. The main measures for managing the cod fishery are a gear mesh size of 130 mm codend and a Minimum Landing Size (MLS) for the Atlantic Cod (*Gadus Morhua*) of 41 cm.

The spawning season of the Flemish Cap cod is known to be short in time and the earliest in the year of all cod stocks in the Northwest Atlantic (Myers *et al.*, 1993); it occurs around March while the Flemish Cap survey is carried out normally in July. The period 1972-1992 presents a quite constant age of 50% maturity around 5 years old. From 1993 till 2002 this age decreased till 3 years old. Since then increased till 2011 where the age of 50% maturity was around 4 years old. In the last two years the 50% maturity age decreased until 3.4 (González-Costas and González-Troncoso, 2014).

The aim of this analysis is to describe the spatial and seasonal fleet activity and cod distribution in the Flemish Cap area in the last years. One of the objectives of this study was to try to know where the spawning areas of Cod 3M stock are and if there is any spatial pattern where mature or immature individuals are located in different spatial areas.

### Material and Methods

To analyze the spatial and seasonal cod fishing activity and the seasonal distribution of cod in Flemish Cap the Daily Catch Reports (DCR), Vessel Monitoring System (VMS), Spanish Scientific Observers and Flemish Cap surveys data were analyzed. All these data sources didn't cover the same time period, and were used differently depending on the pursued goal. The area that embrace the distribution of cod in the Flemish Cap (up to 600 m depth) was only fully covered by the EU survey and the Spanish Scientific Observers databases, while the DCR and VMS databases provided information up to 500 m depth due to the 600-meter isobaths are not completely defined.

The VMS (2008-2013) and Spanish Observers data (2007-2008, 2010-2013) were used to analyze the spatial and seasonal fishing activity. The VMS data represent the entire effort of all countries in Division 3M, while Spanish observers data only represent a percentage of the effort made by the Spanish fleet in this Division.

One of the first steps to look for the spawning and recruitment areas is to know the length distribution of cod fishes in the Flemish Cap surveys in different fishing grounds and depths. Maturity at length and age of the Flemish Cap female cod is determined by a histological method since 1990 at summer, when the EU-survey is carried out (Saborido, 1997). Maturity at Age is an important parameter for the stock assessment and it is calculated yearly for this stock. The parameter of length at 50% maturity by year will be used to disaggregate each year's length distribution in "immature" and "mature" individuals and they are plotted to see if there is any spatial pattern.

Next there is a description of each data analyzed and the information provided by each data source.

**Daily Catch Reports (DCR):** The Fisheries Commission and Scientific Council Ad hoc Working Group on Catch Reporting (FC-SC WG-CR) evaluated the data sources and discussed their individual limitations and potentials for utility to validate catch data and/or generate catch estimates (NAFO FC-SC 2014). The FC-SC WG-CR recognized that in their respective current form, Daily Catch Reports (DCR) data is the most useful because of the high level of compliance of the fishing vessels in submitting the DCR and the level of detail which they provide – daily catch by species and by Division.

Since 2011, it has been a requirement for fishing vessels to transmit Daily Catch Report (DCR) by species and by Division. Except in the first few months of 2011 (when fishing vessels were still in the learning curve in fulfilling the daily CAT requirement), there is a generally very good compliance among the vessels in transmitting the DCR report. To avoid the 2011 problems, it was decided to analyze in the present study only the DCR for 2012 and 2013.

**Vessel monitoring system (VMS):** Vessel monitoring system (VMS) data consists of positional and navigational (heading and speed) information, transmitted via satellite from fishing vessels to fishery monitoring centers. Vessels within the NRA are required to automatically transmit their position at regular intervals since 2003. In January 2004, the reporting interval changed from every six hours to every two hours and since 2011 the reporting is hourly. In 2005 there were some transmission problems with the VMS data.

In the present study we have used only the 2008-2013 VMS data in NAFO Division 3M at less than 500 m depth. The main reason to choose this period is to compare distribution of commercial fleet in that period when the 3M cod fishery was closed (2008-2009) and opened (2010-2013). In Division 3M shallower than 500 m depth, in 2008-2009 opened fisheries were shrimp and redfish; In 2010 shrimp, cod and redfish; and since 2011 as the shrimp fishery was closed there have been only two, redfish and cod fisheries.

The method to analyze the DCR and VMS data was the same use by Hintzen *et al.* (2013). Catches from the DCR and effort from the VMS are accounted on grids of 0.250\*0.125 minutes. Fishing days were determined per VMS ping activity based on speed. Between 0.5 and 5.2 knots means fishing. The time period per ping is given in minutes. Divided by (60 \*24) gives days at sea fishing.

**Spanish Scientific Observer data:** Scientific Observers on board of the Spanish commercial vessels data from Instituto Español de Oceanografía (IEO) have been used for the analysis. Besides recording catches, discards and effort, these observers carried out biological sampling of the main species taken in the catch. Most of Spanish vessels are bottom trawl freezer longer than 40 m fishing in international waters. The periods 2007-2008 and 2010-2013 was chosen to analyze these data. The analyzed periods for the Scientific Observers (2007-2008, 2010-2013) and VMS data (2008-2013) are different because the intention was to have at least two years of information when the 3M Cod Fishery was closed. As the observers data for 2009 are not available an extra back year (2007) was considered to fulfill the two years criteria. A set of hauls in depths lower than 600 m was selected and cod length samples by haul and depth were analyzed.

The Spanish fleet is one of the most important working in NAFO fisheries including the 3M cod fishery. The 14% of the total 3M cod TAC is caught by the Spanish fleet and the Spanish Scientific Observers program covers around 20% of the Spanish total effort in the NRA. Spanish Scientific Observers data can give a fairly clear picture of the total fishing activity in NAFO Division 3M and particularly in the cod fishery catch and effort distribution.

Twelve vessels were monitored; eleven of them single bottom trawlers and one of them pair bottom trawler. Depending on the target species, two different mesh sizes were used in depths lower than 600 m; a mesh size of 40 mm for shrimp fisheries and a mesh size of 130 mm for cod and redfish fisheries. The hauls made with 130 mm mesh size were divided in cod and redfish fisheries based on which species was the greater percentage of the catch. A summary of the number of trips and hauls by year and fishery is presented in Table 1.

After a revision of all data, some very high cod catches were detected in the database. After checking this information we think that these data may be measurement errors and it was decided to remove them.

**EU Flemish Cap Survey:** EU Flemish Cap Survey has been taken place since 1988. This survey is carried out by the Instituto Español de Oceanografía (IEO), Instituto de Investigaciones Marinas (IIM) and Instituto Portugues do Mar e da Atmosfera (IPMA) with EU financial support. The results of the Surveys are presented annually in the NAFO Scientific Council and they are published as research papers in the SCR Doc. series. More information in relation to the protocols and the detailed results of the survey are in the reports “Protocols of the EU bottom trawl survey of Flemish Cap” (Vazquez *et al.*, 2014) and “Results from Bottom Trawl Survey on Flemish Cap of July 2013” (Mandado, 2014).

A stratified random trawl survey data from 2007 to 2013 were selected in this document to analyze the spatial distribution, total catch and length distribution of cod and to compare these results with the commercial information (VMS, DCR and Spanish Scientific Observers). For each year and set, the following information was available: total catches by species, length distribution by sex, spatial position and depth range. A summary of the Flemish Cap Survey data about the number of hauls, cod catches and cod measured in the length distribution is presented in Table 2.

Statistical analysis was executed using R software and the main results were plotted using Free and Open Source Geographic Information System (QGIS). The Coordinate Reference System (CRS) used for all figures was the WGS 84 projection and coordinate system.

## Results

### 1. Spatial and Seasonal Fishing Activity

#### 1.1. Fishing activity based on VMS data

Figure 2 shows the effort in fishing days in Division 3M at less than 500 m by 270 km<sup>2</sup> cells and year for the period 2008-2013. It can be observed that in years 2008-2009 the effort was lower than in the rest of the years and was carried out mainly in the Western part and close to the 500 m isobath. In the period 2010-2013 the effort by year was higher and more scattered all around the bank except in the central part where the depth is less.

Figure 3 presents the effort distribution by quarters and years. For year 2008 there is not data available to study the quarter distribution and in 2009 there is information only for the first and second quarter. In the period 2010-2013, when the cod fishery was opened, it can be observed a general pattern with the effort more concentrated in the Western part of the bank in the first quarter, more scattered all around the bank in the second and third quarter and more concentrated in the South Eastern part in the last quarter. This pattern is clearer in the years 2012 and 2013.

#### 1.2. Fishing activity based on Spanish Scientific Observers data

Fishing activity information in relation to mesh size and depth was available from the Spanish Scientific Observers data. The effort (fishing hours) distribution by mesh size, year and depth strata was analyzed. It was decided to use six depth strata in meters (0-99, 100-199, 200-299, 300-399, 400-499 and 500-599). The results show different fishing pattern in relation to fishing depth and mesh size (Figure 4). From available data, fishing activity with 40 mm mesh size was only present in two years, 2007 and 2010, and in both of them the most frequent depth range was the same, from 400 to 499 m, and most of the effort was in the 300-499 m depth. The fishing activity using mesh size 40 mm was only until 2010 because the shrimp fishery in Division 3M has been closed since 2011. In relation to fishing activity with 130 mm mesh size targeting cod and redfish, the most abundant fishing depth is different from the previous one. In the period 2007-2008, when only the redfish fishery took place, this fishery was only carried out in two depth strata, with more than 60% of the effort in the 200-299 depth strata with a small percentage in the 400-499 m strata. But in the period where there are redfish and cod fisheries (2010-2013), fishing effort is observed in all the strata. Most of the effort in this period is distributed at similar levels in the strata between 200-500 m with a small part of the effort in the strata lower than 100 m and greater than 500 m depth. The 2013 pattern was more similar to the 2007-2008 pattern.

Figure 5 shows the maps with the hauls for the different fisheries (shrimp, cod and redfish) before (2007-2008) and after (2010-2013) the cod fishery was reopened. In the first period (2007-2008) only the Western part of the bank was exploited at depths between 300 and 500 m. The shrimp fishery was carried out in the North West of the bank in waters deeper than redfish fishery, which took place in the South West of the bank in shallower waters. In the period 2010-2013 the fishing grounds appear all around the bank in depths from 200 to 500 m, with the shrimp fishery in the North (for 2010 only), the redfish in the West and the cod fishery all around the bank. The cod fishing grounds overlapped with redfish in the Western part, and the redfish fishing grounds overlapped the shrimp in the Northern part.

### 2. Catches spatial and seasonal distribution

The catches distribution was analyzed with the DCR, VMS and Spanish Scientific Observers data. The DCR of each vessel was split in fishing cells based on the VMS day effort of each vessel.

#### 2.1. Catches distribution based on DCR data

The DCR were available only for 2012 and 2013. Figure 6 presents the cod and redfish catch distribution in Division 3M at less than 500 m by 270 km<sup>2</sup> cells and Figure 7 shows the cod and redfish CPUE distribution for the same period. The higher cod catches and CPUEs were concentrated in the South West of the bank. The higher redfish catches and CPUEs distribution were different in 2012 and 2013. In 2012 took place in the Southern part and in 2013 in the North Western part of the bank.

Figure 8 presents the cod and redfish CPUE distribution in Division 3M at less than 500 m by 270 km<sup>2</sup> cells for 2012 and 2013 by quarter. The higher cod CPUEs were in the first and second quarter and they were concentrated in

the South Western part of the bank. The CPUEs were lower in the third and fourth quarter and they were more scattered all around the bank. The temporal redfish CPUEs distribution was less clear in this period.

## **2.2. Cod distribution based on Spanish Scientific Observers data**

The Cod 3M CPUE (kg/h) distribution based on the Spanish Scientific Observers data for the period 2010-2013 is presented in Figure 9. In addition to the spatial distribution, the centroid value of all CPUE data was calculated, to see if there is a change in the spatial CPUE distribution from year to year. The centroid calculated with the Scientific Observers is similar for years 2011 and 2012 and it is located in the South Western part of the bank. In 2010 and 2013, the centroid was in the central part of the bank.

In relation to the spatial distribution of cod length distribution by depth, it was also analyzed in the period 2010-2013, when cod fishery was reopened after the moratorium, based on the Spanish Scientific Observers data. Figure 10 shows the length distribution by depth strata. It can be observed a general increasing trend of the mean length with depth, with the smallest fish in shallower waters. This general trend was different in 2013 when the mean length in all strata with information were similar and mean length was lower (around 40 cm) compared with previous years.

## **2.3. Cod distribution based on Flemish Cap Surveys.**

The availability of Flemish Cap Survey data and its spatial distribution allows knowing where the higher cod concentrations are. Looking at the surveys CPUE from 2007 to 2013, there is a clear distribution pattern where year by year CPUE was higher (Figure 11). The centroid value of all surveys CPUE data was calculated, to see if there is a change in the distribution year to year. We can observe that the centroid appears in the central part of the bank in all years.

The cod length distribution by depth strata from Flemish Cap Survey from 2007 to 2013 are presented in Figure 12. A general pattern can be observed in all years; fish with less than 50 cm are at less than 400 m depth and fish with more than 50 cm are at depth more than 400 m. In the years where the fishery was closed (2007-2009) a general increase of the mean length with the depth in all strata can be observed; this pattern is less clear in the period 2010-2013 where the mean length in the strata less than 400 m depth are quite similar and smaller than the mean length observed in depth more than 400 m.

## **3. Areas where spawning aggregations occur and areas with important concentrations of cod below a minimum landing size (MLS).**

Based on the fishery information and due to the mesh size used in the cod fishery (130 mm) and that fishery was closed in the period 1999-2009, it should be difficult to study the spawning aggregations and the areas with important concentrations of fish below a MLS. The Flemish Cap survey information is the basic information to describe in this document the spawning aggregation and recruitment areas.

### **3.1. Cod spawning aggregations**

Table 3 presents the Age 50% maturity and length 50% maturity for cod 3M stock in the period 2007-2013. The percentage of mature and immature females was calculated per year in the Flemish Cap survey samples from 2007 to 2013 to see if there is any pattern or change in the proportion among years (Figure 13). Except for 2009, there are no significant changes in the proportion of mature and immature female individuals in the samples where the mean of the seven years analysed is around 13% mature and 87% immature. Figure 14 present the mature fish percentage by depth strata and it can be observed a general pattern of increasing the percentage of mature fish with depth.

Figure 15 shows the maps with the numbers of mature and immature females aggregated for years 2007-2009 when cod fishery was closed and 2010-2013 when it was reopened. Looking at the Figure 15 where green dots are for mature and yellow dots for immature, results show that there is a clear change in the number 3M cod individuals in the two period analysed, with fewer individuals in the first period, when the cod fishery was closed. It can be observed in both periods that most of the immature individuals are concentrated in the central part of the bank where depths are lower, while the mature females are more regularly distributed over the entire bank at depths less than 500 m.

### 3.2. Minimum Landing Size (MLS)

The minimum landing size defined for cod will be used to separate Flemish Cap Survey catches in two groups: cod fish bigger than 41 cm or smaller than 41 cm, to see where the proportion of these individuals in the stock is.

Figure 16 shows that the proportion of cod below the minimum landing size was around 50% in 2007-2009 and this proportion increased until a peak of 94% in 2011 and a slight decrease in the last years. This high increase of the proportion of cod below the minimum size was due to the good recruitments in the period 2009-2012.

In Figure 17 it can be observed that whereas bigger cod fish have remained in similar number in the time series, the small cod fish have had important changes in the times series, so the change in abundance of small fish is the main responsible of the change in the proportion of individuals by minimum landing size.

Figure 18 presents the proportion of individuals bigger than the MLS by year and depth strata. As in the case of the proportion of mature individuals a general pattern of increasing the percentage of fish bigger than the MLS with depth can be observed in all years.

The spatial distribution of individuals based on MLS gives similar plots as the mature and immature individuals with different distribution in the period with low abundance (2007-2009) than in the period with high abundance (2010-2013). In this case, for instance, individuals below 41 cm are less abundant than immature individuals, as cod reach maturity at bigger sizes than the established conservation size (Figure 19).

### Discussion

The use and combination of four different data sources to analyze spatial and seasonal fleet activity and cod distribution in Flemish Cap has provided interesting results. Different data coverage in relation to spatial resolution, years analyzed or data quality was the first issue to be considered.

In relation to spatial and seasonal fishing activity the VMS and Spanish Scientific Observers onboard commercial vessels data were used. VMS data provided a high spatial resolution of the fishing activity that for years 2008-2009 had a very low effort, mainly in the Western part and close to the 500 m isobath. In these years, as the cod fishery was closed, the main target species were shrimp and redfish with a depth ranging from 300 to 500 m. When cod fishery was opened in 2010, a clear change of fishing activity and target species was observed. The fishing activity targeting cod and redfish were the main activity from 2010 onwards. A significant increase in the spatial area of fishing activity to the East and West of Flemish Cap was observed and changes in the fishing depth were also appreciated.

Regarding spatial and seasonal distribution of catches, three data sources were used: DCR data, Spanish Scientific Observers onboard commercial vessels and Flemish Cap Survey data. As DCR data were available only for years 2012 and 2013, these two years CPUE data were compared with the other data sources. Looking at the Figure 7, the highest cod CPUE based on DCR data are in the South Western area of Flemish Cap. When comparing it with Figure 9 cod CPUE based on Spanish Scientific Observers data for the same years, for year 2012 the centroid of CPUE is also in the South Western area of Flemish Cap but however, the centroid cod CPUE value for year 2013 is in the Eastern part of Flemish Cap. As Observers data used are for Spanish vessels, a possible change in the exploitation pattern of this fleet is detected to Eastern shallower waters ranging from 200-300 m. The change in depth to shallower waters is directly linked to a change in cod length distribution as the mean length is smaller, around 40 cm for year 2013 in this depth range from 200-300 m.

Finally a comparison of previous commercial information with survey data should be done. In Figure 11 for years 2012 and 2013, cod survey CPUE centroid is in the central area of Flemish Cap and this centroid area is very constant in the last years of the time series analyzed. Hence, one conclusion that could be extracted from this analysis is that till 2012 the commercial fishing activity focused their effort targeting cod in deeper areas where larger cod is more abundant but this pattern was different in 2013 at least for the Spanish fleet analyzed in this document. This change in the fishing pattern has been observed in other fleets as it can be deduced from the size distributions of commercial fleets in 2012 and 2013 (González-Troncoso *et al.* 2013 and González-Troncoso *et al.* 2014). The mode observed in the length distribution of catches in the 2013 fishery was very close to the MLS

(41cm) unlike in 2012, when it was around 60 cm. The main reason to this drop in the mode size of catches seems to be due to market reasons rather than biological reasons.

The spawning season of the Flemish Cap cod is known to occur around March while the Flemish Cap survey is carried out normally in July thus it is not possible to well evaluate the spawning locations from the survey results because it is conducted in July and cod spawn in March. Therefore what has been discussed in this paper is the distribution of different maturity stages in July based on the survey information more than the spring spawning aggregations. Mature and immature females were extracted based on Length 50% maturity by year. Figure 13 shows that, despite the Length 50% maturity changes with the years, the sampled population maintains similar proportion of mature and immature individuals in the time series except for the year 2009. The spatial distribution of mature and immature cod female individuals in two periods (Figure 15) to separate when the fishery was closed and open show a general pattern in both periods with the immature fish more concentrated in the central part of the bank where the depths are less and the mature fish more regularly distributed all around the bank at depth less than 500 meters. It can be observed that in the period 2007-2009, when the abundance was lower, the mature and immature distribution area was lower than the period 2010-2012, where the abundance was higher and the individuals are distributed over the entire bank at depths less than 500 m. When we analyze the proportion of the mature fish by year and depth strata it can be observed that the proportion of mature fish increases with depth and there are two different patterns: one when abundance was lower and the fishery was closed (2007-2009) with a more linear increase of the proportion of mature fish with depth and a smaller depth range and other pattern when abundance was higher and fishery was opened (2010 -2013) with low proportion of mature fish less than 400 meters and a higher proportion at less more than 400 meters depth.

The proportion of cod below the MLS (41 cm) has shown a peak in year 2011 due to the big recruitments in the period 2009-2012, but the number of large individuals is stable in the time series. With a length of 41 cm cod are still mostly immature, which means that an important portion of immature individuals are allowed to be fished in the stock. As would be expected, the spatial distribution of concentration of cod below a MLS (Figure 19) presents a very similar pattern to the distribution of mature and immature females with the fish less than MLS more concentrated in the central part of the bank where the depths are less and the fish bigger than MLS more regularly distributed all around the bank at depth less than 500 meters. When we analyze the proportion of fish bigger than the MLS by year and depth the same patterns of proportion the mature individuals is also observed. This distribution by length and depth was similar in the cod commercial catches by depth (Figure 10). This different cod depth distribution has been cited in other studies, both in the NAFO area (Sinclair, 1992) and in the North Sea area (Heessen, 1993) and it seems to be related with temperature and salinity conditions.

### **Acknowledgements**

This research was funded by the European Union funds under the Framework Contract MARE/2012/21 - "Scientific advice for Fisheries beyond EU Waters" - Specific Contract No 2 (SI2.681887) "Provision of advice on the development of a multiannual management plan and the evaluation of a management strategy for cod in NAFO Division 3M (SAFEwaters-2)".

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**Table 1.-** Summary of Spanish Scientific Observers onboard by year for the period 2007-2013. Number of trips, hauls by year and fishery.

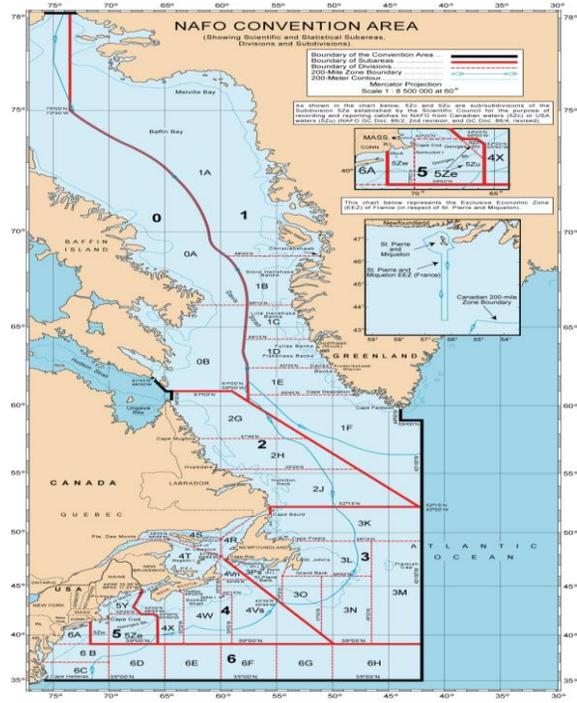
Year	Number of trips	Total Number of hauls	Mean Depth (m)	Shrimp	Redfish	Cod
2007	4	54	363	37	17	
2008	2	10	272	-	10	
2010	6	149	379	22	22	105
2011	3	87	332	-	22	65
2012	4	104	372	-	1	103
2013	6	168	287	-	30	130
Total	25	572	340	59 (10%)	102(18%)	411(72%)

**Table 2.-**Flemish Cap Survey information in relation to cod catches.

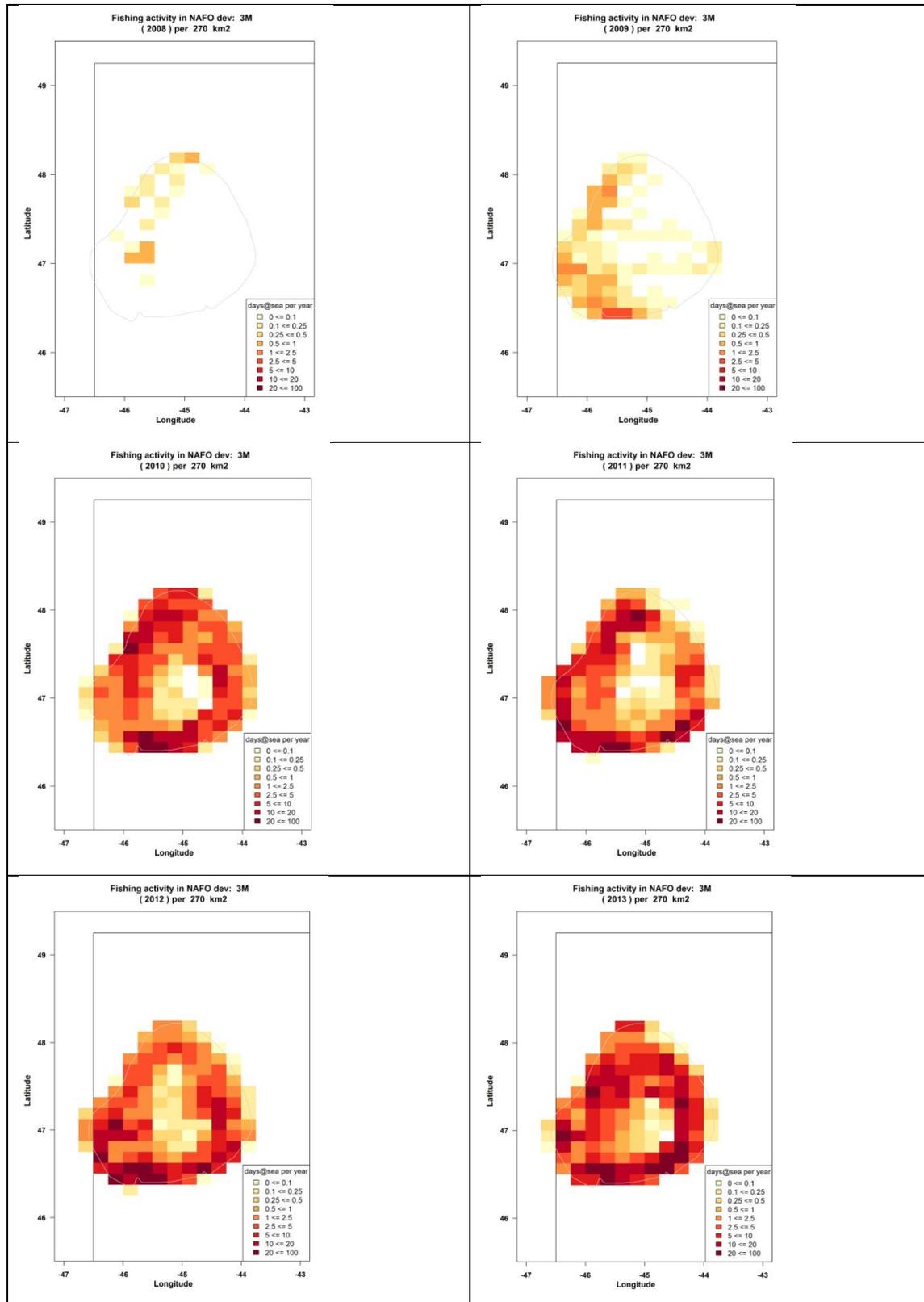
Survey year	Number of hauls	Total cod catches (kg)	Total cod sampled (kg)	% sampled /total catch	Number of cod length sampled
2007	178	3488	2583	74%	2102
2008	176	5890	5159	88%	4566
2009	184	10833	9389	87%	6341
2010	158	7912	5164	65%	9443
2011	141	10793	10474	97%	53997
2012	179	15295	10518	69%	24199
2013	185	10660	9863	93%	16484
Total	1201				111117

**Table 3.-** Age 50% maturity and length 50% maturity for cod 3M stock from the Flemish Cap Survey data.

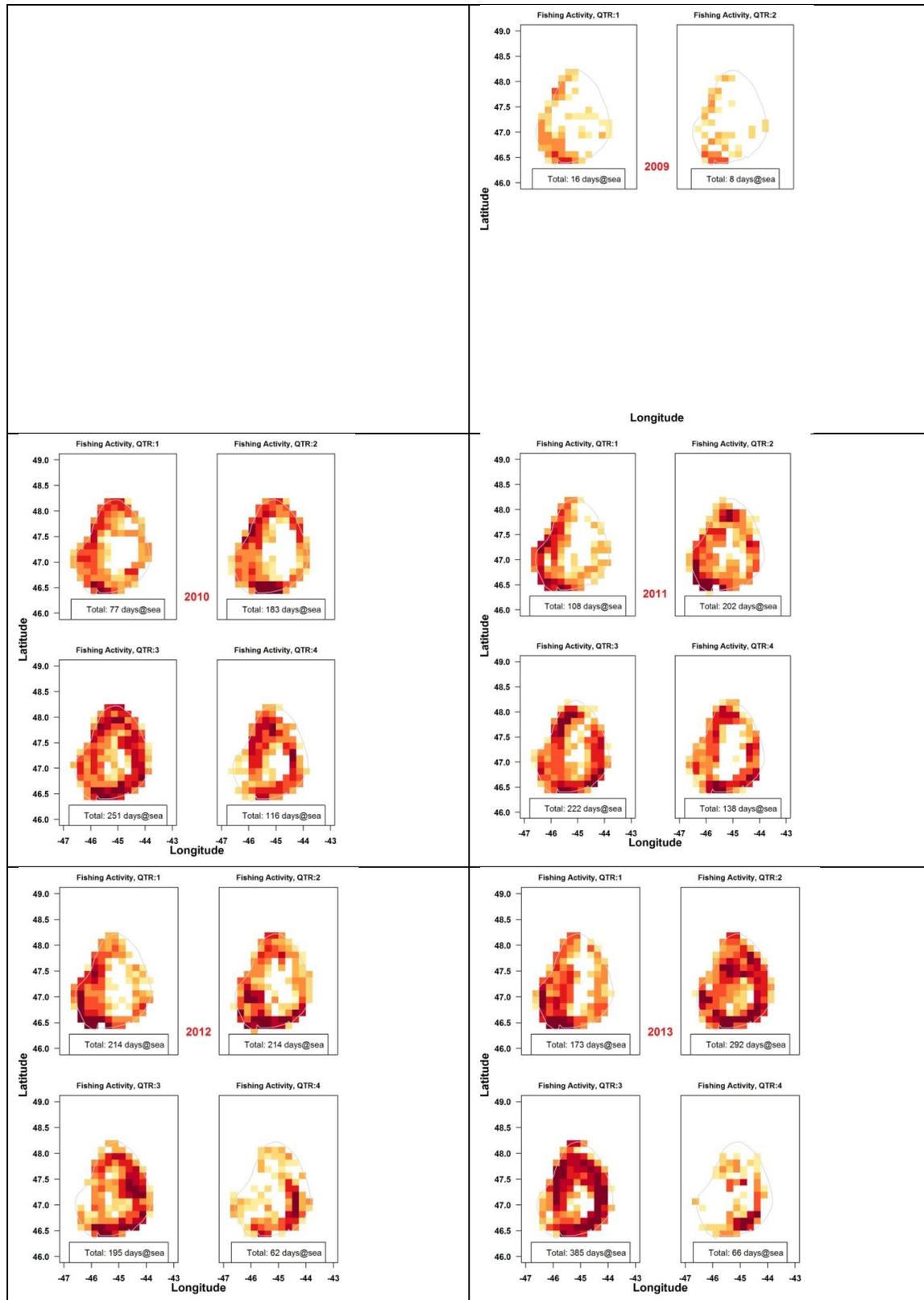
Year	Age 50% maturity (years)	Length 50% maturity (cm)
2007	3.31	57.02
2008	3.37	58.98
2009	3.49	53.65
2010	3.52	53.13
2011	4.13	57.88
2012	3.93	52.43
2013	3.39	46.77



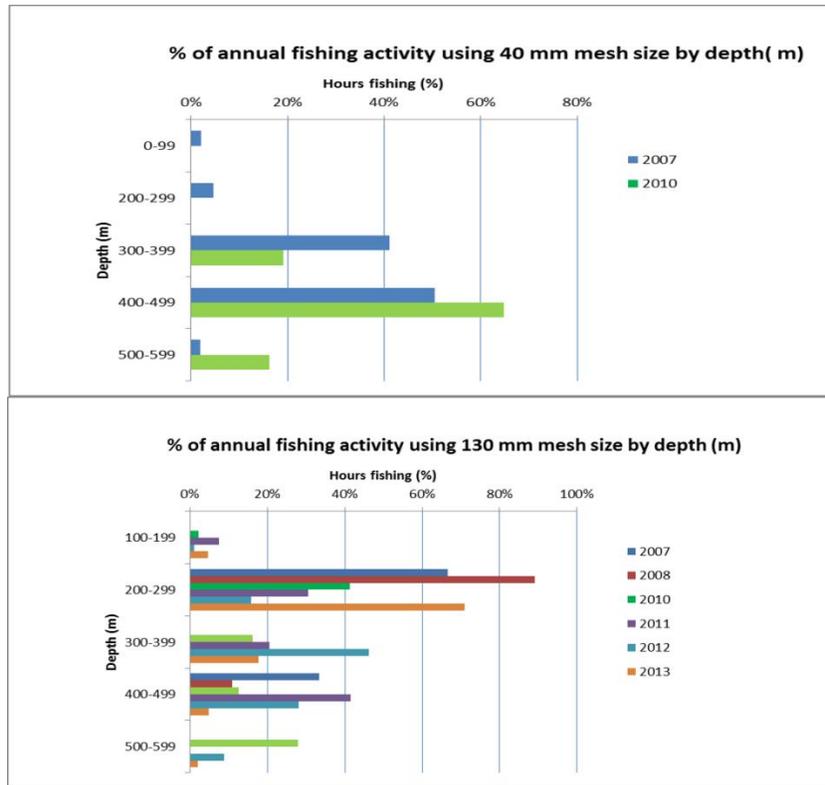
**Figure 1.-** NAFO Convention Area. Limits of Convention Area (black line), and limits of the Regulatory Area (inside fish-blue line and black line).



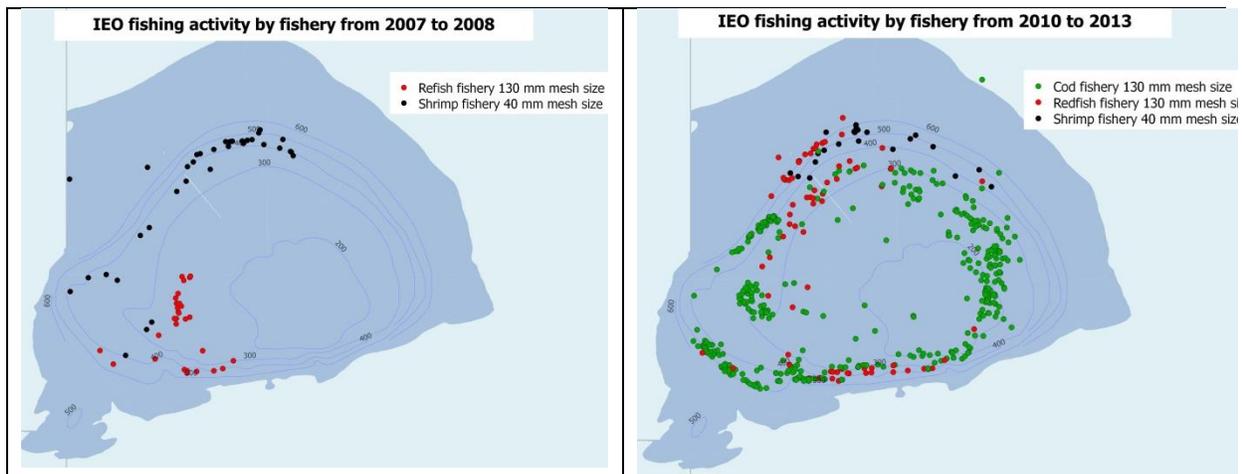
**Figure 2.-** Effort in fishing days in Division 3M at less than 500 m by 270 km<sup>2</sup> cells and year for the period 2008-2013 based on VMS data. The 500 m isobath is plotted.



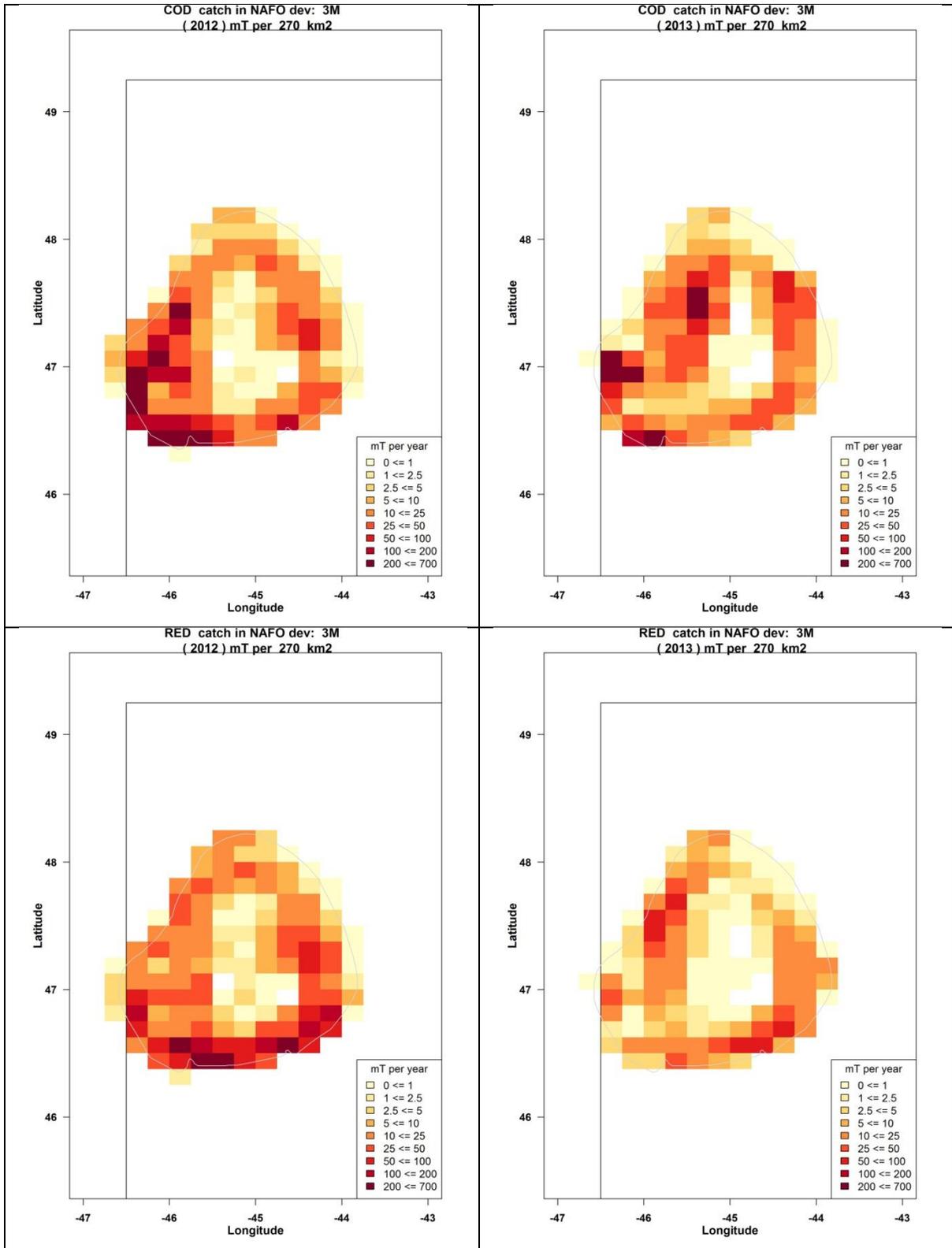
**Figure 3.-** Effort in fishing days in Division 3M at less than 500 m by 270 km<sup>2</sup> cells, quarter and year for the period 2009-2013 based on VMS data. The 500 m isobath is plotted. The colour scale is the same as in Figure 2.



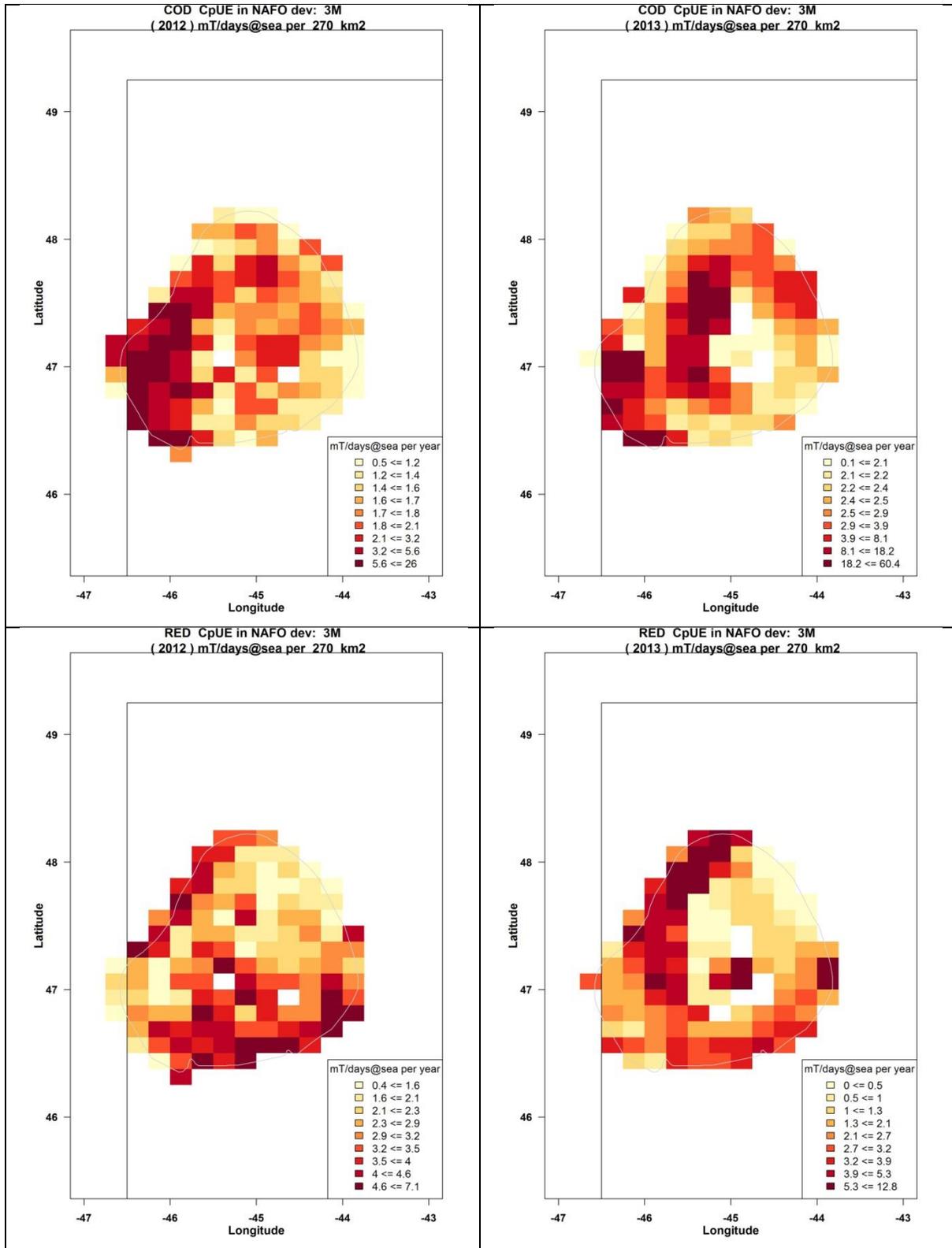
**Figure 4.-** Changes of fishing activity of the commercial fleet by mesh size, year and depth based on the Spanish Scientific Observers data.



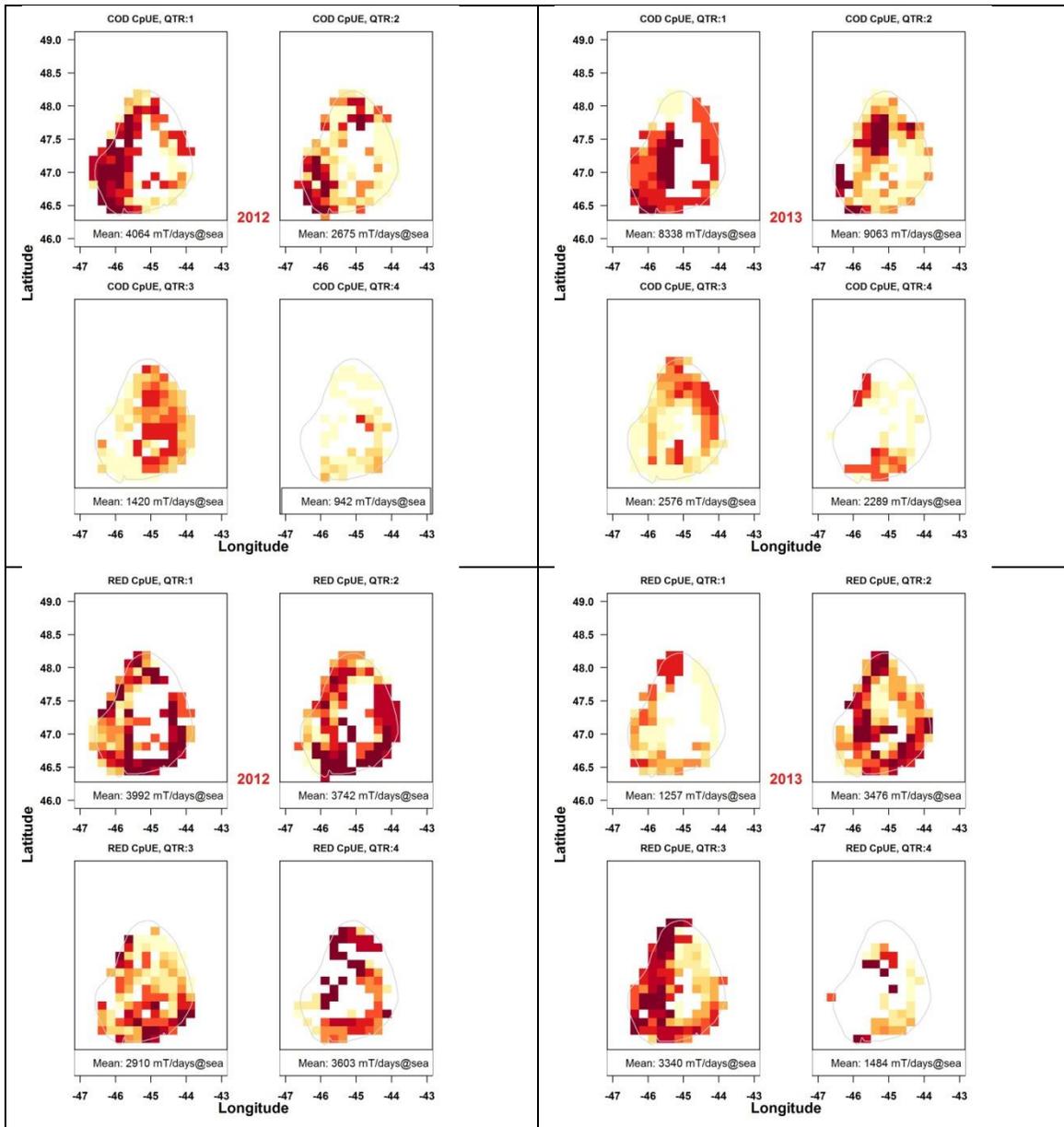
**Figure 5.-** Spatial distribution of Spanish Scientific observer hauls by fishery for the periods 2007-2008 and 2010-2013.



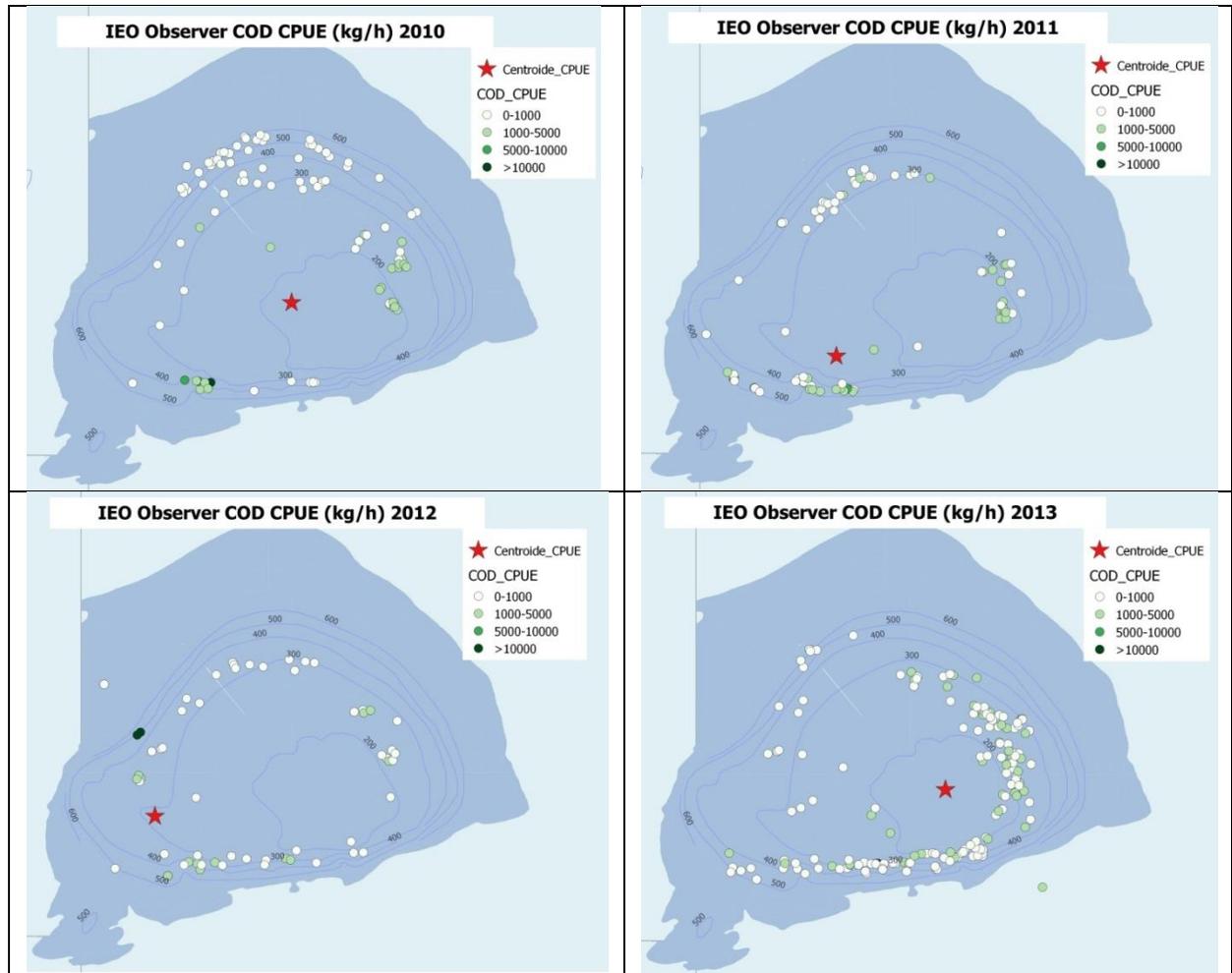
**Figure 6.-** Cod and redfish DCR catches in Division 3M at less than 500 m by 270 km2 cells and year for the period 2012-2013. The 500 m. isobaths is plotted.



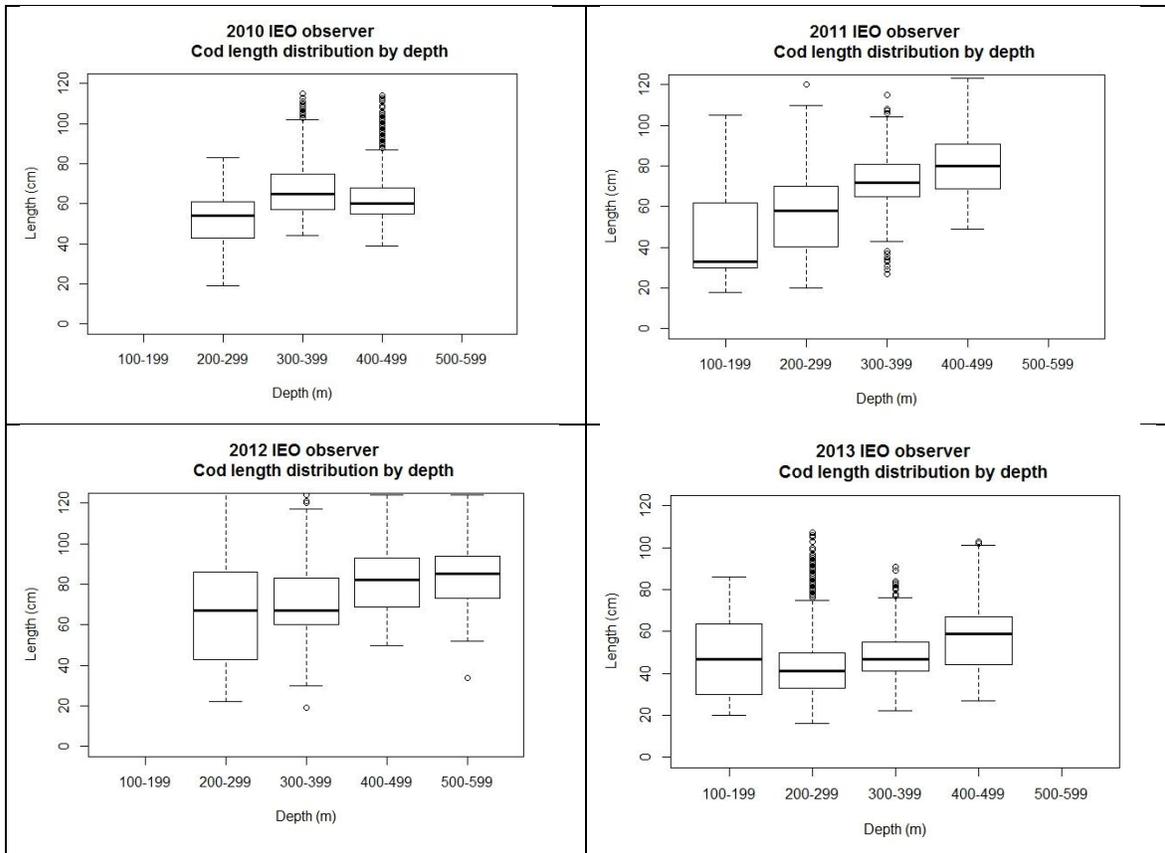
**Figure 7.-** Cod and redfish DCR CPUE in Division 3M at less than 500 m by 270 km<sup>2</sup> cells and year for the period 2012-2013. The 500 m isobath is plotted.



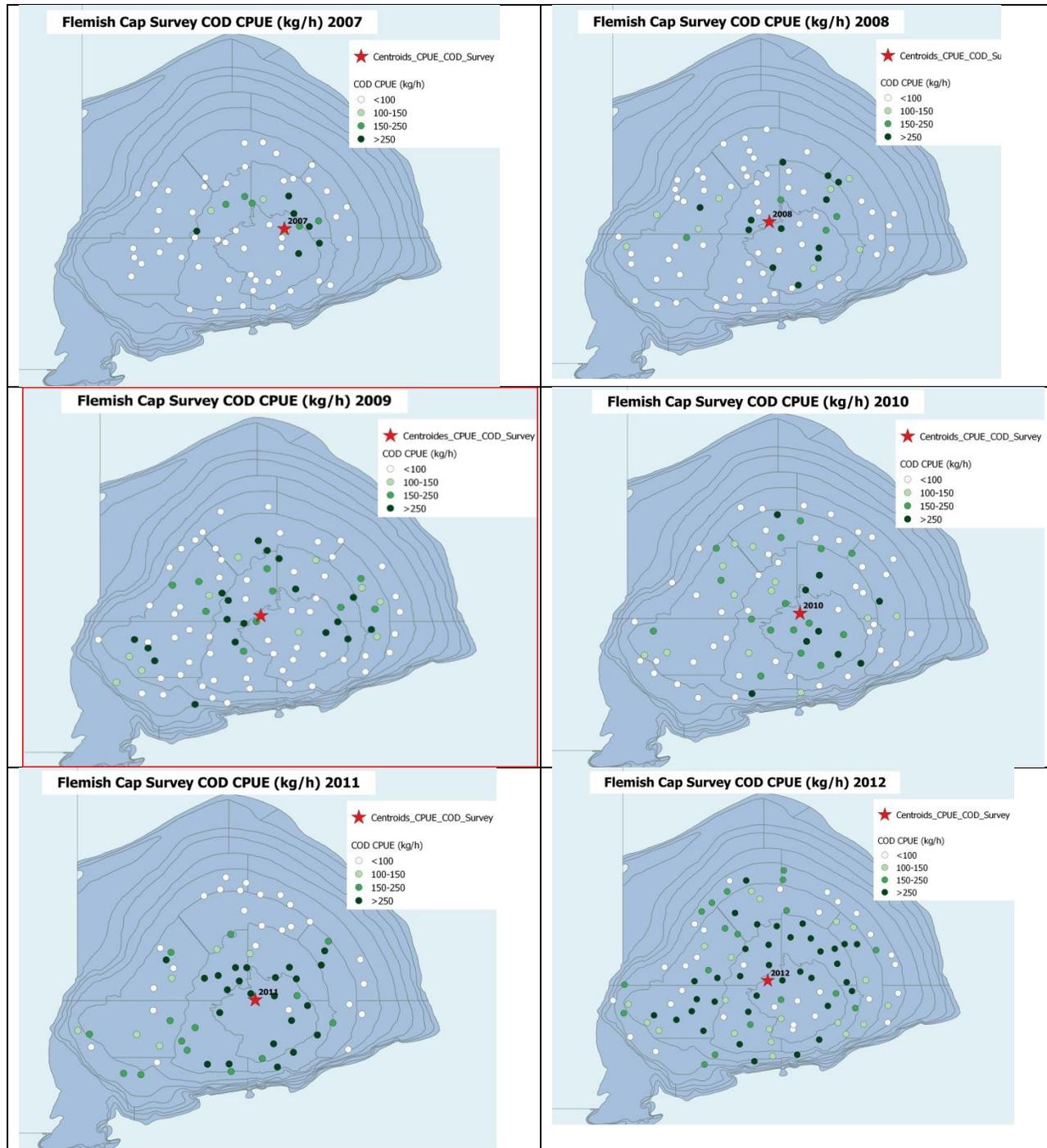
**Figure 8.-** Cod and redfish DCR CPUE in Division 3M at less than 500 m by 270 km<sup>2</sup> cells, quarter and year for the period 2012-2013. The 500 m isobath is plotted.



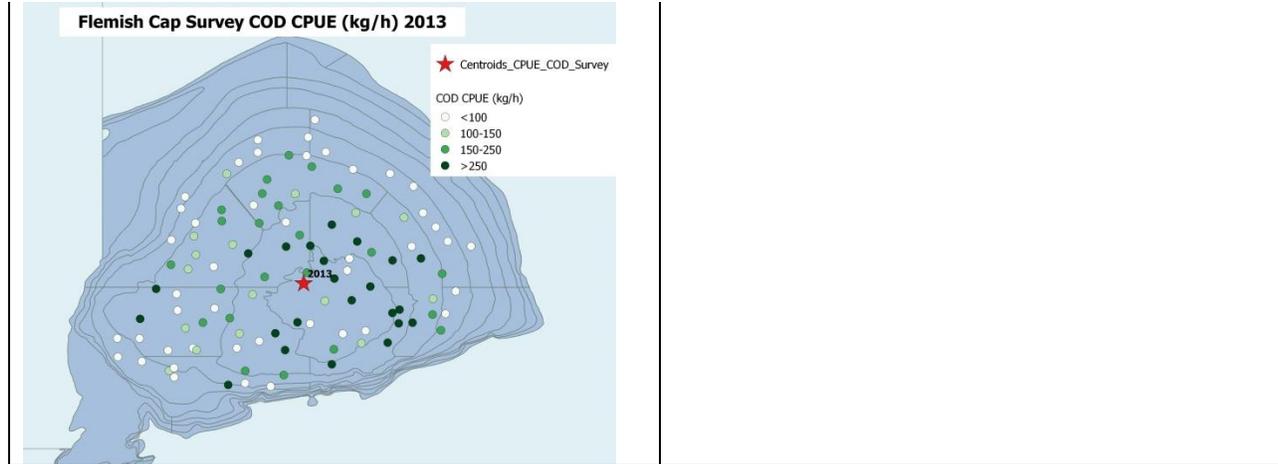
**Figure 9.-** Spatial distribution of cod CPUE (Kg/hour) of the Spanish Scientific Observers data from 2010 to 2013.



**Figure 10.-** Cod length distribution by depth (m) from Spanish Scientific Observers data from 2007 to 2013.



**Figure 11.** Spatial distribution of Flemish Cap Survey cod CPUE from year 2007 to 2013.



**Figure 11 continued.** Spatial distribution of Flemish Cap Survey cod CPUE from year 2007 to 2013.

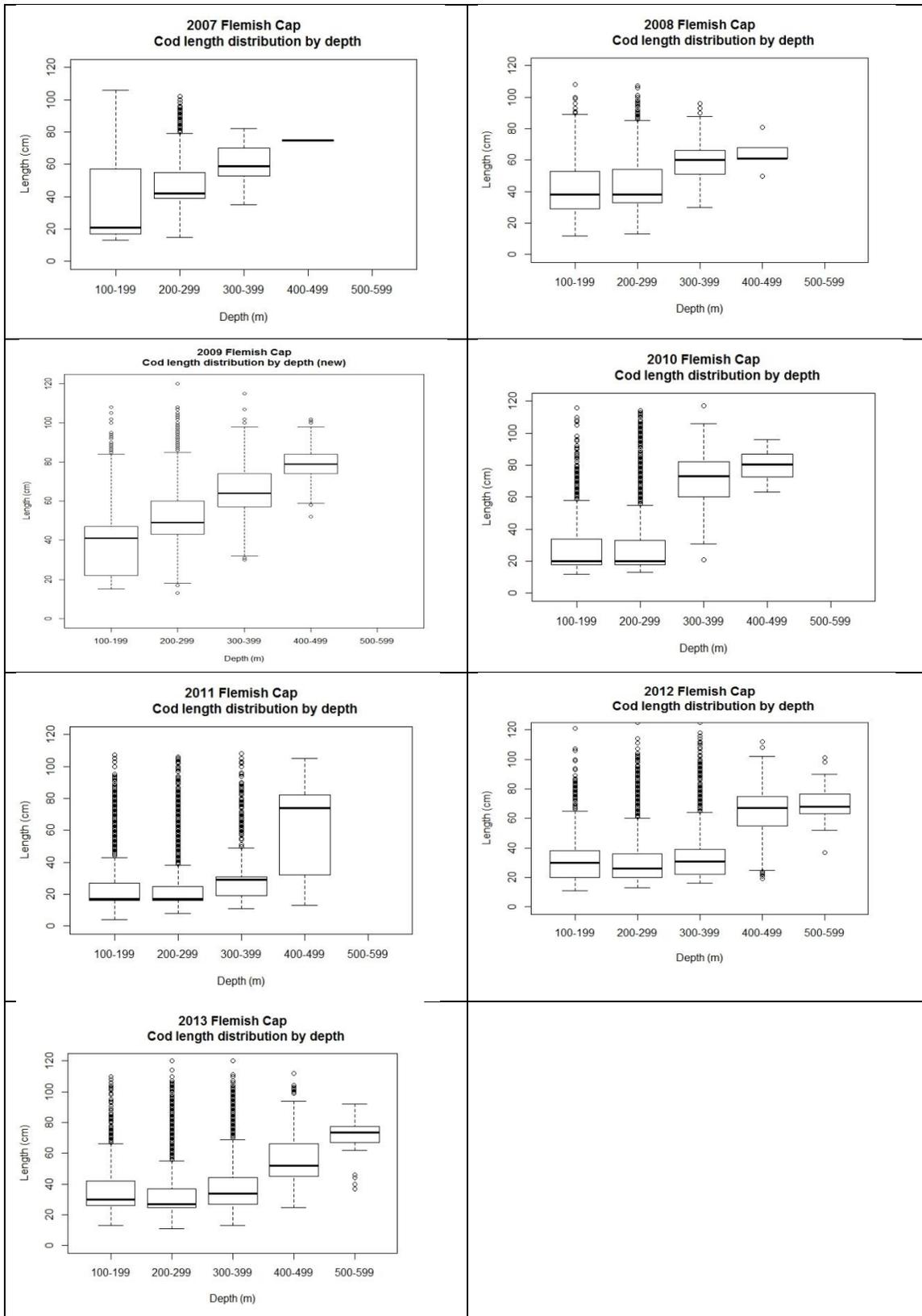
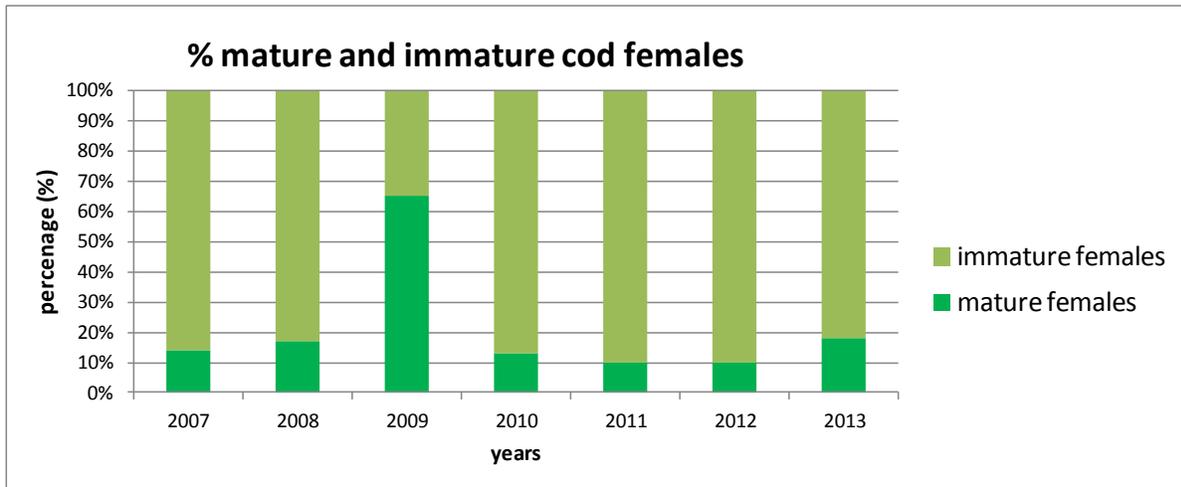
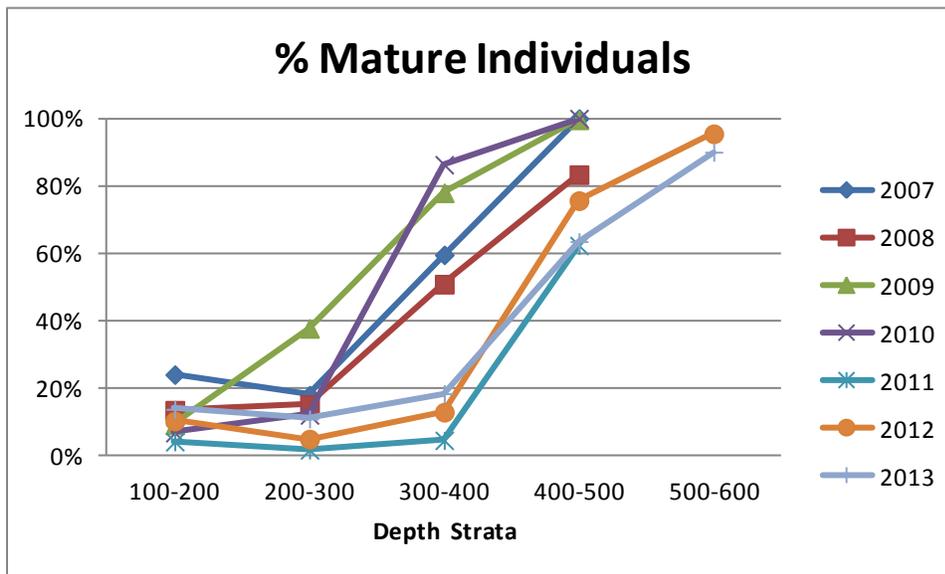


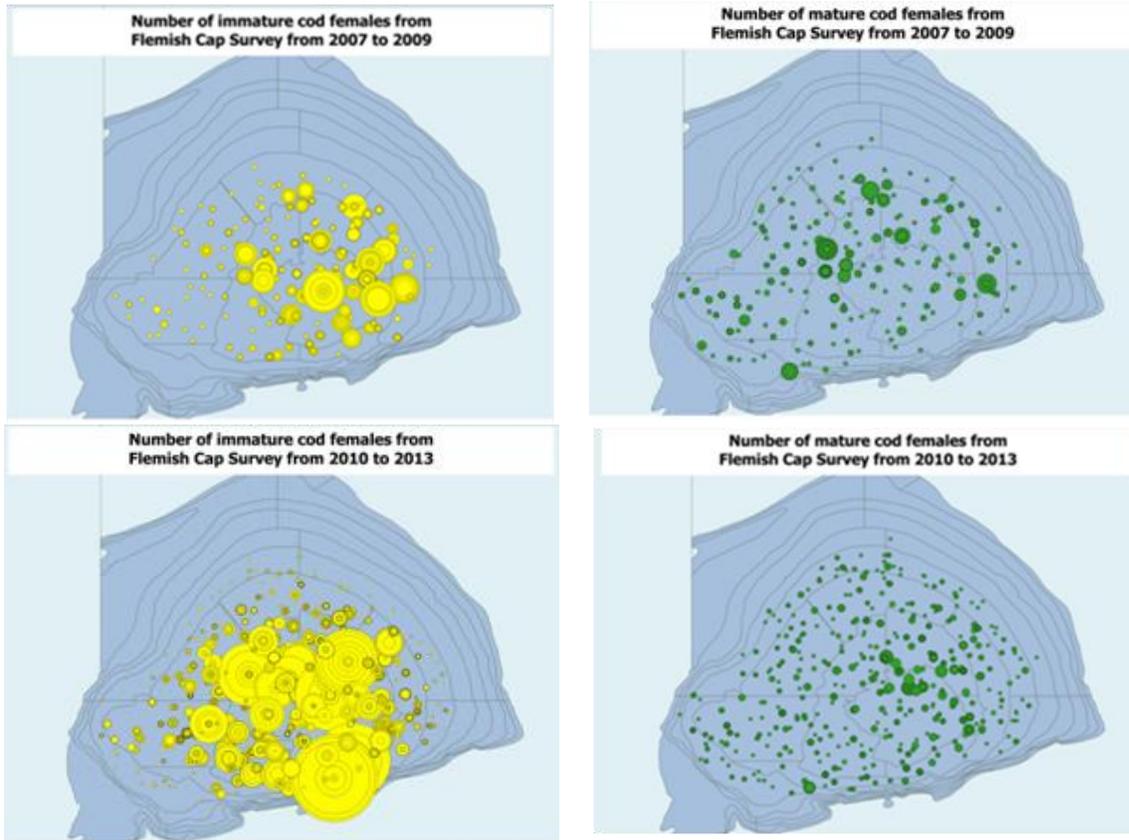
Figure 12.- Cod length distribution by depth (m) from Flemish Cap survey from 2007 to 2013.



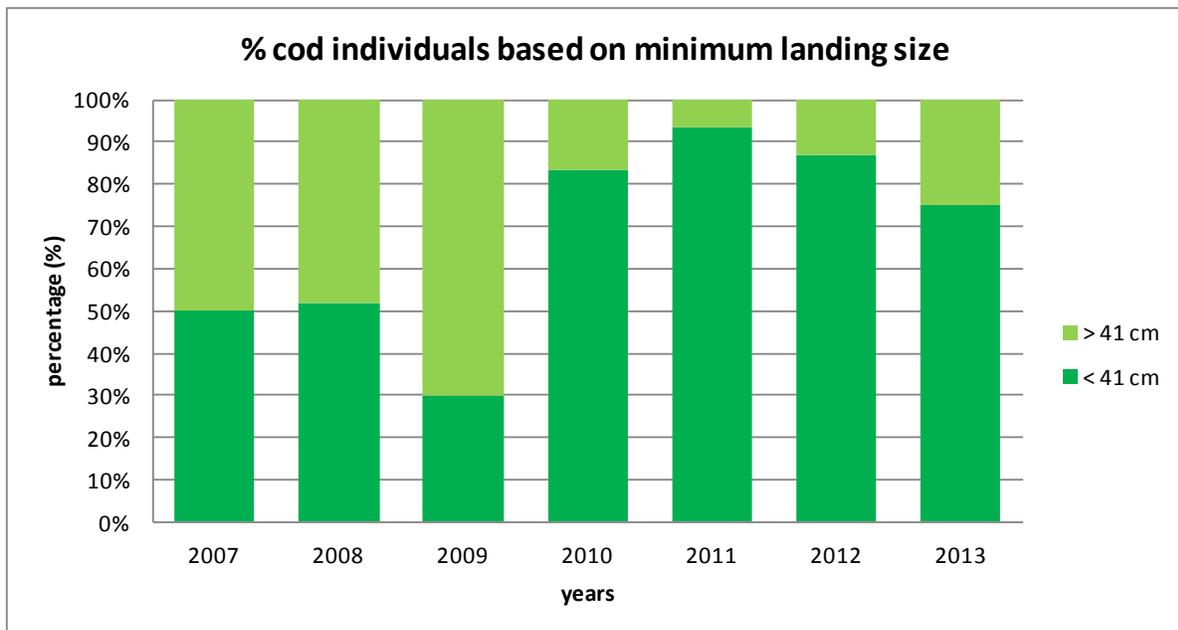
**Figure 13.-** Percentage of mature and immature cod females from Flemish Cap Survey samples.



**Figure 14.-** Percentage of mature cod by year and depth strata from Flemish Cap Survey samples.



**Figure 15.-** Spatial distribution of immature female cod (left panel) and mature female cod (right panel) split in two periods: 2007-2009 and 2010-2013. Data from the Flemish Cap Survey.



**Figure16.-** Flemish Cap Survey number of cod samples based on Minimum Landing Size.

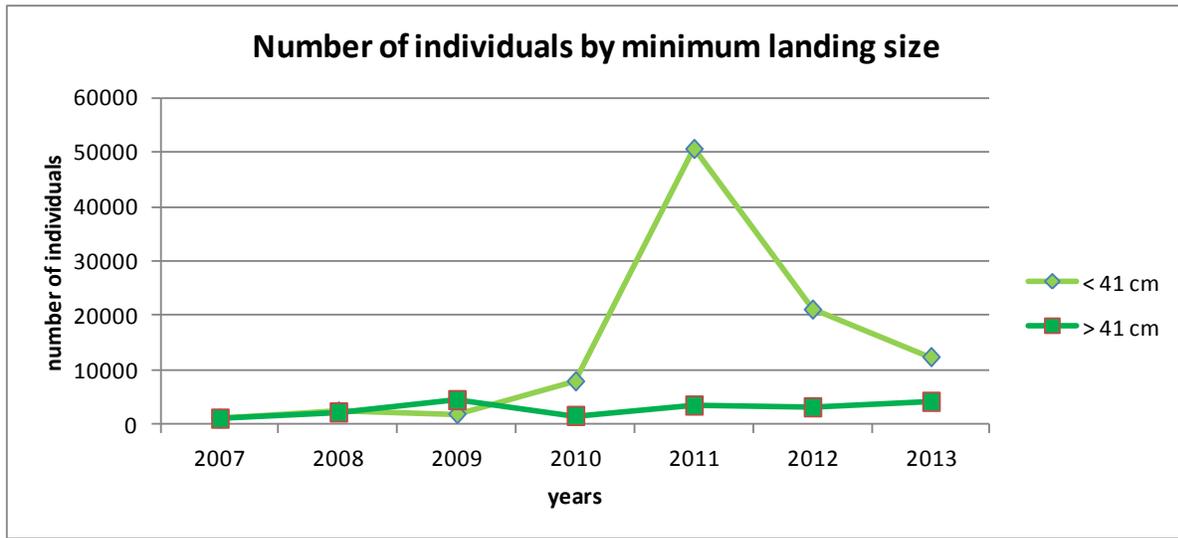


Figure 17.- Number of cod individuals from Flemish Cap Survey samples separated by Minimum Landing Size.

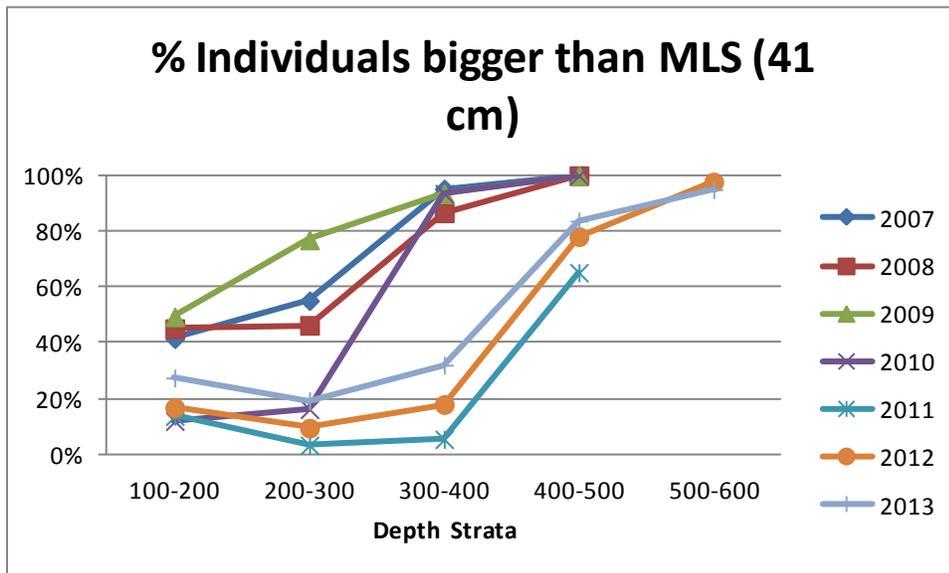
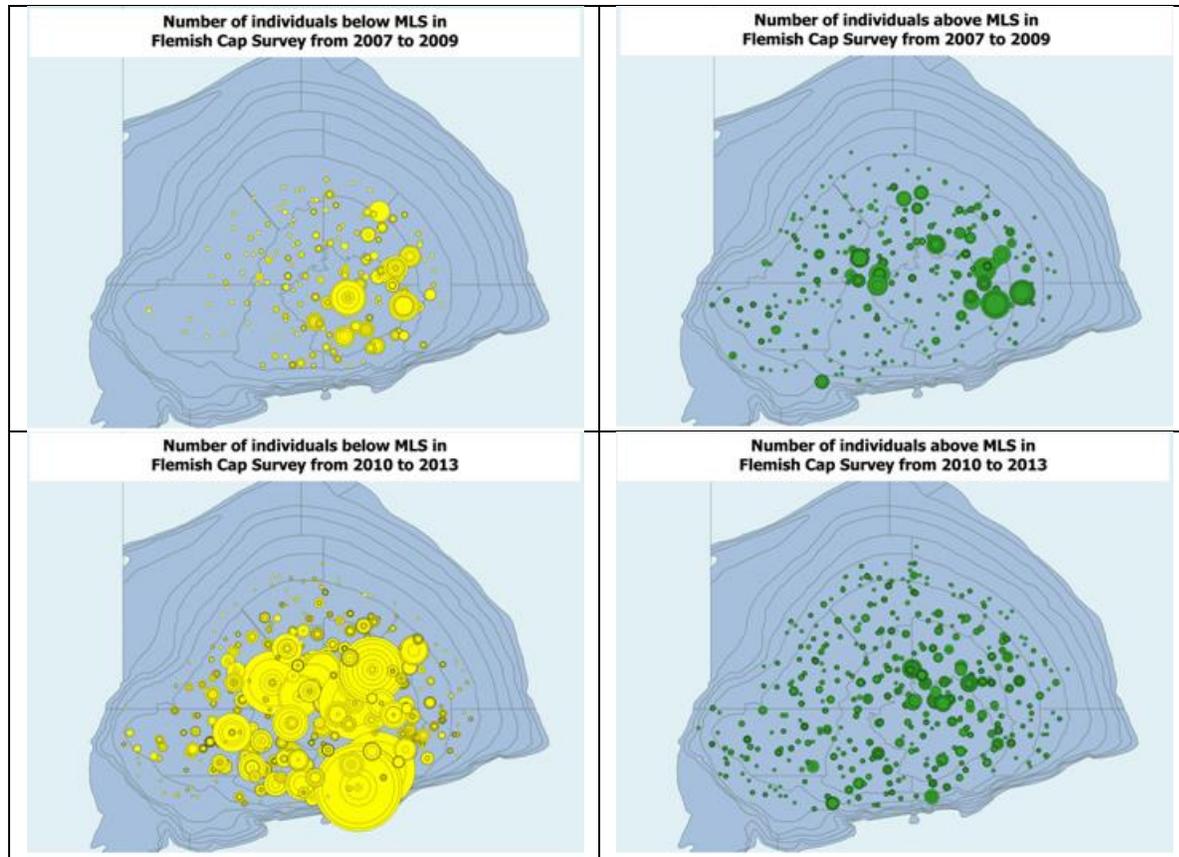


Figure 18.- Percentage of cod fish bigger than the MLS by year and depth strata from Flemish Cap Survey samples.



**Figure 19.-** Spatial distribution of cod below MLS (left panel) and cod above MLS (right panel) split in two periods 2007-2009 and 210-2013. Data from the Flemish Cap Survey.