Juvenile hake (*Merluccius merluccius*) discard minimization in otter board trawling by square mesh escaping window selectivity device.

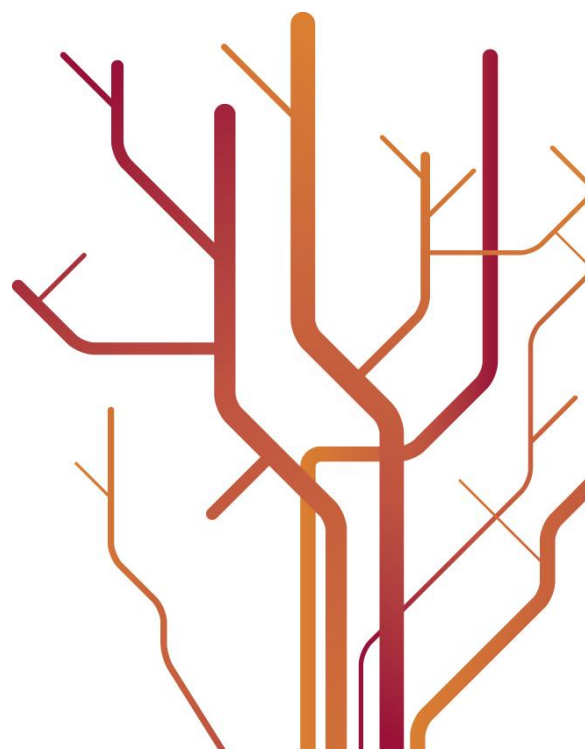## Proving a mandatory selectivity device in the Basque trawling fleet

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1. INTRODUCTION

Fishing gears are the tools with which aquatic resources are captured. The variety of gears and methods to use them is very wide and can be grouped in many different ways. A general classification divides them into active or passive gears. This classification is based on the relative behaviour of the target species and the fishing gear. With passive gears, the capture of fish is generally based on contact of the target species towards the gear (e.g. traps, longlines, gillnets), whereas with active gear capture usually involves a persecution directed to the target species of fisheries (e.g. trawling, dredging, purse seining) (FAO 2001). The purpose of this first section is to give an overview of trawl gears and go deeper in the fleet and trawl gears used by the Basque trawling fleet in northern Spain.

By the other hand, the selectivity of gears has been the battle horse of fishing technologists during last decades. A key definition of selective fishing (FAO 2005) refers to a fishing method's ability to target and capture organisms by size and species during the fishing operation allowing non-targets to be avoided or released unharmed. The catch in many fisheries consists of a mixture of target and non-target species that are usually discarded to the sea. The ability to select targets can be altered through modification of design and operation methods. This study analyses the implementation of a mandatory selective device in European waters for towed gears, in the Basque trawling fleet.

1.1. Bottom trawling

Trawling is defined by the FAO (2001) as cone-shaped netting bags that are towed through the water to catch different target species in their path. Different materials, designs and constructions provide a great variety of metiers* to these fisheries that can be grouped in two main categories, bottom and pelagic trawling. Bottom trawling is based on the contact of the gear with the seafloor to catch benthic or bottom associated species, while pelagic trawling aims to catch fishes on the water column.

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* *Métier: "a group of fishing operations targeting a similar assemblage of species, using similar gear, during the same period of the year and/or within the same area and which are characterized by a similar exploitation pattern" (EC, 2008).*

The trawl can be towed with one or two boats (pair trawling) and there are many different rigs (e.g. twin and triple trawls). The gear and method subject to study in this report is known as otter board trawling, where the trawl gear is basically composed of warps, otter boards, sweeps, bridles and a trawl net (see Fig.1) that drag the bottom. Warps are steel cables that connect the otter boards with the boat which length and diameter may vary depending on the fishing depth and power of the boat. Otter boards provide to the trawl net the horizontal opening due to their rigging and the hydrodynamic forces created when the rig is towed, there is a great variety of designs and sizes. Sweeps and bridles are usually made of a mixture of rope and wire and connect the otter boards with the trawl. The contact of the sweeps with the bottom creates bottom sediment clouds that gather the fish towards the trawl (Wardle, 1993).
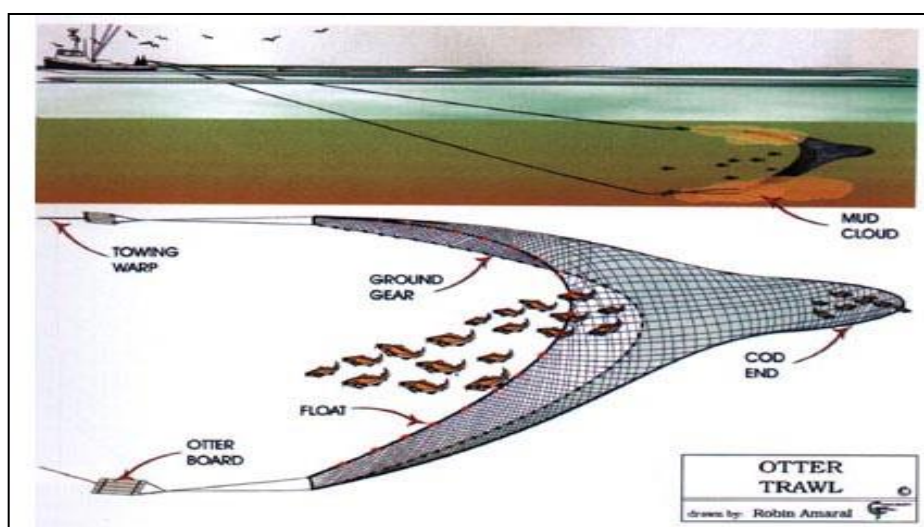
Figure 1: Diagram of otter board trawling from "Bottom Tending Gear Used In New England" by Ronald Smolowitz.

1.2. Basque fisheries

Fishing is a traditional activity in the Basque Country with great social and economic importance, especially for coastal communities. Additionally, this activity involves the constitutive expression of historical processes of cultural and natural heritage of the country (Haig, 2008).

The fishing sector of the Basque Country is constituted, according to data updated to 2008, by a fleet of 278 units with a total capacity that exceeds 85,178 GT (Gross tonnage) and 145,273 CV (Horsepower). The crew number is around 2,600 people. Fishing activity only contributes about 1% of Gross Domestic Product (GDP) and employment in the Basque Country, although socio-economic importance of fisheries is greater than indicated by this data. On one hand, every job at sea generates 3,5 jobs on land, in the canning industry without including retail and fisheries research. In addition, the fishing activity is largely concentrated in some areas which are highly dependent on fisheries, where extractive activities can contribute up to 7% of GDP and fishing accounts for 20% of employment (Haig, 2008).

The Basque fleet is divided in 3 different fisheries taking into account the distance from the coast where they operate: 1) Local waters (artisanal gillnetter and long liners). 2) coastal waters (purse seine and lines targeting small pelagic species and temperate tunas) 3) Long distance waters (big purse seiners operating in non EU waters and targeting tropical tunas, and bottom trawlers operating in EU waters and targeting mix demersal species, mainly hake (*Merliccius merluccius*), anglerfish (*Lophidae*) and megrim (*Lepidorhombus whiffiagonis*).

1.2.1. *Basque bottom trawlers fleet targeting mix demersal species.*

The trawl fishing sector began in the Basque Country, in the early twentieth century, coinciding with the introduction of steam engines as a way of propulsion, which will be later replaced by gas-oil. But it is mainly from the end of World War I when it begins its real implementation, especially in the towns of Pasaia and Ondarroa [1].

The study will be based on the Basque trawling fleet working in ICES (International Council for the Exploitation of the Sea) subarea VIII abd, this is, the Bay of Biscay. The trawl fleet has undergone major changes over the years, but

nowadays it is mainly compound of "baka" otter board trawlers and very high vertical opening (VHVO) pair bottom trawlers (Iriondo, 2008). The fleet passed its peak in the late 70's of last century with 216 fishing units, but today has been significantly reduced and confined to a small number of ports, Ondarroa and Pasaia (Prellezo, 2010). (Figure 2).
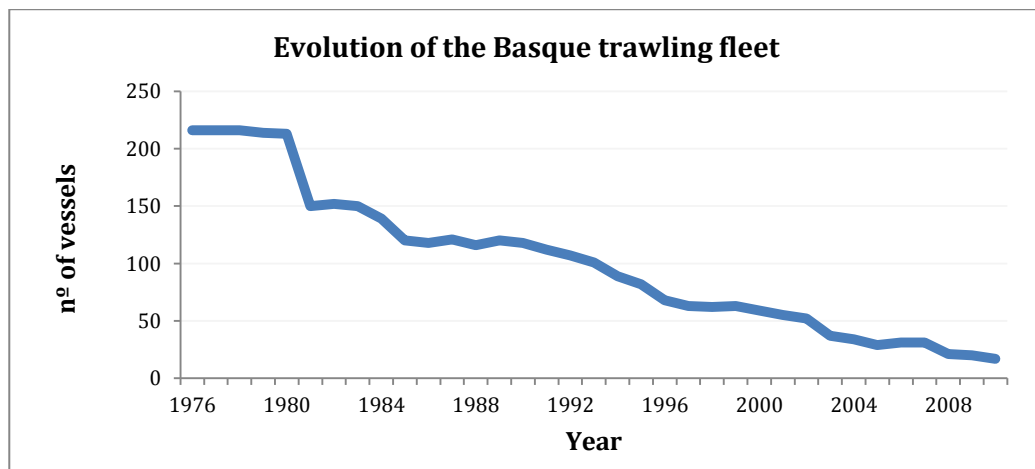
Figure 2: Decay of the Basque trawling fleet from 1975 to 2010. (Source EUSTAT. Basque statistical service)

Mixed fisheries are of great tradition in the Basque Country. These fisheries have hake (*Merliccius merluccius*) as the main target species, but there are several species caught by the fleet, such as red mullet (*Mullus surmuletus*), pout (*Trisopterus spp.*) anglerfish (*Lophidae*) and megrim (*Lepidorhombus whiffiagonis*) (AZTI Arrantza, 2009). During the last decade, the Basque trawling fleet has landed an annual mean of 13.000 tonnes of fish. Although hake, anglerfish and megrims are the main target species, a wide range of species is caught. More than 100 species have been identified within these landings (AZTI Arrantza, 2009)[2].

Nowadays, 27 vessels compound the Basque demersal fleet. The average length is 37 metres, and the average age is 9 years. All of them together suppose a total capacity of 10,065 GT (Gross Tonnage) and 12,804 Kw. Number of crew involved in this fishery is 357 people (Source: Azti-Tecnalia).

Most of these boats spend 6-7 days at sea by trip, and made their landings in Basque ports, Ondarroa and Pasaia. However, in recent years the number of boats landing their catches in foreign ports (Ireland, Scotland, England and France) has increased. Most of these landings are transferred by truck to the Basque country and sold mainly in local markets, but part and especially certain species are sold in French ports (Iriondo et al., 2008).

On the other hand, is well known that trawlers catch bigger amount of bycatch than other gears, species that due to different reasons cannot be sold in the market and are discarded (Kelleher, 2005). Otter trawlers operating in West Ireland (sub-area VII), the discard could reach values above 50% of the total catch (Source: Azti-Tecnalia). The main discarded species, are non-commercial species; Atlantic argentine (*Argentina silus*), boarfish (*Capros aper*), some invertebrates (*Actinauge richardii*), or species that occasionally have a low market price or no quota and are discarded like horse mackerel (*Trachurus trachurus*), mackerel (*Scomber scombrus*) and blue whiting (*Micromesistius poutassou*). During 2005 onwards, an increase in the hake discard is clearly appreciable reaching values of 54% of hake discarded in weight ("Baka" trawlers operating in Biscay in 2005). This high rate of discards could be a result of a real implementation of the technical measures, especially control measures (Perez 2005).

1.2.2. The Bay of Biscay

The Bay of Biscay region (see Figure 3) is situated in temperate latitudes (to the north of 43.5º N and to the south of 48º N, between 1º 40' W and 9º 20 W) with a climate that is strongly influenced by the inflow of oceanic water from the Atlantic Ocean and by the large scale westerly air circulation which frequently contains low pressure system. Large storms occur in the Bay of Biscay, especially during the winter months. A regular pattern in hydrographical conditions throughout the year can be appreciated, characterised by winter mixing and summer stratification, with

phytoplankton blooms occurring during the transition periods (OSPAR Commision, 2000). While the southern part (Cantabrian coast) presents a narrow continental shelf (average of 30-40 Km, but reaching as narrow as 12 Km), the northern part (french coast) presents an extensive continental shelf (150-180 Km on average width) (Koutsikopoulus and Le Cann, 1996).

Figure 3: Satellite image of the Bay of Biscay. (Source NOAA)

In the northern part, the relatively high freshwater runoff is one of the main characteristics. Most of this runoff is related with two French rivers systems; Loire and Gironde (Lavin et al 2000). Most of the water masses occurring in Biscay have a North Atlantic source or result from interaction between waters formed in the Atlantic with water of Mediterranean origin. Deep winter mixing beyond the continental slope north of 40° N is also likely to give rise to the formation of water masses in the upper ocean (0 – 500 m), particularly in the western Bay of Biscay.

This process is subject to significant inter-annual variability. (Detailed information about oceanography of the Bay of Biscay is available in OSPAR Commission BISCAY, 2000).

1.3. Selectivity in towed fishing gears

The interest of reducing the proportion of undersized fish in trawl gears throughout scientist community started in the beginning of the 20th century (Walsh 2000). It was 1955 when the first committee for investigations into fishing gears and fishing methodology, known as the Comparative Fishing Committee, was formed. Later in the 60's with the technological advances in underwater photography, acoustics and trawl-mounted instrumentation provided the first means to study fishing gear in scientific detail (Walsh 2000). In 1983 present Working Group on Fishing Technology and Fish Behaviour (WGFTFB) was formed. The directive of the WGFTFB is to initiate and review investigations of scientists and technologists concerned with all aspects of the design, planning and testing of fishing gears used in abundance estimation, selective fishing gears used in bycatch and discard reduction; and environmentally benign fishing gears and methods used to reduce impact on bottom habitats and other non-target ecosystem components (FAO 2009). There are hundreds of works reported to this group in the last decades with special concern in by-catch and discard reduction in trawl gears as reviewed by Graham (2004). Regarding to the square mesh as selective device there are also many studies in the recent years (e.g. Graham, 2001, Grimaldo, 2007,) reducing some of the negative impacts associated with trawling. Escape panels (e.g. Broadhurst, 2000; Graham et al., 2001), grids (Larsen and Isaksen, 1993), and separator trawls (Main and Sangster, 1985) are a few examples of devices now routinely used in many fisheries worldwide. In the particular case of the hake we found several works in the Mediterranean sea (e.g. Sarda, 2004, Sala 2008, Luchetti, 2008) related to square mesh panels and codends, in Argentina with the development of the DEJUPA grid (Ercoli et al, 1998). Sumalia (1999) studied the impact of management scenarios and fisheries gear selectivity on the potential economic gains from Namibian hake.

Size and species selectivity of commercial fishing gears is considered as an important factor in fisheries management to reduce fishing mortality and to conserve fish stocks, since the selectivity is used to model the vulnerability of fish to the gear as well as the availability. These studies evaluate the effects of introducing selectivity changes in a fishery and help to determine a sustainable exploitation pattern for a species. For further information see the reports of the ICES-FAO Working Group on Fish Technology and Fish Behaviour (WGFTFB).

1.3.1. The selection curve

The selection of fish by a fishing gear can be considered to be the process, which causes the catch of the gear to have different composition to that of the fish population in the geographical area in which the gear is being used (Wileman 1996). Thus, the selectivity of a fishing gear can be considered as a measurement of the selection process that measures the probability that a fish of a given size is retained on encountering the gear. In towed gears this is normally referred as mesh selection, since the mesh length would determine the selectivity of the gear.

The mesh selection could be determined in any part of the gear but traditionally the experiments to determine the mesh selection have only measure the selectivity in the codend. Underwater observations certainly show that large amounts of fish do escape in the codend and for most species this is where the main mesh selection is thought to occur (Wileman 1996).

The selection curve is usually represented as S-shaped (ogive) as shown in the next figure (Figure 4), i.e. a graphical illustration of the probability that a fish of a certain length is retained by the gear given it enters the gear. In most cases we assume that data are normal distributed and hence the selection curve for mobile gear like trawls (and seines) equals the cumulative function of a normal distributed curve (i.e. inside +/- 3 standard deviations). The right side of the curve show

retention of fish for different sizes *r(l)*, while the left side of it show the escape, i.e. 1-*r(l).*
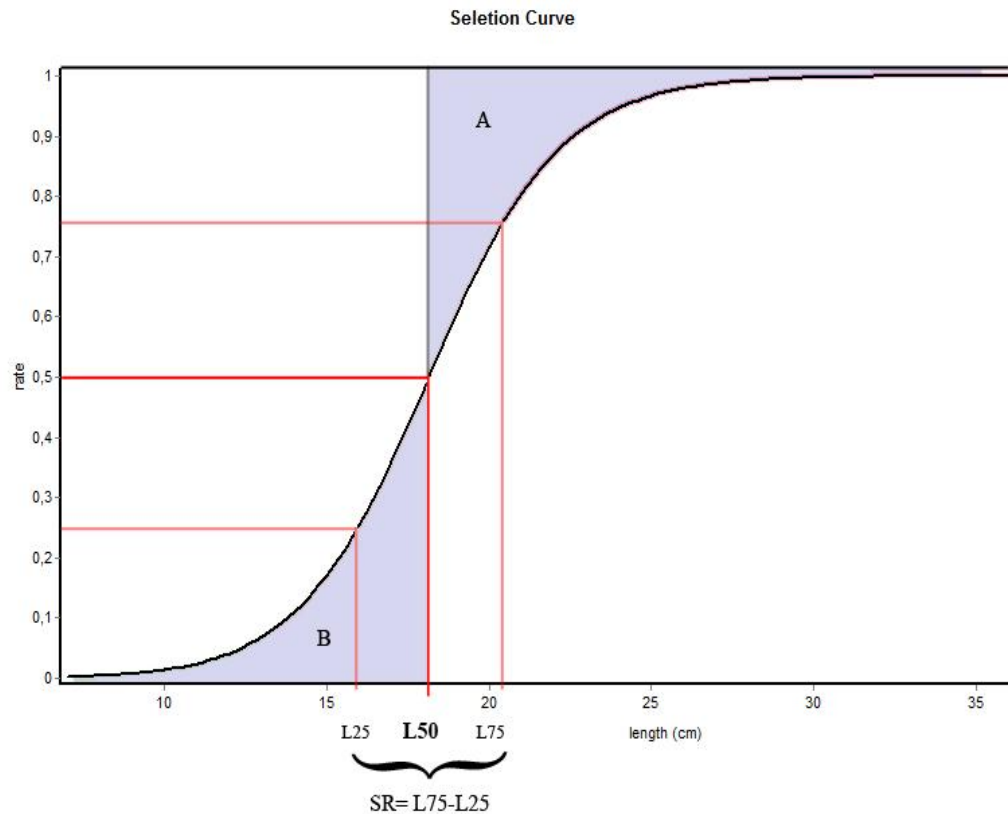
Seletion Curve

Figure 4: Typical s-shaped selection curve for a mobile fishing gear.

Two important selection parameters can be used to describe the size selectivity in the tested gear and they are useful when calculating the effect of selectivity on fish populations. These are the middle selection point (L50%) and the selection range SR. The centre of this curve is at 50% retained level and the fish length at this point is called the 50% retention length or L50. When we assume that data are normal distributed the selection curve is symmetric around L50% (and hence area A and B are equal). The slope of the curve is defined by the 25% and 75% retention lengths. The distance between them is called the selection range (SR). L50 and SR define

the curve mathematically. The logistic selection curve is the cumulative distribution function of a logistic random variable. It is specified by (Wileman, 1996):

$$r(l) = \frac{\exp(a + b\,l)}{1 + \exp(a + b\,l)}$$

Where a and b are parameters to be estimated. This curve is also known as the logit because it can be rewritten:

$$a + bl = \log_e\left(\frac{r(l)}{1 - r(l)}\right) \equiv \mathrm{logit}(r(l)).$$

Note that the length of 50% retention, l_{50} is such that $r(l_{50}) = 0.5$ and therefore

$$a + bl_{50} = \log_e\left(\frac{0.5}{1 - 0.5}\right) = \log_e(1) = 0.$$

That is l_{50} = -a/b

Similar algebra gives the selection range, SR, to be:

$$SR = l_{75} - l_{25} = \frac{2\log_e(3)}{b} \approx \frac{2.197}{b}.$$

A small (short) SR means that the L75 and the L25 are close together so the slope is steep. Considering that the L50 coincides with the minimum landing size (MLS), the shaded area above the 50% retention rate (A) in figure 4, is the loss of marketable fish and the shaded area below the 50% retention rate (B) can be

considered as undersized fish due to discards. A short SR, or steep slope of the curve, would minimize both area A and B, which is in the interest for both the management (less undersized fish caught) and fishermen (less marketable fish excluded). "Knife-edge selection curve" (Beverton and Holt, 1957) should be considered a hypothetical model since it will never describe a real situation. However, knife-edge selection is often used as an approximation to the selection ogive.

Particularly, this study aims to analyse the selectivity of the trawl gears used by the fleet of Basque Country; these are configured with 70 mm mesh size in the codend and a 100 mm square mesh panel in the codend preceding section, as required by the applicable regulation. The panel is placed just ahead of the codend, also in the way specified in the regulations (see Annex I). The mandatory square mesh panel and another three sorting devices were tested by the institute IFREMER in different French fisheries in the Bay of Biscay, trying to find the best selective device for trawling fisheries. After their analysis the panel of square mesh seems the device allowing the best compromise between hake escapement and commercial losses (Meillat 2004).

Even there exist some similarities between French and Basque trawling fleets there are also many differences such us the gear design, fishing grounds, target species, trawling speed and so on. Thus not only is necessary but interesting to analyse the effect of the square mesh panel selectivity device in this multispecies fishery, with special attention focused on hake, but also in another two species such as pout (*Trisopterus spp.)* and red mullet (*Mullus surmuletus*), which are also important target species for this fleet

Thus the proposed study would improve the exploitation pattern of the trawling fleet from the Basque country. With this, in the current scenario of revision of the technical measures for conservation of fishery / marine environment, this study would provide technical arguments to the fisheries sector, to suggest possible technical conservation measures that would affect the fishery.

1.4. Fish behaviour

In a broad sense, fish behaviour can be defined as the adaptation of fish to internal and external environments and to natural and artificial stimuli (He 2010), habitat selection, aggregation patterns, avoidance reactions and learning, may influence the most common stock assessment method.

In a narrower sense, related to fish capture, fish behaviour can be considered the reaction of fish to physical and chemical stimuli associated with the fishing gear and its operation. With the continuous developments in underwater instrumentation, many fish behaviour studies centred on improving fishing gear efficiency and improving the mesh selection process.

1.4.1. Fish behaviour in bottom trawl gears

The process by which the fish enter and are retained involves a complex sequence of fish behaviours in response to the fishing vessel and the different parts that compound the rigging of the trawl (Winger 2010). Analysing this behaviour patterns represent a critical step in the effective design of selectivity devices in trawl gears. Different species would have different behaviour in response to visual and auditory stimuli produced by the vessel, doors, sediment clouds, sweeps, ground gear and trawl netting. There are more than 100 studies since 1960 related to fish behaviour and their interaction with trawl gears, direct observations of fish behaviour (Graham et al., 2004) regarding their response to towed trawls (Glass and Wardle, 1995, Piasente et al., 2004) and to the herding and escape responses to selective systems (Grimaldo et al., 2007; Kim et al., 2008).

Related to hake behaviour in trawl gears, Queirolo (2009) found significant differences were observed in the Chilean hake (*Merluccius gayi gayi*) behaviour in different sections of the trawl, demonstrating that this species is more active in the

mouth of the net. The fish activity was lower in the trawl extension, where the fish were merely carried by the flow into the net.

1.5. EU Management

The European Commission is promoting the use of more selective fishing gears that ones currently employed by the Community fleets. In recent years the discussion, especially in the European Community, has been about the need of identifying responsible fishing methods and ecological response, leading to an "ideal gear". Several studies reveal (Bjordal, 2002) that the fishing methods that drag the bottom (otter trawls, dredges, beam trawls) are less ecological (Fig 5).
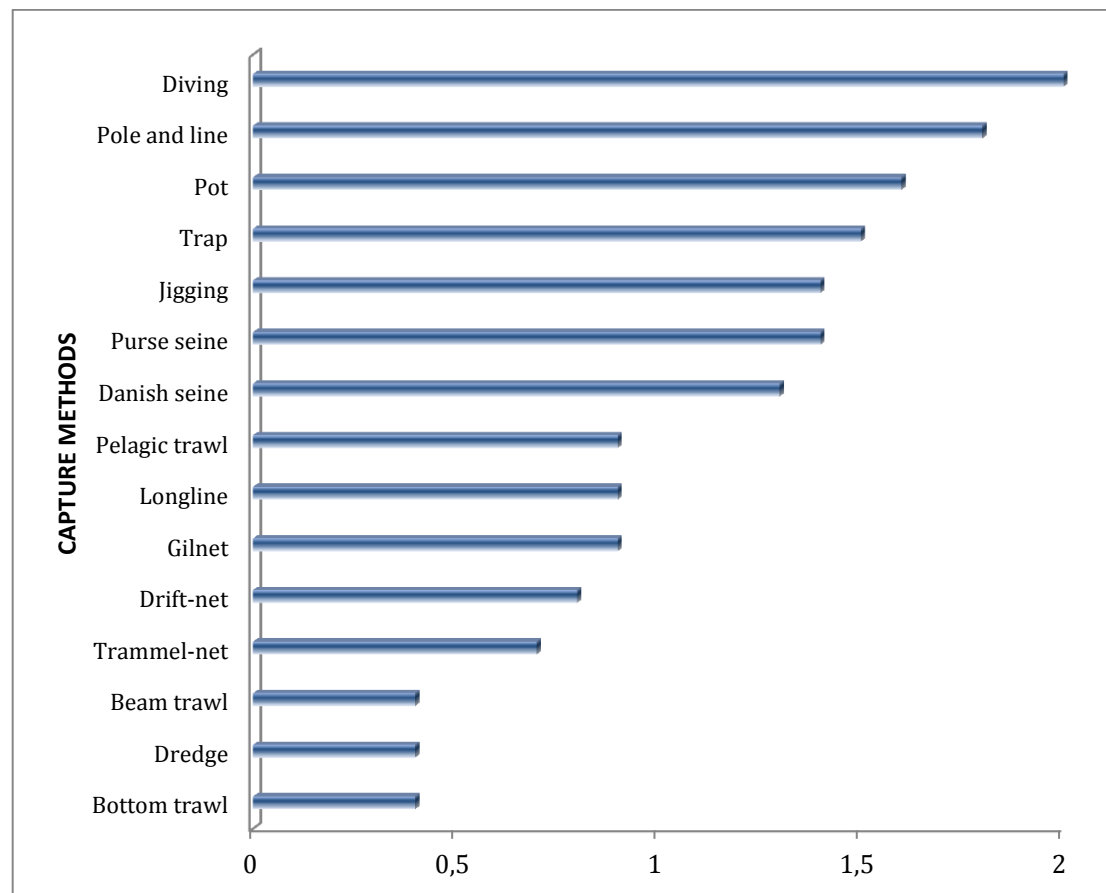
Figure 5: Responsible fishing methods or ecological, classified according to an index compiled from 12 variables (quality of the catch, size and species selectivity, impact on the environment, energy cost per kilo catch, discards, fish caught welfare, safety, life art, art cost, ease of use and applicability (0 = less responsible, 2 = more responsible)).

In addition, the practice of discarding in the Community fishing fleet is being questioned from different political and media strata. The problem of discards in fisheries is a key factor when highlighting the fact that the fishery is not only affecting the species of commercial interest, but also to marine ecosystem as a whole. The impact on the marine habitat of certain fishing gear and the pressure on target species, have implications that go beyond the individual populations and affect the functioning of the ecosystem.

1.5.1. Current scenario

It is a fact that European policies are intended primarily to a reduction or minimization of discards (Communication from the Commission to the Council and Parliament - A policy to reduce by-catches and eliminate discards in European fisheries {SEC- (2007) 380} {SEC (2007) 381}). In the near future the practice of discarding will be prohibited by the European Commission, forcing the vessels to land the entire catch which would be a major setback for the trawler fleet. The boats are not designed for bulk storage of fish and would have no ability to store all the fish from an actual fishing trip. Additionally, the discard ban would result an extra work for the crews. At the same time, the obligation to land the discard would cause a major contradiction; this is the case of those species that despite having commercial value and regulatory size are discarded by some European fleets, as happens with the hake. The reason for the discarding of these species is based on the principle of relative stability, in which some European fleets have no quotas.

The trawler fleet does not seem to be willing to diversify its current activity and switch to a more selective type of gear, due to recent modernizations in the fleet. In this situation, it seems that the only way out is to seek an increased selectivity for

the fishing gear used today, especially the bottom trawl. Mesh size defined by the legislation does not prevent nor bycatch neither catch of undersized fishes (Meillat 2004). An improvement of the selectivity of bottom trawls operating in the Bay of Biscay is thus essential to reverse this situation, especially for hake whose stock is judged in a such state that a rebuilding plan was designed in 2001, been focused on recovering the stock level up to a level consistent with the precautionary approach (Garcia et al. 2011). Conservation of fisheries resources through technical measures for the protection of juveniles of marine organisms entered into force in 2007 by European Council Regulation (Anonymus 2011). One of the technical measures enforced by the Council Regulation (EC) No 41/2007 of 21 December 2006, is the use of selective devices for towed gears. Appendix 3 from Annex III specifies the conditions for fisheries with certain towed gears authorized in ICES zones III, IV, V, VI, VII and VIII a, b, d, e, (see Annex I), to minimize the impact of discards and juvenile overexploitation. This regulation affects directly to the Basque trawler fleet operating in the ICES Zones VIII a, b, d, e. This is the fleet segment subject to study in this report.

1.5.2.   *Implementation of selective devices in the Barents Sea trawl fisheries.*

We found in Norwegian-Russian fisheries management, in the Barents Sea, one of the clearest examples in the use of sorting devices in trawl gears making it possible to develop and implement by-catch reducing devices in trawls. In 1991/1993 the by-catch excluder device Nordmöregrid became compulsory in all northern shrimp trawling. Rigid sorting grids for size selective fish-trawls were developed in the early 1990s (Larsen and Isaksen 1993), and became mandatory in 1997 in the Barents Sea for all fish trawl fleets (regardless of nationality), all trawlers fishing in the Norwegian waters of the Barents Sea have been required to use a sorting grid with a minimum bar spacing of 55 mm followed by a codend with a minimum diamond mesh size of 135 mm (Grimaldo 2007).

1.6. Objectives

This study is a part of a project that is been developed in the Basque research centre AZTI-Tecnalia (www.azti.es). The aim of this research is to determine the parameters of selectivity for the fishing gear used by the trawler fleet in the Basque Country for the main target species of this fishery. While the general aim of the project is to minimize the discarding of fish in general, this would enhance the environmental sustainability of this fishery; the following specific objectives will be addressed:

- Determine the size distribution of the selected species in the catch.

- Analyse the selectivity of the gear setup including the square mesh panel.

- Prioritize species which discard is aiming to reduce, based on technical criteria.

- Characterize the behaviour of different fish species in the different sections of the trawl gear with underwater observations.

2. METHODS

2.1. Data acquisition

The data acquisition for the present study was carried out onboard the fishing vessel F/V "Gure Gaskuña" (figure 6) during the winter of 2011 in the French coast (ICES subzone VIII abd). Two cruises were conducted as described in Table 1. During these cruises the vessel operates in commercial way, with the conventional gear, with intent to fish in the fishing grounds in which normally works, with the only exception that some of the hauls were used to try to determine the gear selectivity.

Figure 6. F/v "Gure Gaskuña" source: Marm

Table 1. Cruise description

Departure Port	Departure date	Arrival Port	Arrival date	Days at sea	ICES Div.
Ondarroa (Spain)	28/11/2011	Ondarroa (Spain)	4/12/2011	7	VIIIabd
	17/12/2011		23/12/2011	7	

The main characteristics of the fishing vessel "Gure Gaskuña" are described in the table below (table 2).

Table 2. Main characteristics of the fishing vessel "Gure Gaskuña"

Name	Calling signal	Total length (m)	Power (HP)	GT
Gure Gaskuña	ECNV	39	590	*432*

The trawl gear used during the cruise is the conventional trawl used by this fleet known as "baka" and is shown in the figure 7. The footrope is 102 meters long, the headline 81 meters and develop a vertical and horizontal opening around 2 and 30 meters respectively (measured with Scanmar trawl monitoring system). The rigging is composed by 600 meters of steel cable (22 mm diameter) attached to Morgere Polyfoil otter boards (4 m^2 and 1000 kg) that develop a distance of about 140 meters. The sweeps constructed with a mixture of PE (polyethylene) and wire (42 mm diameter), are 400 meters long.

The commercial codends used by the Basque fleet are built of 70 mm nominal mesh size. After measuring the codend with mesh gauge OMEGA according the guidelines established by Regulation (EC) No. 517/2008 of the Commission on June 10, 2008, where 20 meshes are measured following a line, then the gauge calculate the mean length of the meshes, the value obtained for the codend used during the sea trials was 75.3 mm mesh size.
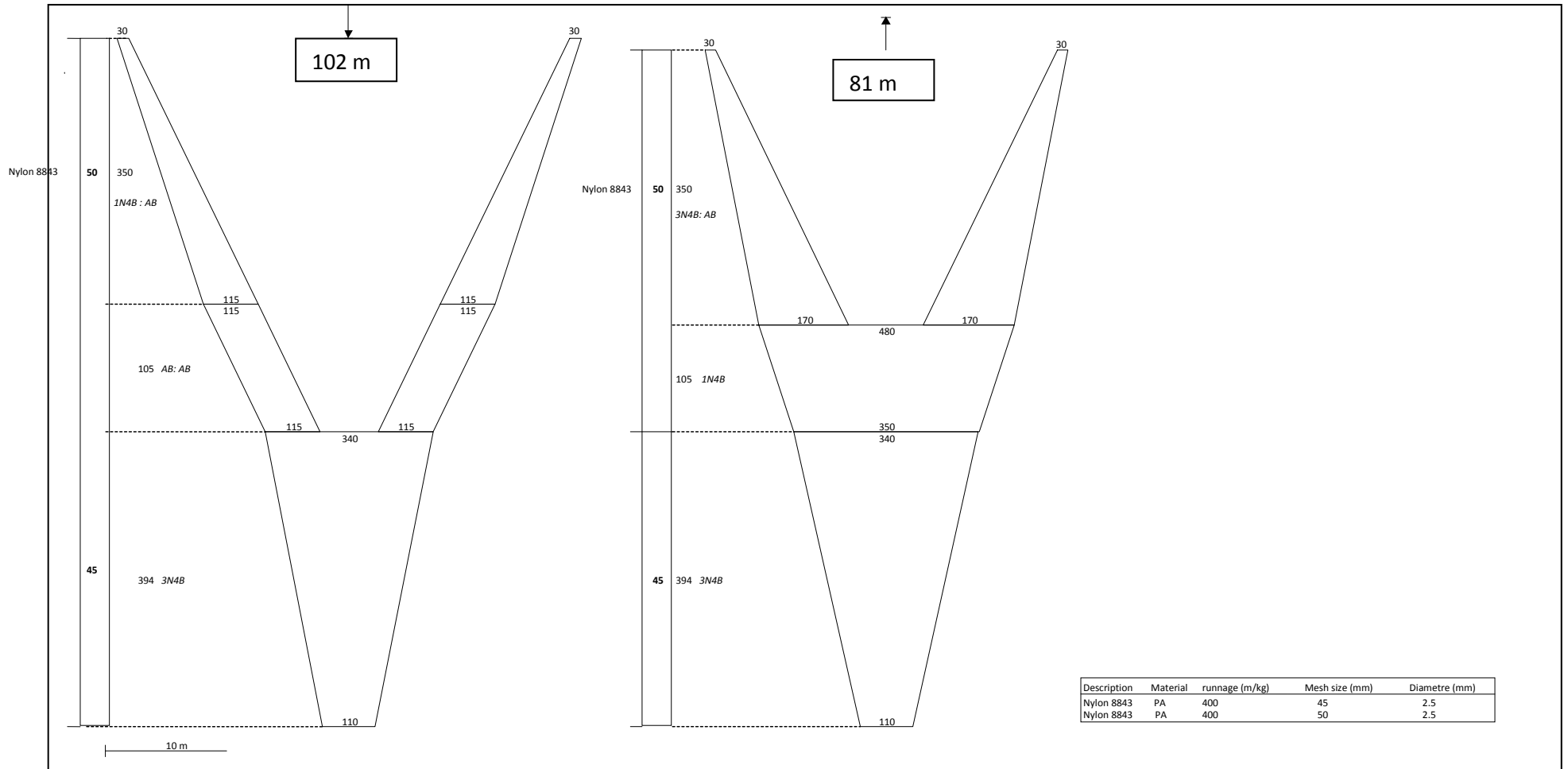
Figure 7: "Baka" bottom trawl, 102 m footrope trawl.

In Order to determine the gear selectivity of the commercial codend, we used the cover codend method described by Wileman (1996). The codend cover constructed with a netting panel of 37.0 mm mesh size and 13 meters long (figure 8), mounted with two rigid rings of 5 and 6,3 meters of perimeter) to avoid the contact and masking effect between the codend and the cover (figure 9). The length of the codend cover is 1,5 times the codend length as recommended by Stewart and Robertson (1985). The cover codend method is considered as a valid method when the catch is small (Wileman 1996).

To test the dual selection system 70 mm codend + 100 mm square mesh panel used in this fishery, sea trials were performed with a 3 compartment setup for collecting fishes escaping through the selectivity device, codend and the retained fish in the codend.

The selected species were measured onboard to the nearest centimetre below in the hauls with 3 compartments setup. For the data analysis, the method to assess dual selection systems proposed by Sistiaga (2010) has been used. This method is integrated in the software SELNET* and takes into account the "contact likelihood", which can be interpreted as the proportion of fish attempting to escape through the selectivity device.
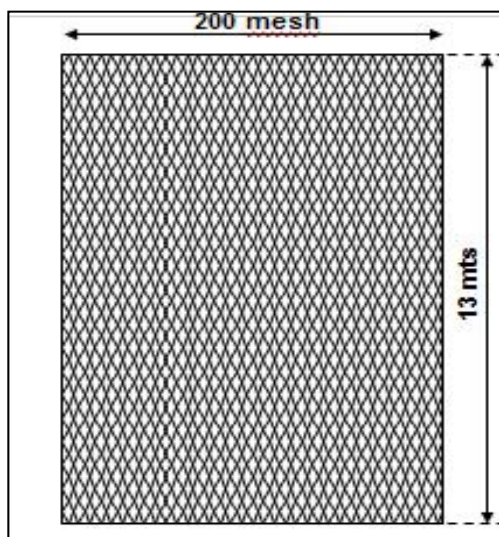
Figure 8: Cover codend netting panel
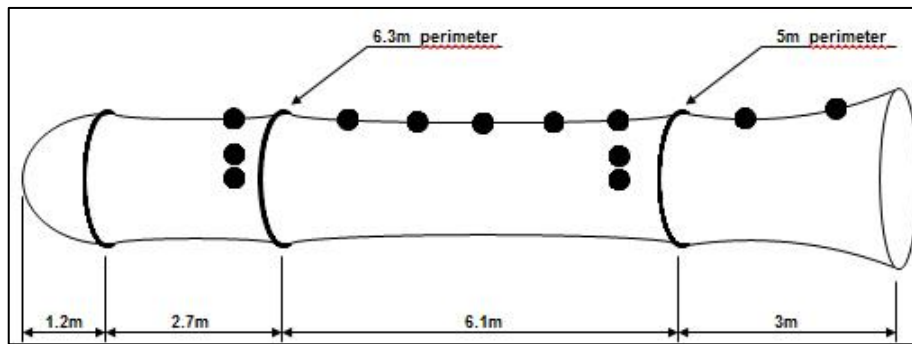
Figure 9: Complete codend cover scheme.

Figure 10 Codend cover at the trawl factory and on board.

The mesh size of the mandatory square mesh panel was 106.6 mm. A collecting bag was placed over the square mesh panel, in order to collect all the fish escaping through the panel (Figure 11 and 12). This small collecting bag of 48.7mm mesh and 3.6 meters long was fitted with three rings of PVC and floats, to avoid the net closing and masking effect. The complete gear setup is shown in the figure 13. All the mesh measurements where done according to guidelines of the OMEGA gauge as described earlier.
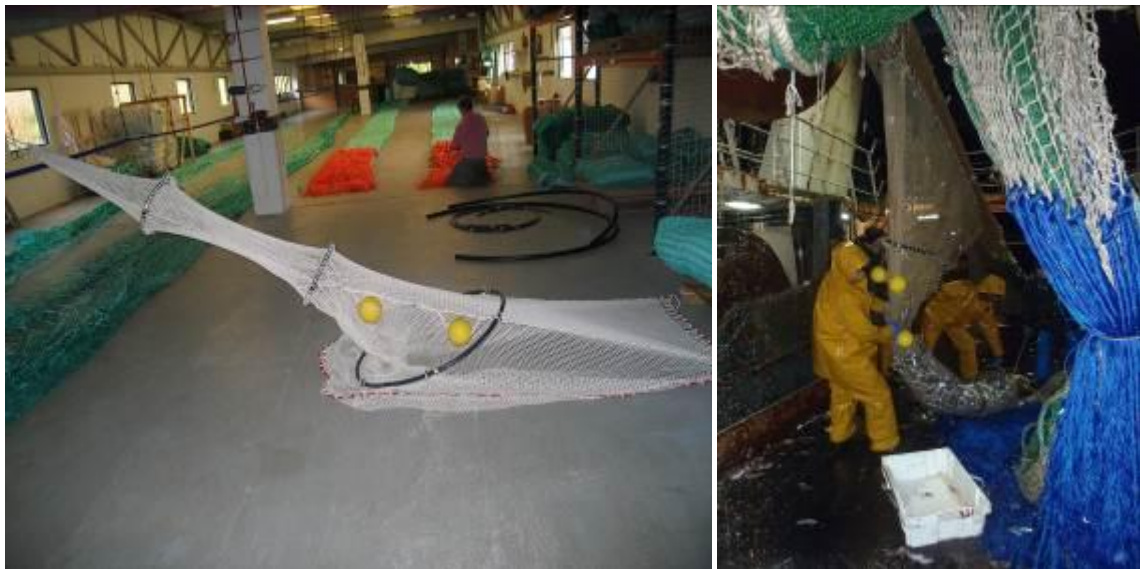
Figure 11:. Collecting bag to cover the square mesh panel.
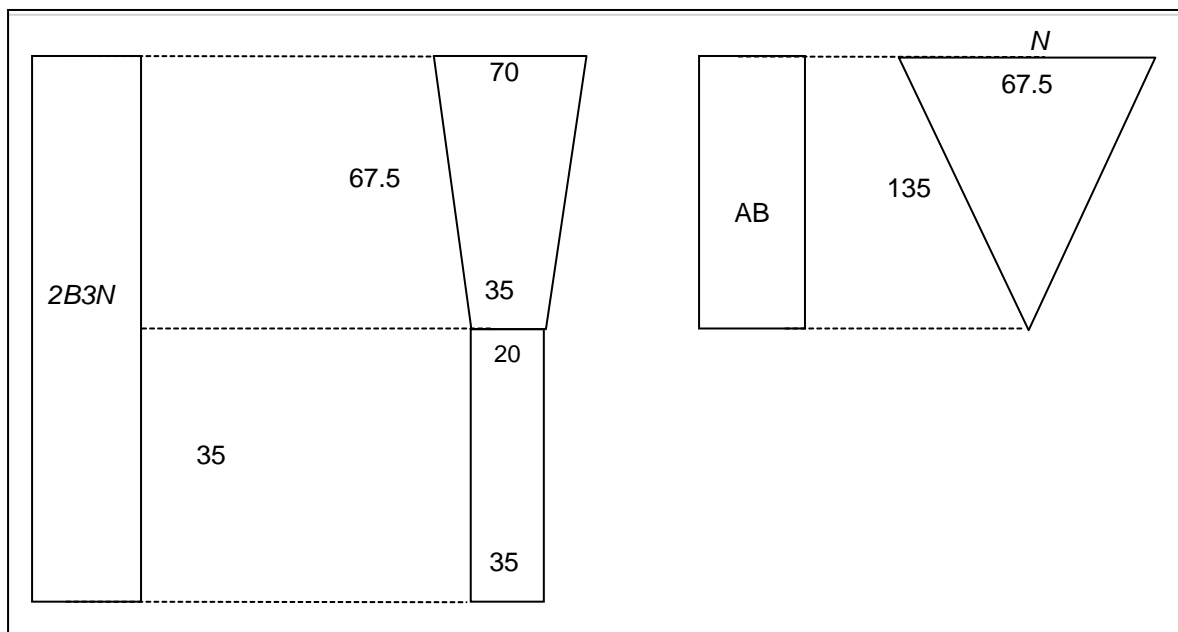
Figure 12: Construction-drawing of the collecting bag for the square mesh panel.
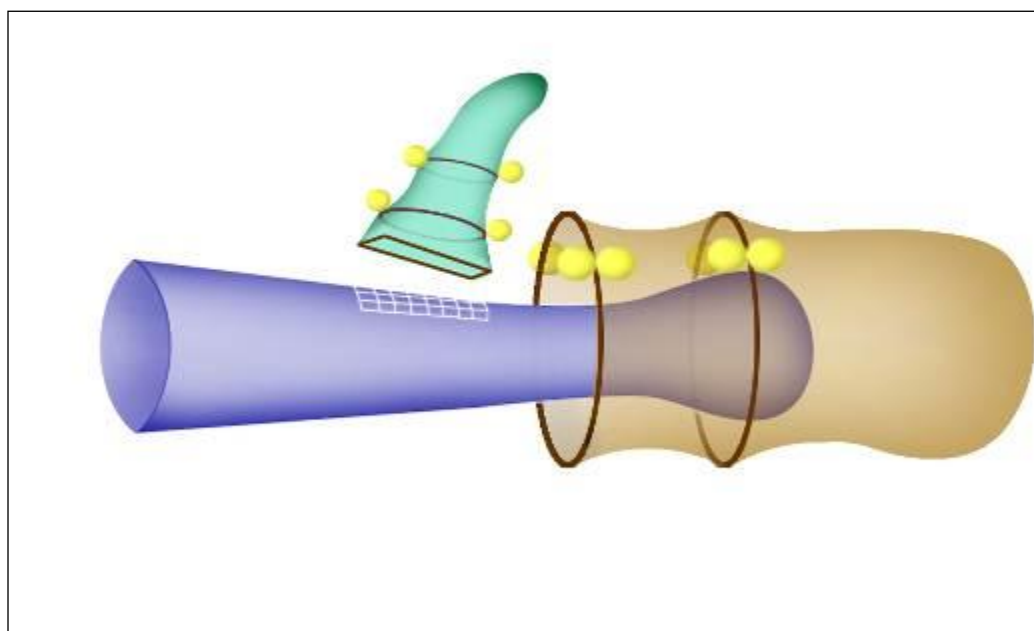
Figure 13. The trawl gear complete setup used for selectivity experiments

The selectivity setup was used in 15 hauls during the two cruises and fish samples from the codend and two covers were collected and measured in order to determine the selectivity of the gear. Previous studies with underwater observations, revealed that escapement through the square mesh panel was quite low, showing huge turbidity in this part of the trawl that could affect fish visibility and behaviour related to the panel contact. In order avoid this effect; during the second cruise another identical second square mesh panel was placed in 8 hauls. This one fitted 6 meters ahead the mandatory one.

The selectivity determination was focused on three species, hake (*Merluccius merluccius*), red mullet (*Mullus surmuletus*) and pout (*Trisopterus spp.*). Although these species provides information about the selectivity parameters of the gear, also were selected due to their usual presence in the catch and their important economic value. Length measurements for these species were recorded to the nearest centimetre below. For large catches, due to lack of time and resources, subsampling was carried out.

2.2. Data analysis

The model structure for data analysis it's identical to the one described by Sistiaga (2010) since the method to collect the data is a three-compartment setup, codend, codend cover

and square mesh panel cover. Sistiaga (2010) not only considered the dual aspect of the selection process in a combined selection device but also the "grid contact likelihood" (Cgrid) which can be interpreted as the proportion of fish attempting to escape through the selectivity device, in our case instead of Cgrid we will use Cpanel.

Because we used a three-compartment experimental design for each haul and each length class (l), our data included the number of fish in the square mesh panel cover (npcl), in the codend cover (ncc_l) and in the codend (nc_l). Assuming that the fate of each fish is independent of that of other fish, the number of individuals of a specific length class l present in the three compartments (PC, CC, and C) can be modelled using a multinomial distribution with length-dependent probabilities for escapement through the square mesh panel ($e_{panel}(l)$) and through the codend ($e_{codend}(l)$) and for being retained in the codend r(l). For the fish actually coming into contact with the square mesh panel and attempting to escape through it, we assumed that the length-dependent retention likelihood can be described by a logit model with the parameters $L50_{panel}$ and SR_{panel}. We assumed that the likelihood of the fish coming into contact with the square mesh panel (C_{panel}) can be modelled by a single length independent number that ranges between 0.0 and 1.0. A C_{panel} value of 1.0 would mean that every fish came into contact with the square mesh panel and attempted to escape through it. For the fish entering the codend, we assumed that the retention likelihood can be described by a logit model with parameters $L50_{codend}$ and SR_{codend}. On a haul-by-haul basis, the parameters C_{panel}, $L50_{panel}$, SR_{panel}, $L50_{codend}$, and SR_{codend} were estimated simultaneously by maximizing the corresponding likelihood function for the assumed model. Thus, function (1) was minimized, which is equivalent to maximizing the likelihood for the observed data.

$$\sum \{ncl \times \ln(r(l)) + npc_l \times \ln(e_{panel}(l)) + ncc_l \times \ln(e_{codend}(l))\} \qquad (1)$$

The summation is over the length classes (each 1 cm wide). The length-dependent likelihood functions are given by:

$$e_{panel}(l) = C_{panel} \times (1.0 - \log it(l, L50_{panel}, SR_{panel}))$$
$$e_{codend}(l) = (1.0 - \log it(l, L50_{codend}, SR_{codend})) \times (1.0 - e_{panel}(l)) \qquad (2)$$
$$r(l) = 1.0 - e_{panel}(l) - e_{codend}(l)$$

where

$$\text{log}it(l, L50, SR) = \frac{\exp((\ln(9) \times (l - L50)/SR))}{1.0 + \exp((\ln(9) \times (l - L50)/SR))} \qquad (3)$$

The data were analysed using the computer software SELNET (SELection in trawl NETting). SELNET is a flexible software tool developed to acquire, analyze, and simulate size selectivity and catch data for towed fishing gears. Apart from being able to analyse data obtained from sea trials using a two-compartment experimental sampling setup (such as the standard covered codend and paired gear methods described in Wileman et al., 1996), SELNET enables the analysis of data for experimental designs involving multiple compartments by means of complex selection models that include the one represented by (1)–(3).

Using a three-compartment setup is a more complicated approach than using a two-compartment setup. Thus, this approach involves pooling data for all the hauls in each study case and applying (1)-(3) to the pooled data. According to Fryer (1991), pooling haul data and then applying the standard methods for estimating parameter standard errors would lead to an underestimation of these errors and consequently of their 95% confidence intervals (CI). To solve the problem of underestimating the confidence limits for the average parameter values, SELNET used a double bootstrapping method (Efron, 1982; Manly, 1997) instead of the standard approach. According to Millar (1993), if between-haul variation is not of primary interest, then fitting the model to the pooled data should remain a reasonable approach to estimate the "average" selectivity for the fishery. Therefore, the sample of experimental hauls for each study case must be a representative sample from that fishery (Millar, 1993). Each bootstrap resulted in a "pooled" set of data, which then was analyzed using (1)–(3) and the procedure described above for estimating the combined parameters. Thus, each bootstrap run resulted in a set of values for $L50_{combined}$, $SR_{combined}$, C_{panel}, $L50_{panel}$, SR_{panel}, $L50_{codend}$, and SR_{codend}. Series of 2000 bootstrap repetitions were run for each study case using this method, which enabled us to estimate the 95% confidence limits (Efron percentile) for the average value of each parameter.

To analyze the effect in the square mesh panel, SELNET allows the possibility to perform a 2-compartment analysis, with the same data, comparing the catches of the codend against the ones in the codend cover. The clogit model account for the situation where not all fish would be able to contact the codend netting and attempt to escape through the meshes. This is accounted for by the contact parameter c (constrained to the interval [0.0; 1.0]). For a value of 1.0 clogit simplify to the logit model. 1-c quantify the likelihood for fish not having at least one escape attempt through the codend meshes given it enters the codend, and is expressed as:

$$\text{clog}it(l,\ L50,\ SR, c) = 1.0 - c + c \times \frac{\exp((\ln(9) \times (l - L50)/SR))}{1.0 + \exp((\ln(9) \times (l - L50)/SR))} \tag{4}$$

As for the three compartment setup, series of 2000 bootstrap repetitions were run for each study case using this method, which enabled us to estimate the 95% confidence limits (Efron percentile) for the average value of each parameter.

3. RESULTS

3.1. Sea trials

During the cruises a total of 54 hauls were performed, 15 of them with the gear setup showed in figure 13, for selectivity experiments. The haul characteristics are shown in table 3; with dark background the 15 sets with the selectivity setup. All the hauls had a similar duration, close to 3 hours, and they were conducted at a speed around 4 knots.

During the first cruise the vessel operated around 46º N, the depth range vary from 19 to 82 fathoms, but two fishing grounds were clearly differentiated. Shallow waters about 25 fathoms and deeper waters about 75 fathoms presented different catch compositions between both grounds. A total of 29 hauls were performed where 9 of them were done with the covered codend method and the square mesh panel cover (Fig. 10). 3 of these 9 hauls were rejected due to trawl damages while fishing.

The same pattern was followed in the second cruise, but in a more southern area, around 45º N. Nevertheless, in this cruise only two hauls were made in deep waters. A total of 26 hauls were performed; 6 of them were done with the selectivity device. Figure 14 shows in blue the hauls performed with the covered codend method and the square mesh panel cover, from 1 to 9 in the first cruise and from 10 to 15 in the second cruise.
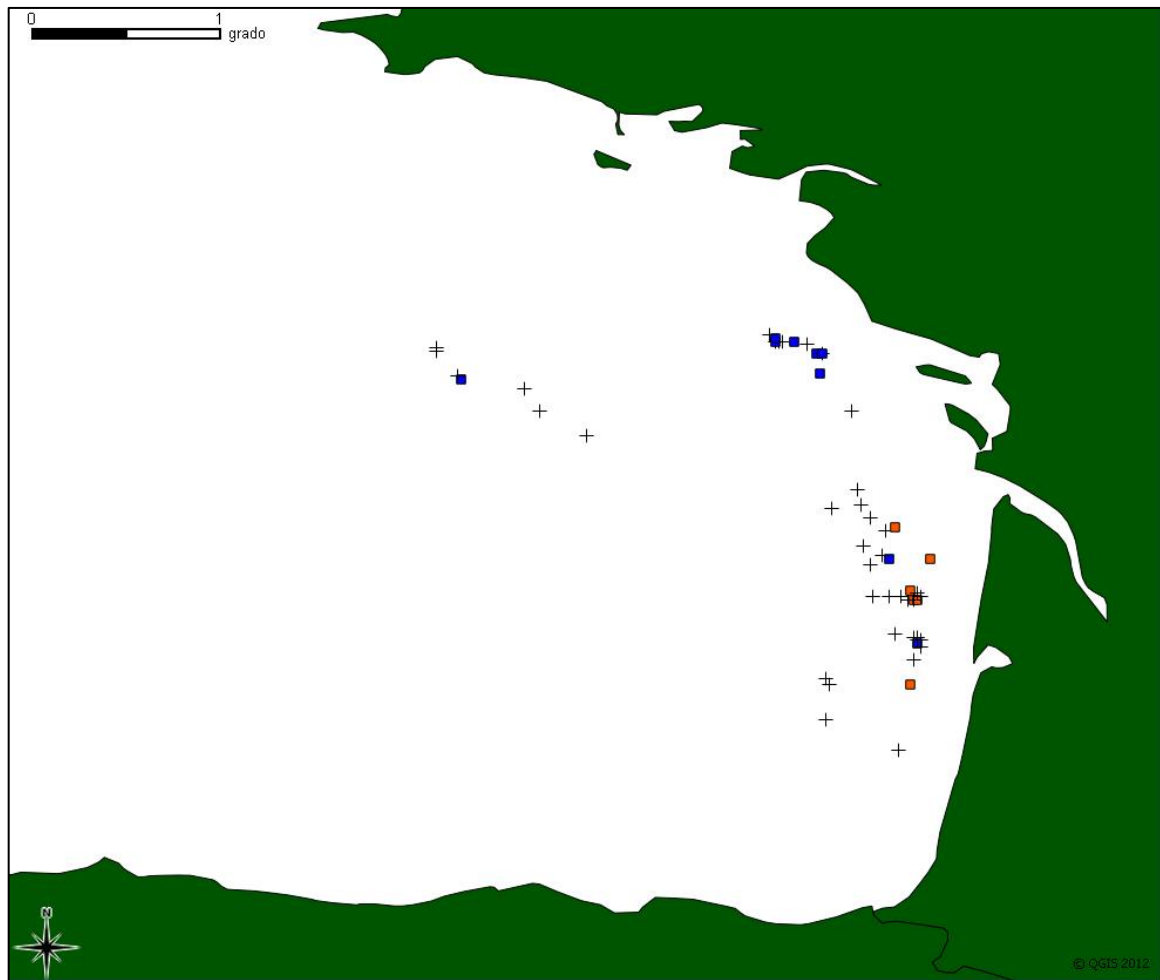
Figure 14. Plotted hauls during the two cruises. Blue spots, hauls from 1st cruise for selectivity experiments, orange spots hauls from 2nd cruise for selectivity experiments. Crosses the rest of commercial hauls.

In tables 3a and 3b haul information about the two cruises are given, i.e. showing dates, times, areas, towing depths and towing speeds.

Table 3a and 3b: Hauls description showing date, time, area, depth (fathoms) and towing speed for each haul.

(3a) First cruise

| Haul nº | Haul start | | | | | Haul finish | | | | | Speed |
	Date	Hour	Lat.	Long.	Depth (fath)	Data	Hour	Lat.	Long.	Depth (fath)	(knots)
1	29/11/2011	0:40	44º 13´N	01º39´W	54	29/11/2011	4:52	44º 30´N	01º 37´W	52	4
2	29/11/2011	6:55	44º 47´N	01º 33´W	38	29/11/2011	9:55	44º 59´N	01º 35´W	36	4
3	29/11/2011	10:40	45º 01´N	01º 36´W	36	29/11/2011	14:00	45º 14´N	01º 42´W	35	4
4	29/11/2011	14:30	45º 14´N	01º 42´W	35	29/11/2011	18:05	45º 15´N	01º 41´W	35	4
5	30/11/2011	0:20	46º 01´N	01º 54´W	25	30/11/2011	3:20	46º 12´N	02º 03´W	26	4
6	30/11/2011	3:50	46º 13´N	02º 04´W	23	30/11/2011	6:50	46º 22´N	02º 13´W	22	4
7	30/11/2011	7:35	46º 23´N	02º 18´W	27	30/11/2011	8:30	46º 22´N	02º 07´W	26	4
8	30/11/2011	9:15	46º 23´N	02º 17´W	27	30/11/2011	12:00	46º 18´N	02º 04´W	21	4
9	30/11/2011	12:30	46º 19´N	02º 05´W	18	30/11/2011	15:30	46º 24´N	02º 21´W	27	4
10	30/11/2011	16:10	46º 23´N	02º 16´W	25	30/11/2011	18:35	46º 21´N	02º 04´W	20	4
11	30/11/2011	19:25	46º 19´N	02º 03´W	19	30/11/2011	22:25	46º 24´N	02º 19´W	26	4
12	30/11/2011	23:00	46º 23´N	02º 18´W	26	01/12/2011	2:00	46º 20´N	02º 02´W	17	4
13	01/12/2011	2:55	46º 19´N	02º 03´W	18	01/12/2011	5:55	46º 24´N	02º 19´W	26	4
14	01/12/2011	7:00	46º 24´N	02º 18´W	27	01/12/2011	8:45	46º 20´N	02º 04´W	´22	4
15	01/12/2011	12:00	46º 22´N	02º 08´W	20	01/12/2011	12:50	46º 24´N	02º 12´ W	21	4
16	01/12/2011	13:20	46º 23´N	02º 12´W	21	01/12/2011	14:00	46º 24´N	02º 18´W	24	4
17	01/12/2011	14:35	46º 25´N	02º 20´W	22	01/12/2011	17:00	46º 26´N	02º 23´W	27	4
18	02/12/2011	0:15	46º 08´N	03º 38´W	77	02/12/2011	3:15	46º 10´N	03º 55´W	75	3,9
19	02/12/2011	3:55	46º 11´N	03º 58´W	78	02/12/2011	6:40	46º 20´N	04º 05´W	79	3,9
20	02/12/2011	7:30	46º 21´N	04º 06´W	79	02/12/2011	10:00	46º 12´N	03º 59´W	76	3,9
21	02/12/2011	10:40	46º 12´N	03º 59´W	80	02/12/2011	13:05	46º 21´N	04º 06´W	79	3,9
22	02/12/2011	13:50	46º 20´N	04º 06´W	79	02/12/2011	16:20	46º 12´N	03º 58´W	78	3,9
23	02/12/2011	18:50	46º 01´N	03º33´W	72	02/12/2011	21:35	45º 54´N	03º 20´W	76	3,9
24	02/12/2011	22:15	45º 53´N	03º 18´W	75	03/12/2011	1:00	45º 46´N	03º 07´W	70	4
25	03/12/2011	6:50	45º 31´N	01º 51´W	36	03/12/2011	7:45	45º 28´N	01º 49´W	35	4
26	03/12/2011	8:10	45º 27´N	01º 48´W	35	03/12/2011	10:45	45º 17´N	01º 44´W	36	4
27	03/12/2011	11:20	45º 15´N	01º 44´W	38	03/12/2011	14:20	45º 04´N	01º 38´W	37	4
28	03/12/2011	14:50	45º 02´N	01º 38´W	37	03/12/2011	17:05	44º 54´N	01º 35´W	36	4
29	03/12/2011	21:05	44º 34´N	02º 01´W	79	03/12/2011	0:15	44º 22´N	02º 02´W	82	4

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(3b) Second cruise

Haul nº	Haul start					Haul finish					Speed
	Date	Hour	Lat.	Long.	Depth (fath)	Data	Hour	Lat.	Long.	Depth (fath)	(knots)
1	17/12/2011	22:30	45° 02´N	01°47´W	45	18/12/2011	2:00	45° 16´N	01° 49´W	40	4
2	18/12/2011	2:35	45° 18´N	01° 50´W	38	18/12/2011	6:15	45° 31´N	01° 59´W	41	4
3	18/12/2011	6:50	45° 30´N	02° 00´W	43	18/12/2011	10:10	45° 23´N	01° 45´W	32	4
4	18/12/2011	10:40	45° 23´N	01° 43´W	30	18/12/2011	14:15	45° 37´N	01° 50´W	36	4
5	18/12/2011	14:55	45° 36´N	01° 52´W	35	18/12/2011	18:25	45° 25´N	01° 40´W	26	4
6	18/12/2011	19:00	45° 24´N	01° 40´W	25	18/12/2011	21:25	45° 15´N	01°30´W	23	4
7	18/12/2011	22:10	45° 14'N	01° 29´W	24	19/12/2011	1:40	45° 04´N	01° 38´W	37	4
8	19/12/2011	2:20	45° 02´N	01° 42´W	41	19/12/2011	6:35	44° 45´N	01° 40´W	49	4
9	19/12/2011	7:40	44° 49´N	01° 34´W	34	19/12/2011	10:50	45° 01´N	01° 34´W	34	4
10	19/12/2011	11:15	45° 01´N	01° 34´W	34	19/12/2011	14:15	44° 48´N	01° 33´W	36	4
11	19/12/2011	14:45	44° 49´N	01° 33´W	36	19/12/2011	18:15	45° 24´N	01° 35´W	34	4
12	19/12/2011	18:50	45° 04´N	01° 35´W	36	19/12/2011	22:15	44° 32´N	01° 40´W	46	4
13	19/12/2011	22:55	44° 50´N	01° 40´W	48	20/12/2011	2:25	44° 36´N	01° 40´W	54	4
14	20/12/2011	3:25	44° 34´N	01° 35´W	47	20/12/2011	6:45	44° 47´N	01° 33´W	37	4
15	20/12/2011	7:30	44° 49´N	01° 33´W	35	20/12/2011	10:45	45° 02´N	01° 33´W	33	4
16	20/12/2011	11:20	45° 01´N	01° 33´W	33	20/12/2011	14:25	44° 48´N	01° 33´W	36	4
17	20/12/2011	15:05	44° 46´N	01° 32´W	37	20/12/2011	17:55	44° 34´N	01° 33´W	44	4
18	21/12/2011	13:05	44° 42´N	01° 34´W	40	21/12/2011	18:15	45° 02´N	01° 32´W	31	4
19	21/12/2011	18:45	45° 03´N	01° 33´W	32	21/12/2011	22:20	45° 12´N	01° 49´W	41	4
20	21/12/2011	23:00	45° 12´N	01° 48´W	40	22/12/2011	2:45	45° 03´N	01° 33´W	34	4
21	22/12/2011	3:15	45° 02´N	01° 32´W	32	22/12/2011	6:50	44° 48´N	01° 31´W	30	4
22	22/12/2011	7:25	44° 48´N	01° 32´W	30	22/12/2011	10:45	45° 02´N	01° 34´W	34	4
23	22/12/2011	11:20	45° 01´N	01° 34´W	34	22/12/2011	14:30	44° 48´N	01° 33´W	38	4
24	22/12/2011	15:00	44° 48´N	01° 33´W	37	22/12/2011	18:30	45° 02´N	01° 35´W	35	4
25	22/12/2011	22:00	44° 36´N	02° 02´W	82	23/12/2011	0:50	44° 25´N	02° 02´W	80	4
26	23/12/2011	1:25	44° 23´N	02° 02´W	83	23/12/2011	3:50	44° 13´N	02°00´W	83	4

During the cruises three different species were studied, hake, red mullet and pout. Anglerfish and megrims were discarded in this study due to their shape. The size distribution for the three species in the different compartments has been analysed, as well as the average selectivity parameters of the gear.
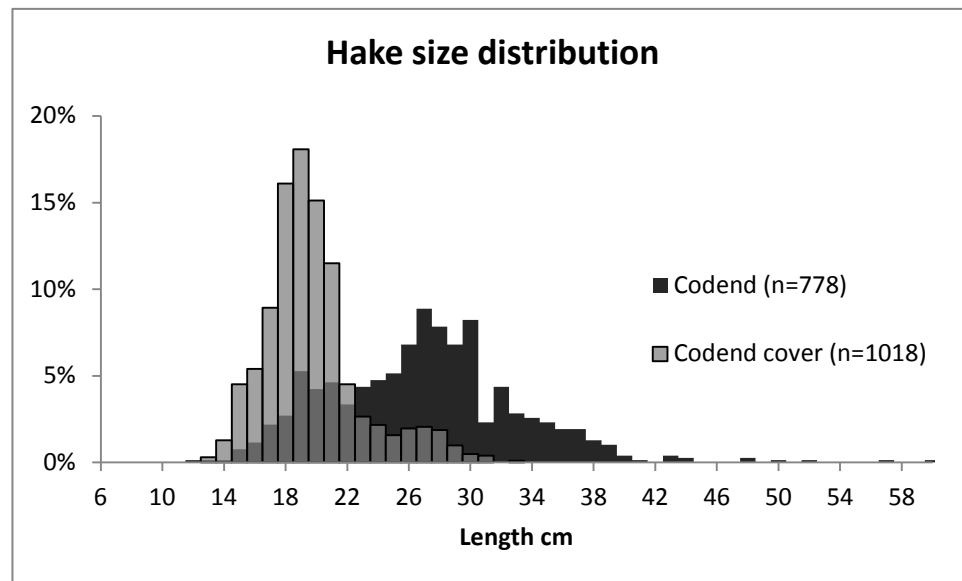
3.2. Size distribution

In this section the size distribution of the selected species is analyzed for the codend and codend cover catches. The size distribution of fishes escaping through the square mesh panel has been excluded in this first comparison and described later on, due to the order of magnitude and would not be appreciated in the charts. In the following table are described the catches of the selected species per haul and per compartment are described.

Table 4: N° of fishes measured onboard per specie, haul and compartment.

Haul n°	HAKE			RED MULLET			POUT		
	Codend	SQM Panel	Codend Cover	Codend	SQM Panel	Codend Cover	Codend	SQM Panel	Codend Cover
CRUISE 1									
2	289	6	30	839	19	479	41	2	14
4	16	2	3	2050	19	2250	0	0	0
6	12	0	0	165	1	508	177	0	26
9	2	0	0	1020	19	217	213	4	11
12	0	0	0	131	2	477	160	0	13
13	0	0	0	82	4	212	171	1	28
14	4	0	0	43	0	145	0	0	0
16	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0
CRUISE 2									
6	22	0	15	0	0	0	54	1	22
7	24	0	33	27	0	49	98	0	79
10	0	4	664	22	0	14	378	5	111
12	52	0	13	34	2	8	206	0	14
14	80	0	124	64	0	32	467	0	277
16	277	0	136	7	0	2	14	0	6
Total	778	12	1018	4484	66	4393	1979	13	601

3.2.1. Hake (Merluccius merluccius) size distribution.

The graph below (Figure 15) shows the relative proportion retained by the codend and codend cover according to the size distribution obtained from measurements made in the 12 hauls in which the codend cover was placed.

Figure 15. Frequency /size distribution of the hake in the codend and codend cover.

The length range for this species is between 12 and 60 cm. In the codend we found the same range, with a mode of 27 cm. In the codend cover, the length range goes from 13 to 33 cm, with 18 cm mode. The codend cover catch mostly represents the juvenile individuals which can escape through the codend, whilst in the cover it can be appreciated that the mayor part of the catch is between 23 and 30 cm. Lengths between 12 and 33 are overlapped in both compartments.

3.2.2. Red Mullet (Mullus surmuletus) size distribution.

The next histogram (Figure 16) shows the length distribution in the codend and the codend cover for the red mullet (*Mullus surmuletus*). The range oscillates between 9 and 33 cm, where the different lengths are overlapped in both compartments, although the percentage of fishes with lengths above 16 cm is slightly superior in the codend. The mode for these distributions is located at 16 for the codend cover and 17 cm for the codend compartment.
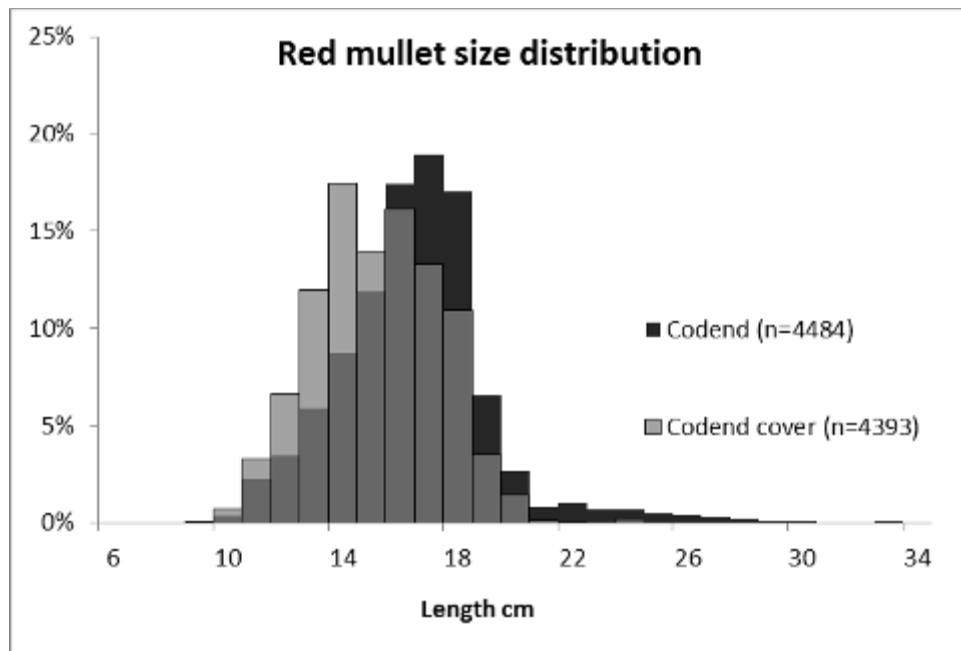
Figure 16. Size distribution of the red mullet in the codend and codend cover.

3.2.3. Pouts (Trisopterus spp.) size distribution.

The next histogram (Figure 17) shows the length distribution in the codend and the codend cover of pouts that can include this two species: *Trisopterus luscus and Trisopterus minutus*. These two species are not differentiated on board, despite the fact that these species are grouped in 2 or even 3 commercial categories based on size. Individuals may be of any of two species in any of these categories. The total length range goes from 7 to 38 cm. Lengths between 14 and 27 are overlapped in both compartments and the mode is located at 21 cm in the codend cover and 22 cm in the codend. Individuals below these mode lengths are more abundant in the codend cover.
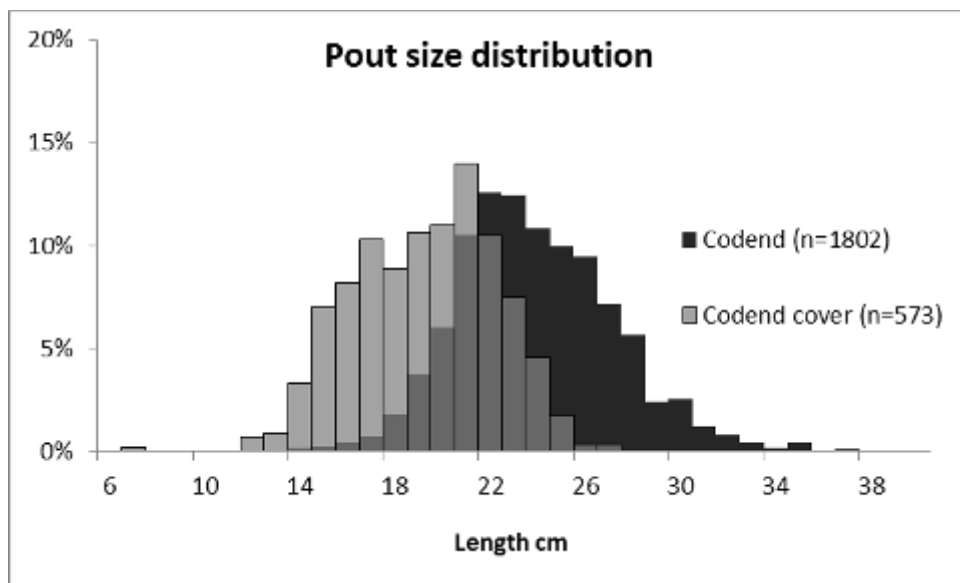
Figure 17. Percentage of retained Pout in the codend.

3.2.4. *Square mesh panel size distribution.*

The fish escaping trough the square mesh panel was very low, with only 12 hakes, 66 red mullets and 13 pouts (Figure 18).
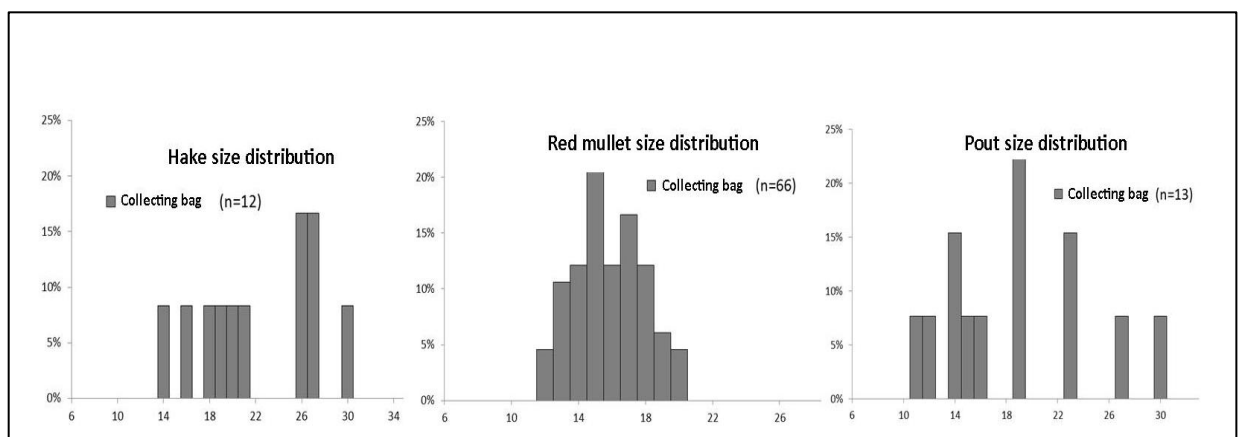

Figure 18. Percentage of the selected species in the square mesh panel-collecting bag

In addition to these three species selected to determine the selectivity, there were some other species that could not be measured due to lack of time and resources. Besides the species appeared in larger amounts, there were others whose amount was testimonial. However it is important to list them since due to their shapes and sizes, a priori they were

not expected to appear in this compartment, due to expected low swimming ability of these specie. These species include some flatfish such as Wedge sole (*Dicologoglossa cuneata*), Scaldfish (*Arnoglossus spp*), Megrims (*Lepidorhombus spp.*) and some molluscs such as squid (*Loligo vulgaris*) and cuttlefish (*Sepia spp.*).

3.2.5. Boxplot.

A boxplot is a way of summarizing a set of data measured on an interval scale. It is often used in exploratory data analysis. It is a type of graph, which is used to show the shape of the distribution, its central value, and variability. The picture produced consists of the most extreme values in the data set (maximum and minimum values), the lower and upper quartiles, and the median [3]. The measurements that are far from others in the data set are represented out of the whiskers and considered as outliers. Boxplots are very useful when large numbers of observations are involved and when two or more data sets are being compared. The next figure (19) shows a comparison between the three selected species in each compartment during the sea trials. In table 5 the numerical representation of the boxplot is shown.
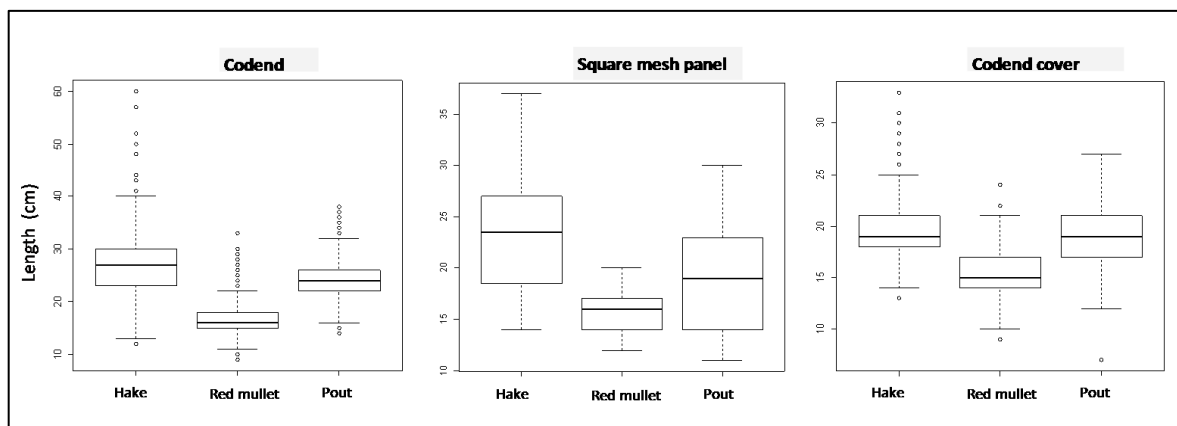
Figure 19. Boxplot of the selected species in the three compartments.

Table 5: Numerical representation of the boxplot statics

CODEND						
(cm)	Min	1qt.	Median	Mean	3qt.	Max
Hake	12	23	27	26.9	30	60
Red mullet	9	15	16	16.4	18	33
Pout	14	22	24	24.1	26	38
SQUARE MESH PANEL						
(cm)	Min	1qt.	Median	Mean	3qt.	Max
Hake	14	18	23	23.4	27	37
Red mullet	12	14	16	15.8	20	20
Pout	11	14	19	18.6	30	30
CODEND COVER						
(cm)	Min	1qt.	Median	Mean	3qt.	Max
Hake	13	18	19	19.7	21	33
Red mullet	9	14	15	15.2	17	24
Pout	7	17	20	19.3	22	27

3.3 Selectivity analysis in SELNET

To test the dual selection system data from the three-compartment setup were analyzed using the software SELNET that has been developed to analyse selectivity data for towed fishing gears. SELNET can handle collection and analysis of data for a number of different experimental designs such as covered codend, paired gear, catch comparison and catch data (Herrmann 2009).

The selection curves for every single haul were calculated. Afterwards pooled data for the three species was compared for three-compartment setup and two-compartment setup, which would determine the effect of the square mesh panel in the selection process. In the following tables (6 and 7) are displayed the selectivity parameters for two-compartment and three-compartment setup respectively. The bootstrapping enables us to estimate the "Efron percentile" 95% confidence limits for the average value of each parameter.

Table 6: 2-compartment setup, average selectivity results and 95% CI (in brackets)

Especie	L50$_{codend}$ (cm)	SR$_{codend}$ (cm)	Contact	P-Value	Deviance	DOF
HAKE	20.91 (16.6-25.2)	---- (0-14.1)	0.74	0.9999	10.92	34
RED MULLET	13.25 (….-19.6)	13.15 (…-20.09)	1.0	0.000	12.10	20
POUT	18.10 (….-20.6)	10.82 (…-8.7)	0.75	0.8283	1.74	24

Table 6 shows that Effron percentile lower limits are not defined when applying the clogit model on the data due to the CI for the contact. The relative poor contact could be caused by high turbidity. But other factors could also affect it. For example attachments to the codend like protection bags on the lower panel of the codend. By the other hand the selection range for hake is not defined because there is a proportion of fish (about 30%) that don't have contact with the codend or they never attempt to escape. The turbidity and codend protection play an important role again.

Table 7: 3-compartment setup, average selectivity results and 95% CI (in brackets)

Especie	L50$_{dual}$ (cm)	SR$_{dual}$ (cm)	L50$_{panel}$ (cm)	SR$_{panel}$ (cm)	L50$_{codend}$ (cm)	SR$_{codend}$ (cm)	C$_{panel}$	P-Value	Deviance	DOF
HAKE	20.44 (17.6-24.3)	8.59 (5.8-11.9)	37.58 (1-37.6)	1.00 (-7.7-7.9)	20.28 (17.3-24.1)	8.38 (5.7-11.5)	0.0198	0.0049	10.31	69
RED MULLET	13.47 (5.6-19.6)	13.23 (6.6-31.3)	20.52 (15.7-20.5)	1.00 (1-5.9)	13.36 (5.2-19.6)	13.08 (6.6-31.3)	0.0092	0.0000	13.47	41
POUT	16.06 (10.6-19.0)	7.48 (3.9-19.6)	185.54 (……)	5.62 (1-17.1)	15.54 (8.3-19.0)	6.68 (3.9-11.9)	0.0783	0.0000	14.07	53

To compare the average selectivity parameters results from 2-compartment setup and the results from the 3-comparment setup (dual selection), we confronted L50$_{codend}$ (2-compartment) and L50$_{dual}$ (3-compartment). The difference is given by few millimetres in the case of the hake and red mullet and two centimetres in the best of the cases for the pout. The same occurs with the Selection Ranges (SR$_{dual}$ and SR$_{codend}$), which practically is the same for both setups. This suggests that the effect of the square mesh escaping panel for the selected species is unappreciable and it's confirmed by the "Contact" parameter (C$_{panel}$ in table 6), where only the 1.9 % , 0.9% and the 7,8% of the hakes, red mullets and pouts respectively, attempt to escape through the square mesh panel. The

data derived from the square mesh escapement denotes the lack of robustness of these data due to the low escapement.
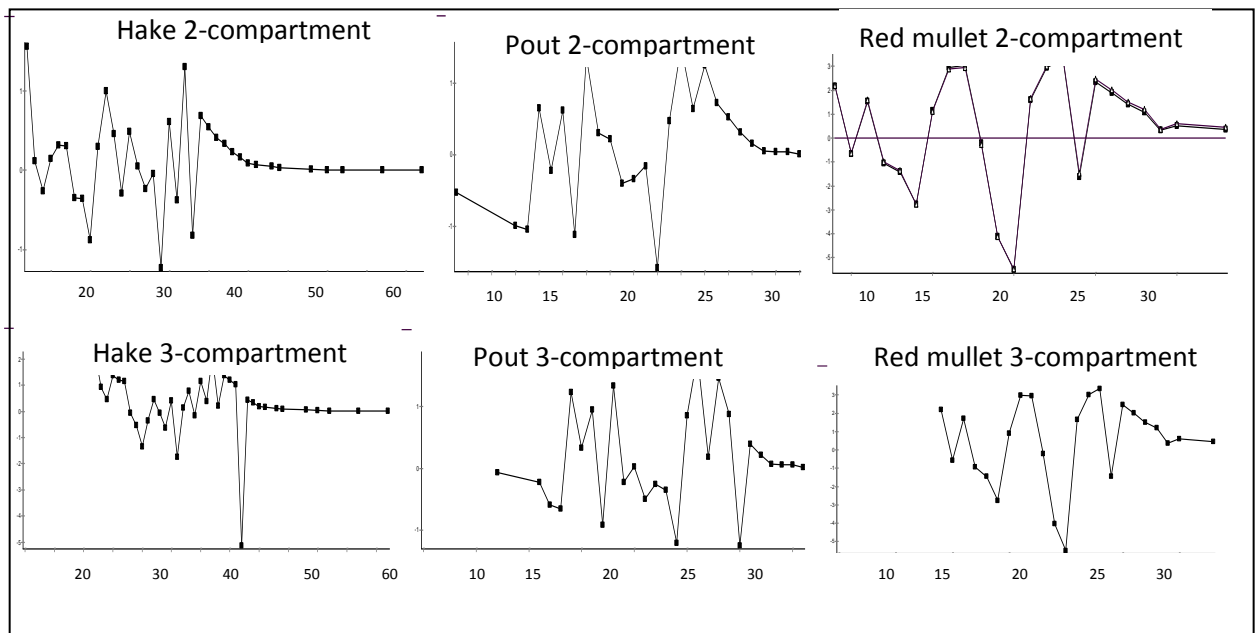
Figure 20 : Partial residuals plots of codend retention, panel escapement and codend escapemnt for 2 and 3 compartment setup for the selected species.The upper plots show the residuals for the clogit model while the ghraps below show the residuals for the dual selection model. Lengths are given in cm.

2-Compartments setup
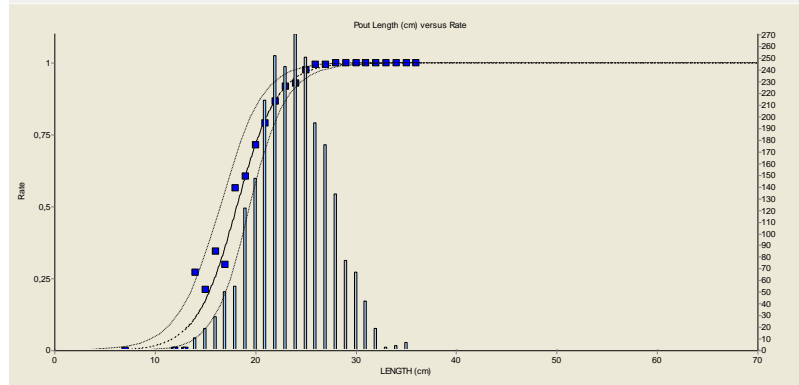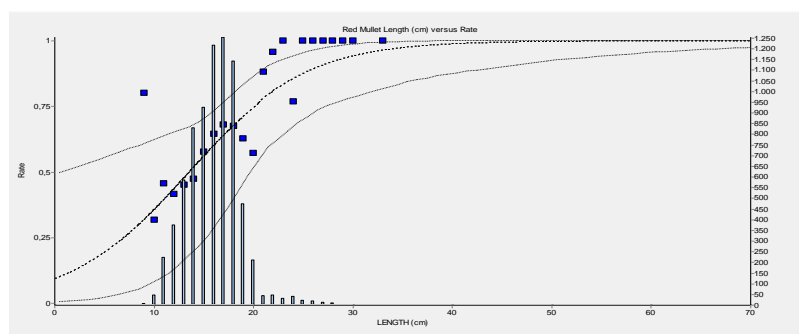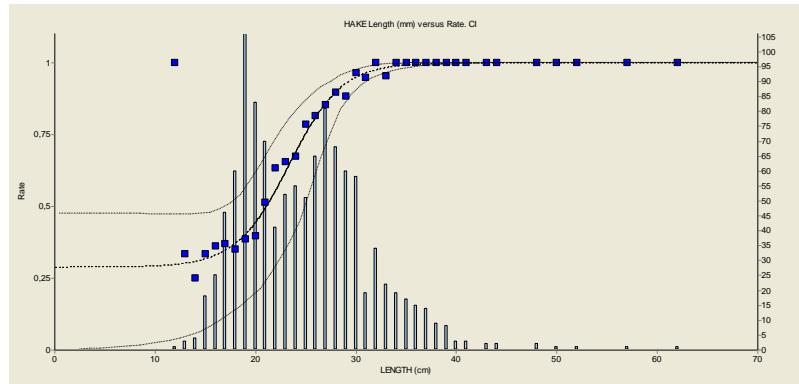
3-compartments setup
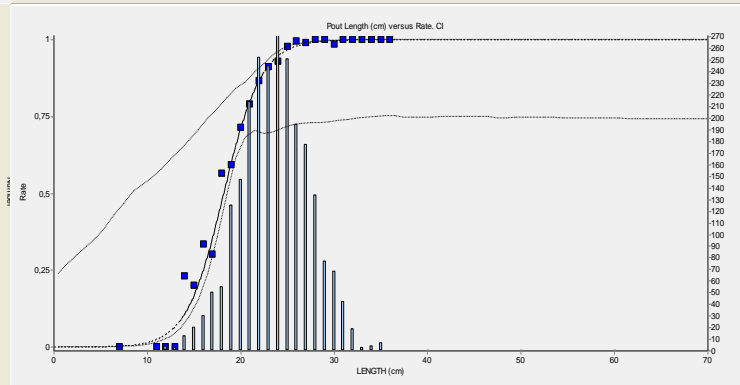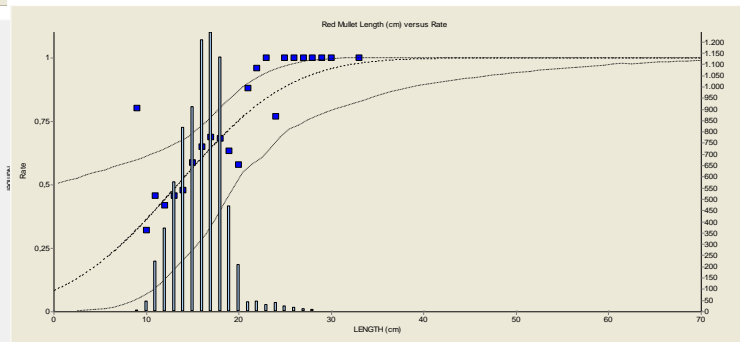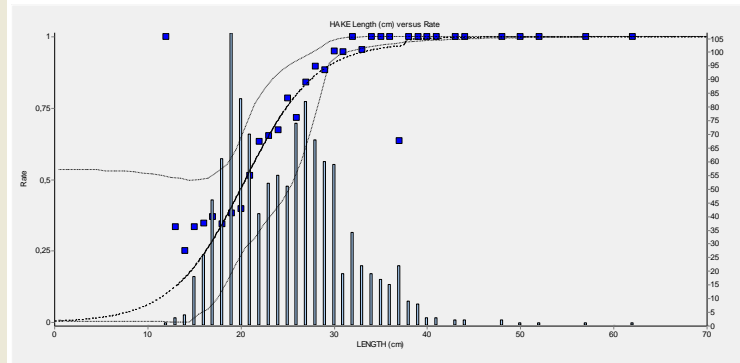
Figure 21: Mean selection curves, lengths vs rates and size distributions. The doted lines are the 95% confidence intervals.

The comparison between the dual selection and the codend selection curves is represented graphically in the following plots (Fig. 22), where the black line represents the 2-compartment setup or the setup that do not consider the escapement through the square mesh panel, the grey line represents the dual selection systems and the dots are the rates from data series.

In the three study cases both lines are practically overlapped, the dual selection curve just improve few millimetres the selection curve of the codend in the case of hake and red mullet. In the case of pout, the improvement is slightly better for lengths between 10 and 20 centimetres.
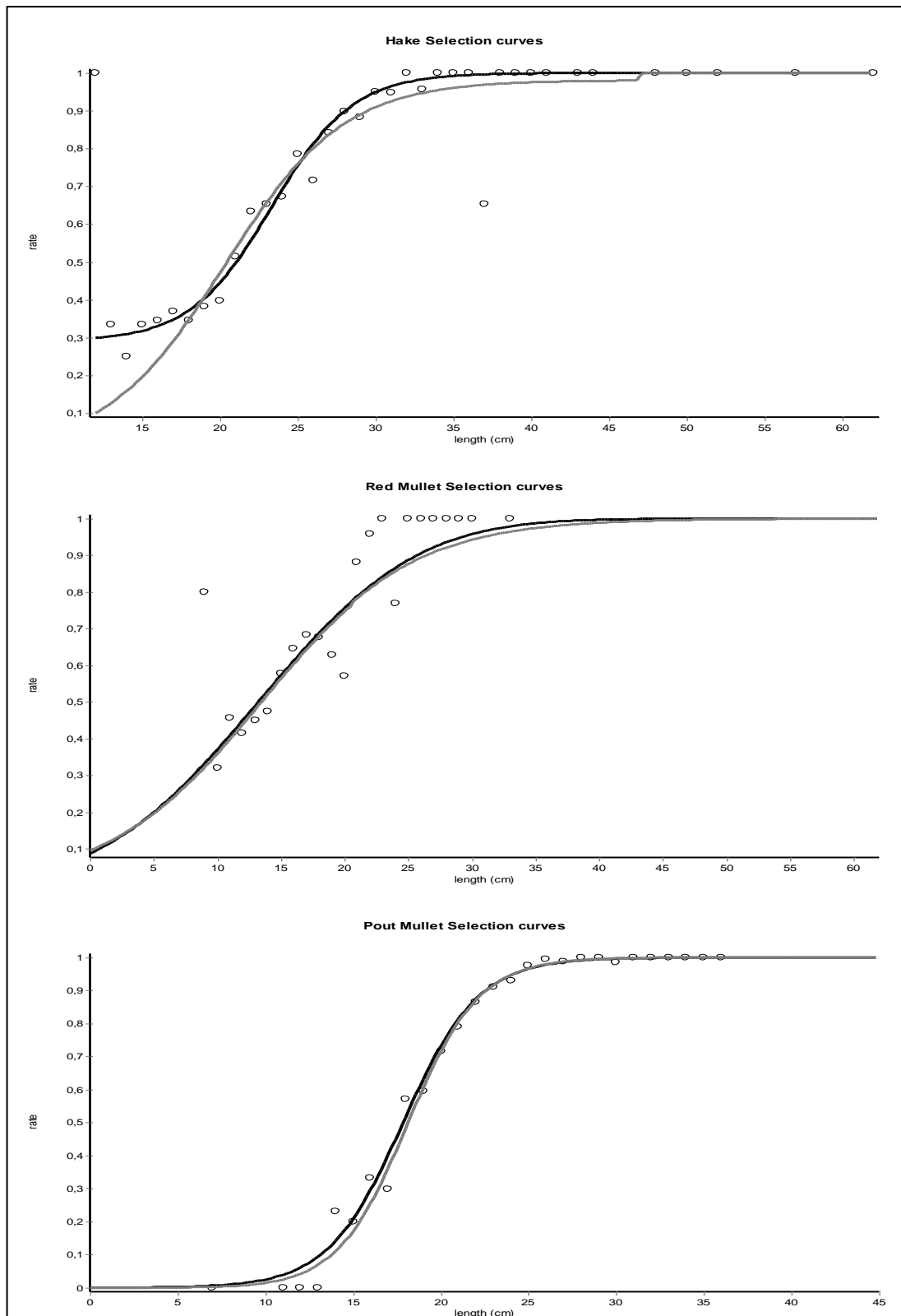
Figure 22: Selection curves for the three selected species. Black line represents the codend selection, the grey line the dual selection system and the dots are the rates from data series.

4   DISCUSSION

The experimental designs used in this study are line with recommendation from the ICES (Wileman at al. 1996, Sistiaga et al. 2010). The results show somewhat disappointing escape results for the selective device we have tested, compared to similar studies (i.e. Sala et al. 2008 and others). It is therefore suggested that further trials should be performed to reduce some of the uncertainties pointed out in this work. Despite few hauls and hauls with small numbers of escapees, I have chosen to use methods for data analyses as recommended by the ICES.

To find the ideal selective device for this kind of fisheries is a complicated task, since it's a multispecies fishery with more than 20 target species and many other marketable species. The fishing grounds, season, depth and many other factors give to this fishery a great variability, which complicates the solution to the problem of discards.

The low escape-panel contact found in the selected species, especially in the case of the hake can be attributed to different factors such as behaviour, high turbidity and high trawling speed (4 knots). Other species such as horse mackerel, mackerel and sardines were found in bigger amounts than hake, red mullet or pouts, which lead to assume that the collecting bag was working properly. Nevertheless this assumption needs to be checked with underwater observations. The poor codend contact results suggest that there was also some factor affecting negatively to the selectivity, the lack of visibility produced by the turbidity could explain these results.

Regarding to the behaviour of the hake, Queirolo (2009) through direct observation of the Chilean hake (*Merluccius gayi gayi*) in the trawl mouth and in the extension, demonstrated that this species is more active in the mouth of the net and the fish activity was lower in the trawl extension, where the hakes were merely carried by the flow into the net. Ten different behavioural categories were established. The behavioural response in the codend extension for hake was defined as fish motionless, resting on panel of netting or observed drifting back toward the codend.

Isaksen et al. (1997) used 120 and 105 mm square mesh top panels (7 meters long) in the codend and they didn't found any significant or clear difference with the size distributions, in the commercial codends with diamond mesh of 112 mm. They also performed direct observations of Namibian hake in trawl gears with square mesh panels. Hardly any active escape behaviour among the hake was observed through any of the different mesh size square mesh panels, in different sections of the trawl. The selectivity parameters they found (L50=38,8 cm and SR50=10,5 cm) were more due to the "wash-out" process than active escapement and they referred to this kind of selectivity as passive filtration that would vary depending on catch rates, weather conditions or towing speed.

The team that carried out the experiments described in this thesis, have long experience on trawling observation with many hours of underwater footage, from which they conclude that the hake has a really passive behaviour, even in pelagic trawl gears were the trawling speed is around 2 knots (Figure 23).
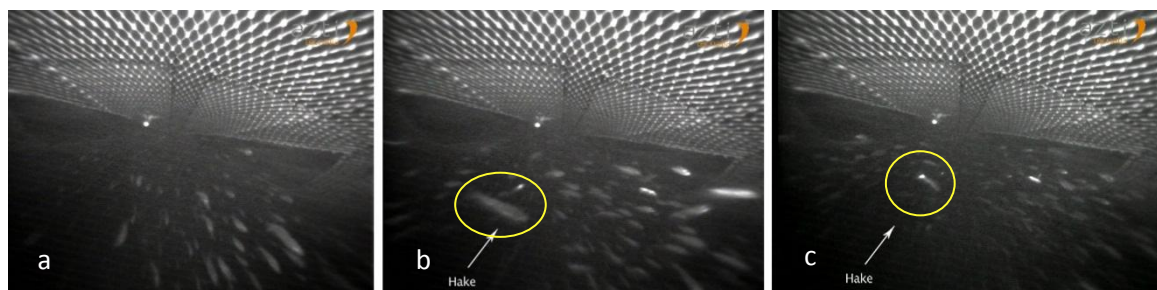
Figure 23: I this sequence we can observe horse mackerel swimming at trawling speed and towing direction (a). A hake passes between the horse mackerels carried by the flow with any swimming movement (b, c).

By the other hand the observed pouts, as other gadoids, have a more typical escape reaction and can swim at trawling speed even in the extension section as shown in the figure 24. Few red mullets have been observed close to the lower panel in the extension and with low swimming activity. More observations of these three species are required in order to obtain relevant conclusions on their behaviour.

Figure 22: Pout swimming in towing direction at trawling speed.

Meanwhile other species such as the horse mackerel (*trachurus spp*) or mackerel (*Scomber scombrus*) can swim during long periods in the towing direction, at the same speed as the trawl before exhaustion (Fig. 23).

Other studies related to the hake (*Merluccius hubsi*) selectivity in Argentina (Ercoli et al, 1998), developed the DEJUPA sorting device that is composed of a rigid grid and a funnel that conducts the hake in front of the grid, to force the contact with the selective device. With 32 and 37 mm bar spacing in the grid and 100 and 120 mm diamond mesh size codends respectively they obtained a L50 of 35cm in both cases, which is considered the length of first maturity for this specie.

Other studies with positive results on European hake (Merluccius merluccius) selectivity in the Mediterranean were conducted by Sarda (2004) and Sala (2007), Luchetti(2008), used a sorting grid and square mesh codends respectively. During the grid experiments, Sarda also used a guiding funnel inside the trawl to maximize the contact. By the other hand, the square mesh codend is known to be more size selective than the diamond mesh codend, especially in species with passive behaviour inside the trawl and this is what Luchetti (2008) proved in the Mediterranean.

Several selectivity experiments with square mesh exit windows (Graham and Kynoch, 2001), (Grimaldo et al., 2007) and square mesh codends (Halliday et al., 1999) in northern fisheries, are reported with positive results in selectivity for haddock, cod and pollock. These species showed more active swimming ability than the hake, red mullet or pouts. The exit windows proposed by Graham et al. 2001 and Grimaldo et al. 2007 were however placed in the codend and not in the preceding section.

Metin (2003) proved that in the Aegean Sea, in Turkey, the use of square mesh escape window in the codend top panel increases the escape of juvenile red mullet. In our case we didn't obtain similar results but there are many reasons for that. Our escaping window is not in the codend but in the preceding section. Our trawl is bigger, the codend longer and the trawling speed is about the double leading on higher exhaustion when the catch arrives to the codend and the extension piece.

The towing speed and turbidity are factors that could alter the results for the selected species, especially in the final section of the trawl. At 4 knots trawling speed the use of square mesh panel should be located in the codend in order to increase the contact with the selective device of the selected species. The results obtained, low contact on the square mesh panel and in the codend confirms the relative passive behaviour of the hake and the selectivity parameters obtained are due to the passive filtration process described by Isaksen et al. (1997). In the selection curve of the codend for hake we found that the 30% of the hakes never attempt to escape which means that they never contacted the meshes of the codend

The trawling fishery management in ICES subzones VIIIa,b,d essentially relies on conservation measures, a total allowed catch (TAC) for hake together with a minimum landing size (MLS, 27cm) and minimum trawl mesh size (70 mm stretched mesh) that did not meet the expectations. These measures have failed to prevent high discard levels of many species that characterize the fishery (Marcher 2008). This fishery is highly multispecies, and catches are largely composed of target species and non-target species, which often are discarded in large quantities. This leads to wasteful high fishing mortality

and therefore contributes to misexploitation (by growth over-fishing) of the fish stocks production potential. Thus the implementation of technical measures in trawl gears such as selectivity devices is required for the improvement in the management of the fishery.

Although technical measures may conserve resource, particularly to supplement a broader management policy, new regulations should be planned with great care, and any measures should be tested properly before implementation (Suuronen 2007). In this sense must be said that the implementation of the square mesh panel in the Bay of Biscay was only proved partially by French researchers of the IFREMER, so still some fisheries that have been enforced to use the square mesh panel without a previous proper test of the effects in the fishery, as in our case study.

To date, no quantitative assessment of potential benefits, from an improved exploitation pattern for the stock and the fleets, is available. This is however a key issue for fisheries management (Marcher 2008). There are many evidences of the benefits of size-selectivity measures improving the exploitation pattern of fisheries with high levels of by-catches and discards (Beverton and Holt,1957; Ward 1994; Suuronen, 2007). The uses of sorting devices avoid the catches of juvenile individuals and increase the age at first capture. Improving the selectivity leads to a more efficient exploitation of the stock's growth potential.

The changes in the exploitation pattern derived from the use of selective devices would entail socio-economic effects. The economic impact of introducing a selective device, such as the square mesh panel to the Basque trawling fishery would likely be considered. The need to evaluate the socio-economic effects of new gears is an important issue to be considered.

5   CONCLUSIONS

- Both, the codend cover and the square mesh panel-collecting bag, that retains the fish escaping through the codend meshes and through the square mesh panel, operate correctly and are valid for the collection of information on gear selectivity. Despite our results, further studies are recommended to gain more knowledge about the variability presented in this metier.

- The models used for of dual selection and codend selection fits the data and are valid for the analysis of data. The lack of robustness in part of the data (e.g. square mesh escapees) produced results that are out of the limits of the confidence intervals. More sea trials are required and the sampling should be extended.

- Depending on the fishing grounds, especially in reference to fishing depth, the composition of the retained and the discarded catch changes, and this would affect the design and placement of any selectivity device.

- The codend mesh size of 75.3 mm used in the cruises makes a regular selection of hake in relation to their MLS (27cm), the L50 is 20 cm and SR is 8.5 cm

- The red mullet shows overlapped lengths in the codend and the codend cover. Nevertheless lengths above 16 cm are more frequent in the codend.

- The same pattern occurs in the pout case; the lengths between 12 and 28 are overlapped. Nevertheless lengths above 28 cm, show a retention rate of 100% in the codend and the length with 50% of retention is between 23 and 24 cm.

- The results show few fish escaping through the square mesh panel (i.e. a low proportion of escapees) and hence it could be concluded that there's a low panel contact for the investigated species.

- The selectivity of the gear with or without the square mesh panel is practically the same for the hake and red mullet while pout shows a higher contact, that still being quite low about 7,8%.

- Another species such as the blue whiting and the argentine escape almost entirely through the commercial codend, appearing in the codend cover. The horse mackerel also escape through the codend meshes but only as a fraction. Finally the overall fraction of megrims is retained in the codend.

- Individuals of almost all species appear on the collecting bag that contains the escape of square mesh panel. The most abundant species in the cover are the horse mackerel, mackerel and sardine. According to the literature these are fish species with more pelagic behaviour and more active escape behaviour during the capture process of trawls.

6   RECOMMENDATIONS

To improve the success in this particular case, the following suggestions are recommended to consider:

- To carry out more selectivity experiments (100 mm square panel and 70 mm diamond codend), in different seasons and areas to determine the variability in the Basque trawling fleet and data improving.

- Verify the correct functioning of the 3-compartment setup with underwater observations.

- Include in the research other species such as horse mackerel, mackerel and blue withing which are found in big amounts and are usually discarded. These species have a more active behaviour than the studied species and thus more chance to scape, and constitutes for more than the 50% of the discards (Ruiz 2012).

- To carry out this kind of experiments during commercial fishing is not an easy task, since the research team have limited chance to decide how, where and when to fish. To avoid disturbing activities during commercial fishing operation can lead to difficulties in performing valid sea trials. It would be interesting to carry out selectivity experiments onboard a more suitable vessel, i.e. a research vessel designed for the purpose.

- Behavioural studies, with underwater observations of the selected species would be interesting in order to design and apply an effective selective device.

- To carry out experiments on alternative or complementary technical devices (e.g. grids, separator panels) in order to improve the overall selectivity of the trawl for the case of the hake.

- To carry out case studies on the socio-economic impact of introducing selective devices.

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8   ANNEX

8.1 Annex I

Appendix 3 from Annex III Condition for fisheries with certain towed gears authorized in ICES zones III, IV, V, VI, VII and VIII a, b, d, e

(a) Specifications of the top square mesh window

Specifications of 100 mm, measured as inner opening, square mesh window in the rear tapered section of the trawl, Danish seine or similar gear with a mesh size equal to or larger than 70 mm and smaller than 100 mm. The window shall be a rectangular section of netting. There shall be only one window. The window shall not be obstructed in any way by either internal or external attachments.

(b) Location of the window

The window shall be inserted into the middle of the top panel of the rear tapered section of the trawl just in front of the untapered section constituted by the extension piece and the codend.

The window shall terminate not more than 12 meshes from the hand braided row of meshes between the extension piece and the rear tapered section of the trawl.

(c) Size of the window

The length and the width of the window shall be at least 2 m and at least 1 m respectively.

(d) Netting of the window

The meshes shall have a minimum mesh opening of 100 mm. The meshes will be square meshes, i.e. all four sides of the window netting shall be cut all bars. The netting shall be mounted such that the bars run parallel and perpendicular to the longitudinal axis of the codend. The netting shall be single twine. The twine thickness shall be not more than 4 mm.

(e) Insertion of the window into the diamond meshes netting

It shall be permitted to attach a selvedge on the four sides of the window. The diameter of this selvedge shall be no more than 12 mm. The stretched length of the window shall be equal to the strength length of the diamond meshes attached to the longitudinal side of the window. The number of diamond meshes of the top panel attached to the smallest side of the window (i.e. one metre long side which is perpendicular to the longitudinal axis of the codend) shall be at least the number of full diamond meshes attached to the longitudinal side of the window divided by 0,7.

(f) Other

The insertion of the window into the trawl is illustrated below.