UiT THE ARCTIC UNIVERSITY OF NORWAY

Faculty of Biosciences, Fisheries and Economics

Approach to the 2014 discard ban in the EU Common Fisheries Policy and trials with bycatch reducing trawl techniques.

Ixai Salvo Borda

Master thesis in International Fisheries Management
May 2014

Ez altxa sarea, arrain guziak sartu artean

Old Basque proverb

(Do not lift the net, until all the fishes are inside)

May the holes in your net be no larger than the fish in it

Irish Blessing

Acknowledgments

First, I would like to thank my supervisors Roger B. Larsen and Michaela Aschan, for all the help provided during the process of writing this thesis and for all the guidance that they gave me. Without their comments, patience, and advice, the process of building this Master Thesis from an idea to a reality would have not been possible.

In addition, Eskerrikasko to Luis Arregi and Iñigo Onandia from AZTI-Tecnalia for giving me the chance to work with their data and for their advice and quite fast answer to the plenty of questions that I made to them.

I also want to thank Ivan Tatone and all the crew of the R/V Johan Ruud. The help, advise, knowledge and encourage that they give me during the sea cruises is invaluable.

I am grateful also with Charlie Weber and Allison Luettel for the help and assistance during the cruise on board of the R/V Johan Ruud. Charlie, that was discovering the life on board and Allison that shows us how to really survive on a cruise. Their help collecting data, laughs and ideas make the achieving of data more pleasant.

My sincerest gratitude, to all the teachers and staff that have helped me during this International Fisheries Management Master. Especially to Jorge Santos, Melania Borit and Lara Agulló for all the ideas and chances given to improve my knowledge.

A big "thank you" to my partners of the Master for all the sharing of ideas, dinners and good moments that we have spent together. Especially to Marina, Anastasia and Carlos for their support during the writing of the thesis.

I also want to thank my friends in Tromsø for their support and especially for their questions during the master that helped me to view the thesis from more than one perspective

To my friends in Pamplona a big Eskerrikasko because without their curiosity about fishes and cruises the world would not be such a funny place sometimes.

I would like to thank my family for their support in the distance and for asking me twice or even more per day how the thesis was going. Without them I would not be who I am.

Finally thank you. For your support, patience and help in this long way and especially in those moments where all was looking dark and you bring some light for me.

Eskerrikasko zu lauei eta guztiei, ene pausoak gidatzen dezuenak eta zuen laguntza beti emateko prest zaudetenak.

May 2014, Tromsø, Norway

Abstract

The new Common Fisheries Policy (CFP) proposes a change in the old fisheries regulation of the EU. The aim of this thesis is to give a description of the new regulation with a focus on the discard ban and the landing obligations. Because the use of selectivity devices is crucial on this new regulation, the efficiency of the square mesh window (SMW) as selectivity device was evaluated. The efficiency of the device as a bycatch reducing system was studied in the Norwegian prawn (*Pandalus borealis)* fishery. His efficiency was compared with the mandatory by-catch reducing device Nordmøre-grid. For that, selectivity studies were performed in Balsfjord, Norway. The obtained data was used to observe if the SMW would accomplish the bycatch levels aimed in the new CFP. In addition, the data of the SMW performance was compared with data from similar experiments conducted with the SMW in the Bay of Biscay by the research centre of AZTI-Tecnalia. This was made to compare the performance of the SMW in species rich fisheries with species poor fisheries. Data was descriptively analysed and selectivity analyses were made using SELNET to obtain a clear understanding of the selection patterns. Results show that the SMW does not work efficiently as a selectivity device in target species fisheries, in a clear contrast with the effective selective capacity shown by the Nordmøre-grid. Results also prove the inefficiency of the SMW for mixed species fisheries. Both studies prove the inefficiency of the device to accomplish the bycatch regulation adopted through the new CFP. These results, taking into account the actual development state of the different selective devices in the European fisheries, allow us to conclude that more selectivity studies are still needed to achieve the European target of less than 5% bycatch to avoid discards in mixed fisheries. For that, developments of the SMW or the use of combinations of different devices is suggested.

Key Words

Common Fisheries Policy, European Regulation, Selectivity devices, Square mesh window, Nordmøre-grid, Balsfjord, Bay of Biscay, Selectivity analyses.

Abstract (Spanish)

La nueva Política Pesquera Común (PPC) propone un cambio en la antigua regulación de la Unión Europea (UE). En esta tesis se pretende realizar una descripción de la nueva regulación teniendo como objetivo la prohibición de los descartes y la obligación de desembarcar todas las capturas. El uso de métodos de selectividad es crucial en esta nueva regulación. Debido a esto, en esta tesis se analiza el dispositivo de selectividad de ventana de malla cuadrada (VMC). La eficiencia del dispositivo para reducir las capturas indeseadas fue estudiada en la pesquería de gambas (*Pandalus borealis)* de Noruega. Esta fue comparada con la del dispositivo de parrilla de uso obligatorio Nordmøre-grid. Para ello, se realizaron estudios en el fiordo de Bals, Noruega. Los datos obtenidos fueron usados para observar si la VMC podría cumplir los objetivos marcados en la nueva PPC. Además, los resultados obtenidos con la VMC fueron comparados con experimentos similares realizados con la VMC en el Golfo de Vizcaya por el centro de investigación AZTI-Tecnalia. El objetivo es observar y comparar el funcionamiento del dispositivo en pesquerías con muchas especies con otras de pocas especies. Los datos fueron analizados de manera descriptiva y se realizaron análisis de selectividad con SELNET para obtener un claro entendimiento de los patrones de selectividad. Los resultados muestran que la VMC, en un claro contraste con el Nordmøre-grid, no funciona satisfactoriamente como dispositivo de selectividad en pesquerías con una especie diana. Los resultados muestran también la ineficiencia de la VMC en pesquerías mixtas. Ambos estudios, demuestran que el dispositivo no será capaz de cumplir los objetivos de la nueva regulación en torno a las capturas indeseadas. Teniendo en cuenta los resultados obtenidos y el estado actual de desarrollo en la UE de los diferentes dispositivos de selectividad, se puede concluir la necesidad de desarrollar más estudios para alcanzar el objetivo de tener menos de un 5% de capturas indeseadas en pesquerías mixtas. Para ello, se recomienda un mayor desarrollo de la VMC o el uso de dispositivos de selectividad combinados.

Key words (Spanish)

Política Pesquera Común, Regulación Europea, Dispositivos de selectividad, Ventana de Maya Cuadrada, “Nordmøre-grid”, Balsfjord, Golfo de Vizcaya, Análisis de selectividad.

Table of contents

List of Tables

List of Figures

1 Introduction

The release of the new European Union Common Fisheries Policy (CFP) (The European parliament and The European Council, 2013) have changed the European fishery state from an open discard policy (European Council, 2013) to one that bans discards for commercial species. This is an attempt to reduce the high level of bycatch and discards from fishing vessels in EU waters. This discard ban has being applied through a landing obligation forcing fishers to land all the catch. Good fishing techniques and the use of selectivity devices improves the efficiency of the fishery by a more selective fishing that reduces bycatch. The new EU policy leads to a forced improvement of the use of any kind of selectivity device.

The European Union (EU) has been managing the European fisheries since the 1980s with a number of different reforms. New challenges call for modern approaches to control the unsustainable overfishing and discarding. That takes place in large parts of the European fishery system. These discards are estimated to 23% of the total catches of the EU fisheries (European Council, 2013). The fragility of marine ecosystems is influenced by the fishing and is directly related with both the welfare of coastal communities and European fishing industry (European Commission, 2013).

1.1 Bycatch

The Food and Agriculture Organisation (FAO) defines bycatch as the "Catch that a fisher did not intend to catch, did not want to catch, did not choose to use, or which should not be caught whatever reason" (FAO, 2009). Bycatch is a big concern when it represents an important proportion of the catch in a specific fishery (Kelleher, 2005). Bycatch can be the result of the interaction of ecological, technical, legal and economic circumstances. Any kind of decisions that try to mitigate bycatch has to be based on an adequate analysis of the underlying problems before any solutions are introduced (FAO, 2009). The most direct effect of bycatch is the discard, mortality and waist of the non-targeted species (King 2007). The act of discarding represents the process of throwing unwanted, untargeted, catch fish overboard (King, 2007). Most fishing gears cannot catch only the targeted fish species in a selective way and, therefore, a proportion of the catch will be thrown away alive, dying or dead (FAO, 2009). These non-target species can be divided into those that are not the target, but still have some commercial value, by-product, and those bycatch species that are unwanted for many reasons with no commercial value, are threatened or are protected (King, 2007). Although normally the by-product species are also landed and included in the market, in very selective fisheries, like prawn (*Pandalus borealis)* fishery, both kind of non-target species are discarded and considered as bycatch (Davis, 2002).

Bycatch is one of the most significant problems that the modern marine fisheries management has to deal with. Discarded species suppose a serious problem to the effective management of fisheries due to the high mortality of the released species (Pascoe, 1997), and because they aggravate the overfishing problem (FAO, 2009). The works around the discard problem and the specific actions have had a focus on preventing bycatch from arriving to the deck. Solutions focus on the modification of the fishing gears to increase the selectivity of the fishing device (Hall et al, 2000). These modifications can be done by increasing mesh sizes in an attempt to reduce the capture of non-targeted species and sizes or installing grids or panels inside the net to allow bycatch to escape (Broadhurst, 2000).

1.2 European regulation

The European Union (EU) has recently adopted the new Common Fisheries Policy (CFP) that introduces a discard ban from 2015 (European Commission, 2013). This implied the implementation of a landing obligation for all the species caught over their catch limits or below their conservation reference size (European Union, 2008), and forces fishermen to land all the commercial species that they catch. This supposes a change from the old policy, which forced fishermen to discard all the non-targeted fish at sea (European Council, 2013). In Article 15 about discards and the obligation to land, the new CFP states some minimum rules, where some exemptions could be applied by management plans, based on scientific advice. This restricts discards to a maximum of 5% of the total annual catches for all the species that are subject to the regulation (The European parliament and The European Council, 2013).

The new policy, released in January 2014, proposes a gradual approach of 3 steps for the application of the discard ban to commercially important species. In 2014 the ban will be applied for pelagic species (including the Mediterranean), extending in 2015 to the most valuable demersal species (cod, hake and sole), and in 2016 to the rest of species. The ban does not take into account any kind of quota or effort management and covers the listed species (European Council, 2011). In both mixed and specific fisheries, the first step will be done directly by fishermen, by applying concrete measures to avoid unwanted catches. These specific measures can be performed by changing the mesh size, restricting access or improving selectivity devices (European Council, 2011). Such effort to avoid unwanted catches is a direct way to avoid any kind of non-targeted species and size-groups (i.e. undersized fish). This will reduce the bycatch level of the fishery contributing to a decline in the discard rate.

According to the new Common Fisheries Policy, (EU) No 1380/2013, new measures are needed to reduce the current levels of non-target catches to progressively eliminate discards. These non-target catches and discards are an important waste and have a negative effect in the sustainable exploitation of the resources in marine ecosystems. In the management of the landing obligation, improvements of selective fishing techniques have to be done to avoid and reduce unwanted catches.

In addition to the previously commented Article 15, Article 17, regarding the criteria for the allocation of fishing opportunities by Member States, incentives are being introduced to fishing vessels that deploy selective fishing gears or use selective fishing techniques in order to reduce environmental impact, such as habitat damage, by reducing bycatch (The European parliament and The European Council, 2013).

The discard of 23% of the total catch presented by the European Council (2013) is just an estimate, due to the big fluctuation in bycatch within the different European fisheries, especially in the different trawl fisheries. Discard rates are dependent on the gear, target species and the region (European Commission, 2011). In the beam trawl fisheries, the discard percentage can reach up to 60% of the total catch (European Union, 2008), reaching 90% for some areas like the Adriatic or North Seas (MRAG, 2007). Bottom trawls are in general characterised as non-selective gears being normally used in targeted species fisheries inside mixed species fishing grounds (STECF, 2006). They are categorised as "medium" discarding gears because the discard percentage ranges between 15 and 39% of the total catch that has a lower impact in all the regions (European Commission, 2011). Finally, pelagic trawls with a discard rate below 15% of the total catch had the lowest discard rate of all (Enever et al., 2007).

1.3 Bottom trawling

The FAO defines trawling as "cone-shaped netting bags that are towed through the water to catch different target species in their path" (FAO, 2012). Bottom trawling is based on the contact of the net with the seafloor with the aim of catching benthic or bottom living species. Trawls can be towed with one or two boats (pair trawling) and a range of different kind of rigs can be used (e.g. twin and triple trawls). The gear and method used depends on the fishing target or the objective of the study, if used for research. In this report, the chosen method is known as otter board trawling (Figure 1) in which the trawl gear is composed by warps, otter boards, sweeps and bridles, and a trawl net (adapted from FAO 2001). Warps are steel cables that connect the otter boards to the boat. Otter boards provide to the trawl a horizontal opening. Sweeps and bridles connect the otter boards with the trawl

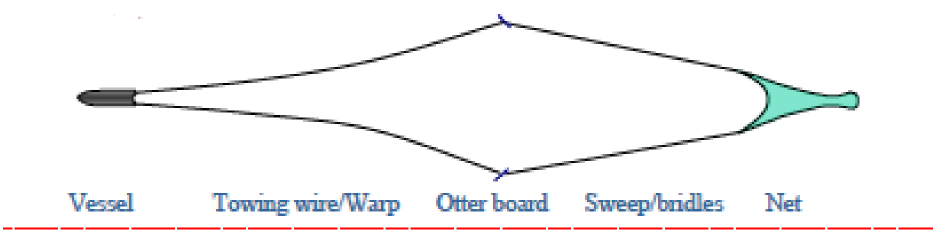


Figure 1. Standard design of an otter board trawling net (Source: Larsen, R. B, UiT 2012)

Trawls are used throughout the most part of the world's oceans (FAO, 1992) despite the fact that they are poorly selective and retain large quantities of non-target species (Broadhurst, 2000). These large quantities of bycatch have attracted worldwide attention in the recent past (reviews: Saila, 1983; Andrew and Pepperell, 1992; Alverson et al., 1994; Kennelly, 1995) and continue being one of the most important issues nowadays (European Commission, 2013). The attention is specially focused on the mortality of species, especially juvenile and subadult individuals because of the effect that bycatch has in the recruitment, biomass and yield of the stocks that are basis of the fisheries (Dayton et al, 1995). Also, it has a big ecological impact in the trophic structures of the communities (Broadhurst, 2000).

This global attention has led to many different management strategies that try to reduce the impacts of large bycatches. One of the options is the idea of using part of the bycatch for human or animal consumption (Peterkin, 1982). This can be a good idea for locations where there is a necessity of alternative sources of food (Gulland and Rothschild, 1984) but does not solve the problem of the underlying ecological impacts related with the mortality of large numbers of individuals. Another management option is to restrict trawling to locations where the number of bycatches is known to be low (Caddy, 1982). However, due to the variability of the fish distribution and life patterns (King, 2007) this option is subject to a big uncertainty (Kennelly et al, 1998). In addition, in fisheries where there are many key species and where the spatial and temporal variability in bycatches is big, it may be better to prohibit trawling altogether (Broadhurst, 2000).

While the previous management options have been used successfully to solve the issue of bycatch in some fisheries, the most applied tools into the majority of the world's trawl fisheries involve changes to conventional trawls, to improve selectivity by minimizing bycatch (Broadhurst, 2000). These modifications, made to conventional trawls by changing the size-selectivity of the gear, are obvious in fisheries with high levels of bycatches and discards (Suuronen et al, 2007). As it has been said before, selectivity measures involve both increasing mesh size and using more selective gears or devices, such as square mesh windows or sorting grids (Macher et al., 2008). These measures increase the age of first capture, the catch per unit effort and the sustainable total yield (Kvamme and Fröysa, 2004), and lead to a more efficient exploitation of the fishing stock. From an economic point of view, catches improve market efficiency with larger individuals that normally receive better prices per weight (Heikinheimo et al., 2006). Although some arguments against selective devices state economical loses, a good use of selectivity devices where the device only affects the non-targeted species results in better landings, due to a more effective fishing. This yields an economical gain as the quality of the market product increases (Macher et al., 2008)

1.4 Selectivity devices

Marine resources are limited and have a big sensitivity to the pressure of fishing activities. Thus, selectivity studies are a very important tool for fisheries managers (Longhurst, 1998). The obtained parameters and observations from the selectivity studies suppose an important base to researchers and managers to predict the best future exploitation pattern for a fishery system (Kvamme and Frøysa, 2004). Because of that, selectivity studies should be performed before, during and after any decision making around a fishery system. They can be good tools to evaluate the effects of introducing selectivity changes, to determinate the sustainable patterns of exploitation for a species, and to assess future problems, such as overexploitation or bycatch and discards (adapted from Sistiaga, 2010).

The use of selectivity devices in trawls starts with the use of diamond mesh selectivity cod-ends that determinate the catch of the fish on the shape of the diamond meshes themselves (Sistiaga, 2010). The selectivity of the diamond mesh cod-ends is determined by the forces of the water flow (hydrodynamics), applied to the trawl and drag-forces created by the catch bulk, i.e. the shape to the cod-end (Herrmann, 2005). These properties are the factors that make this selective method difficult to control. In addition to this uncontrolled selectivity, diamond meshes can be an insufficient tool in fish selection (Sistiaga, 2010). Nowadays, trawls include many different fish excluding devices, like exit windows (Grimaldo et al., 2007), SMWs (Bullough et al., 2007) or sorting grids (Larsen and Isaksen, 1993) that reduce, a high rate, the selectivity role of the diamond meshes of the cod-end.

1.5 Norwegian prawn fishery

Norway was a major prawn producer, with approximately 70000 tonnes of prawn caught annually until 2005. The country is the 14th largest producer of prawn in the world. Due to market challenges and low prices, the total annual catch has been just over 20000 tons since 2005 (Sovik and Thangstad, 2012). However, prawns are not one of the most important targets, and represent about 4% of the value of all the fishery products exportation of Norway (FAO, 2005).

Main stocks exploited by Norwegian fishers are located in the Barents Sea, Skagerrak and the North Sea, in addition to the local stocks that can be found in many of the Norwegian fjords (Gillet, 2008). One of the major problems of the fishery is the low profitability of many prawn vessels due to excess capacity, increase of fuel cost and the failing market prices of prawn (FAO, 2012).

The prawn fishery is regulated by effort control, where licenses are required for the Norwegian, Russian and third country fleets in operation, by the number of effective days of fishing and the number of vessels by country. The minimum allowed mesh size of the codend is 35mm. The use of sorting grids (with maximum 19.0 mm bar spacing) is mandatory, together with temporary closing of areas to protect other species, i.e. cod, haddock Greenland halibut and redfish, from excessive bycatch (Sovik and Thangstad, 2012).

1.6 Basque fisheries

Fishing activity is a traditional activity in the Basque Country, having a big social and economic importance with a direct effect in coastal communities. However, it only contributes to about 1% of Gross Domestic Product (GDP) and employment (Haig, 2008).

Trawl fishing started developing in the Basque Country in the beginning of the 20th century together with the introduction of the steam engines, which later were replaced by gas-oil motors. The big development really started after the First World War (Onandia, 2012). The fleet has changed in many ways during the last century, and nowadays it is mostly composed of "baka", otter board trawls with very high vertical opening (VHVO) pair bottom trawlers (Iriondo et al., 2008). Reaching the highest peak around the 70's of the last century with 216 operating units, the fleet is around 27 vessels these days (Prellezo, 2010).

1.7 Objectives

Nowadays, there are several uncertainties on how the new Fisheries Common Policy with respect to reduced bycatch should be achieved. So far, a selective technique, named the square mesh window (SMW), has been tested in several trawl fisheries and implemented in some of them. Trials in the Basque trawl fisheries of northern Spain did not find encouraging results with the SMW in a mixed species fishery.

Objectives in my work are, in short:

- To give a description of the EU regulations towards a new Common Fisheries Policy focusing on the discard ban and the landing obligations (5% level for regulated commercial species).
- To do a literature review on EU fishing policies and the use of selective devices in trawl fisheries.
- To perform selectivity trials with two different devices to be able to evaluate and discuss the effect of the square mesh window (SMW) in the EU trawl fisheries.
    - To study the use of SMW device in Norwegian prawn target fisheries and compare with the current used device, Nordmøre-grid.
    - To study the use of SMW in mixed species fisheries, Bay of Biscay, using the data from AZTI-Tecnalia. The results will allow to study if there are any differences between mixed species fisheries and singe target fisheries when using SMW.
- To study different selectivity devices in EU to achieve the objectives of the new CFP and give advice for future developments and applications.

2 Literature Review

2.1 European Union Common Fisheries Policy

Fishing is a non-important economic activity inside the EU. With a contribution that can be smaller than the 1% of the gross national product. Such activity employs around 200000 fishermen and the level of catches can be around 7 million tonnes. The market for fish and fish products has evolved in the last years with a decline rate on the fresh fish sales and an increase on the processed fish. However, the employment in fish processing and fishing has declined due to the increase of imported fish and fish products from outside the EU. These facts have increased the competiveness inside the EU fishing industry that is also affected by the overcapacity and shortages of fish to catch (adapted from, European Council, 2008).

Inside the Treaty of Rome (1957), that is, the main text for defining the areas to create new common legislation, fisheries is just mentioned in a short sentence, referred together with stock farming into the definition of "Agricultural products" (Holden, 1994). In the late 1960s, the need for a common approach to the organisation of the European Community markets, both in fish and fish products, and the increase of the structural development of the fishing fleets of the Member States, reflected the need for creating a Common Fisheries Policy (CFP) for the European Union waters and fishing fleets (Symes, 1997).

It was just in 1970 when a basis for future fisheries management was introduced, as anticipation for the entry of new members with fishing interest. In these two regulations (2141/70 and 2142/70), a common European fishing space was created and the modernisation of fishing vessels and on-shore installations was implemented (Holden, 1994).

Until 1977, the fisheries policy in the European Community was having a secondary position by the application of the objectives that where formulated for the Common Agricultural Policy (CAP). The objective of this policy was the increase of the insufficient supply of fish to the Common European market. The objective was to subsidise the fishing industry minimizing fish prices and granting construction of more vessels to increase the catches (Jensen, 1999).

In 1977, the extension of the fishing water of the EU from 12 nautical miles (nm) to 200nm from the coast, in addition to other international changes, required additional controls to manage and ensure equal access to the common pond for all the Member States (Commission of the European Communities, 1976). In 1983, the Common Fisheries Policy (CFP) was created, with four areas of activity: Conservation of stocks, vessels and installations, market controls and external agreements with other nations (Symes and Crean, 1995).

In 1992 due to an overinvestment in vessels and vessel technology overfishing a decrease of the number of landings took place (Horwood, 1996). The review made to the CFP did not suppose an important change, but implemented the research and investment in marine resources trying to protect and conserve the available and accessible living marine aquatic resources (Symes and Phillipson, 2009).

In 1995, a permit system was introduced to state rules, to decide where and when vessels were allowed to fish based in the principle of the variable availability of fishes year by year. To enforce this system, scientific studies were applied to determine the available stock and for guiding the allocation of permits (Committee of the Regions, 1995)

In 2002, the new Reform of the Common Fisheries Policy was made, in an attempt to radically change the overhaul of failing systems. Many stocks, especially the North Sea cod, were reaching dangerously low levels and it was clear that the CFP was failing so how. Because of that, the European Commission reviewed some features of the CFP to undertake a huge change. The changes improved the CFP's system of governance increasing the amount of stakeholder participation, decentralisation, accountability, transparency and coherence. However, the final effects were more rhetorical than real (Gray and Hatchard, 2003).

Between 2009 and 2013, an important debate on European fisheries management was launched. As a result, in February 2013, the European Parliament voted for a reformation of the Common Fisheries Policy, including measures to protect stock and with the goal of finishing with discards (European Council, 2013). The new CFP was released in December of 2013 and applied in January of 2014 (The European Parliament and The European Council, 2013)

Since the introduction of the first Common Fisheries Policy, a big debate on the environmental consequences has being developed inside the scientific community. Some researchers and journalists (Booker, 2007 and Waterfield 2009) claim that the CFPs have had disastrous consequences on the environment. However, the historical evidence shows declining trends of fish stocks due to overfishing since the beginning of the XX century proving that the depletion of fishing stocks is a consequence of the bad management made long before the CFP (Thurstan et al, 2010).

The CFP is a top-down approach to fisheries management, because the EU adopts total competence in the creation of new proposals and decisions, while the Member States are responsible for the policy implementation and enforcement. Critics maintain that the organisation is badly adapted to the task of fisheries management and, because of a lack in understanding of fisheries dynamics, is way too far to accurately correct Total Allowable Catches (TACs) and quotas (Sissenwine & Symes, 2007). The advocates of deeper CFP reforms consider a shift from the command and control traditional management to a more participatory third-order governance that incorporates the fisheries industry and Member States (Sellke & Dreyer, 2011). This management tool could be improved by applying the theory of subsidiarity, in which the decisions are handled by the lower and least centralised competent level (Jordan & Jeppersen, 2000). This principle could facilitate the inclusion of industry concerns into the CFP, involving like that those directly affected, and creating a CFP that encourages compliance and collaboration making easier the implementation of the measurements (Symes & Phillipson, 2009).

2.2 Selectivity devices

The development of fishing technology to reduce unwanted catches can be done in two directions. First, by improving the design of the fishing gear by enhancement of size and species selectivity and, secondly, by developing bycatch exclusion devices that are attached to the fishing gear (Matsuoka, 2008).

Typical solutions to the changes in the conventional mesh-size regulation, to exclude small individuals, include a variety of test by opening meshes widely using square-mesh panels. This tests show reductions of discards around the 40% after the modification of the trawl gear with the panel (Revill et al, 2007). Other kind of modification to the fishing gear can be done by peripheral modifications, such as changing vertical opening and foot-gear arrangement in the case of trawl nets (Valdemarsen, 2001) or changing underwater height of the trawl opening and giving spaces around a foot-rope for installing gillnets (Matsuoka, 2008).

In the case of the development of bycatch reduction devices, the most advanced fishing gears are trawls, having the oldest history of researches starting in the 1970’s with Seidel (1975) and Watson and McVea (1977) with the prawn separator trawl experiments. There are many kind of selectivity devices referred as Trawl Efficiency Device (TED)[1], Bycatch Exclusion Device (BED), and Bycatch Reduction Device (BRD) that have been developed specially for prawn trawling (Matsuoka, 2008). This big development in prawn trawl selectivity devices can be due to the fact that prawn trawling is conducted normally in multi-species fishing grounds, where it is difficult to exclude small bycatch with size selectivity mesh regulations (Watson et al, 1986).

Bycatch reduction devices, used in trawling nets can be made by net webbing or grids. They work according to the key principle of an induced exclusion by the use of mechanical size selectivity (Matsuhita, 2000), such as the net webbing used by High et al (1969) and Seidel (1975) or the metal sorting grid used by Karlsen and Larsen (1989) and open sections like windows or large-meshes (Matsuoka, 2008). In addition to this mechanical selection, a passive exclusion, based on the different behaviour of the catches, is also used, like the large-meshed sky-light designed by Rulifin et al. (1992). In some cases, both principles can be used together as in the TED created by Watson et al in 1986, that used metal grids referred to a deflector and lateral windows.

The function of bycatch exclusion devices depends on fish behaviour and sensory capacity and, because of that, the use of each device differ according to bycatch species compositions in each fishing ground. Another limitation is the chance for organisms to encounter the device (Matusoka, 2008). This fact makes it difficult to develop any kind of exclusion device. The latest obtained important record is made with the Nordmøre-grid, showing a reduction of fish bycatches by 75-97% without affecting the catches of targeted seabed prawn (*Xiphopenaeus kroyeri)* (Silva et al., 2012). Ideas for further development of bycatch exclusion devices attempt to give more consideration to advices coming from fishermen to compensate the possible loss of catches and to improve the reduction of resistance to a net, reducing like that the fuel consumption, to reduce the on-deck work and to improve the quality of the catches (Sisitiaga, 2010).

[1] Do not confuse with the Turtle Excluder Device that has the same acronym (TED) (Jordan et al, 2013)

3 Materials and methods

The efficiency of the SWM was first studied in a single target fishery, i.e. Norwegian prawn fishery, and compared with the most commonly used by-catch reducing device, the Nordmøre-grid. Bycatch levels were used as indicators of discard levels assuming that there is a relationship between them. For that, selectivity studies where performed in Balsfjord, Norway, to acquire enough data. The obtained data were used to compare both selectivity devices and to decide if the Square mesh window may reduce bycatch to levels accepted by the discard regulation adopted through the new CFP.

The obtained SMW data in Norway were compared with data from selectivity trials in the Bay of Biscay using SMW. The idea is to study the performance of the SMW in mixed species fisheries, with a higher number of species using as an example, the Basque mixed species fishery. The obtained results will allow noticeable if the device performs differently in mixed species fisheries comparing to a single target fishery.

Finally, a look to different selectivity devices was made with the aim of giving advice about the effectiveness of using them for achieving the objectives of the new CFP and to set up the basis for future research. The use of alternative techniques may be recommended or the combination of two or more known techniques may be the only way to achieve bycatch levels as described in the new regulations.

3.1 Sampling

The selectivity devices that we used in the study of the Norwegian prawn fishery in Balsfjord were adapted to be similar to the ones used in the Bay of Biscay by AZTI-Tecnalia. Although, the trawls used by AZTI were bigger than the ones that we used in the experiment in Balsfjord. It can be said that the method used is the best adaptation of the method that AZTI used. The square mesh window selectivity device used by us is also similar to the one used by AZTI-Tecnalia. In this way, we were able to compare results from Balsfjord (few species) and Bay of Biscay (mixed and large number of species).

3.1.1 Bay of Biscay

Samples from the Bay of Biscay were collected by the research centre of AZTI-Tecnalia (division located at Sukarrieta laboratories) in the Basque Autonomous Community of Spain during sea trials during June and July 2013. They used a 90 mm diamond knotted mesh trawl size with 70mm mesh size in the codend. The length of the fishing line was 350m and they have a 90m footrope. They used a cover net of 30mm mesh size.

3.1.2 Balsfjord

Norwegian samples were collected from 3 to 12 of February 2014 in Balsfjord using the R/V “Johan Ruud” for bottom trawling (Table 1). During the two cruises that were conducted, 30 hauls were performed with an otter board bottom trawl.

From each haul, all the fish species and size distributions in cover and codend were recorded to the nearest cm. With this, excepted for cod and haddock individuals, the total weights of fish species in cover and codend were measured. Due to the big volume of catch for some species, subsamples were taken instead of measuring all the catch.

In the case of prawns, the total weight of the catch was measured and for individual number calculations, the number of individuals per kilogram was calculated.

All measurements were registered for further data analysis, together with the haul number and selectivity device used (See Appendix 1 for the data collection scheme). In addition to this position, speed and depth data were recorded from the captains’ log of each haul (See Appendix 2 for the captain log scheme).

The sampling trawl is a modified prawn trawl (1424#x65 mm) with headline length of 48.1 m and a fishing line length of 55.2 m. The codend of the trawl has an inner-lining of 10 mm mesh in order to retain all sizes of fish and prawns.

Table 1. Cruise description

Departure Port	Departure Date	Arrival Port	Arrival Date	Days at Sea
Tromsø (Norway)	3/02/2014	Tromsø (Norway)	7/02/2014	5
	10/02/2014		12/02/2014	3

3.2 R/V Johan Ruud

The “R/V Johan Ruud” (Figure 2: R/V Johan Ruud (Source: Marine Traffic) was built in 1976 as a stern trawler for multipurpose research activities in open waters along the coastline and fjord areas. She is prepared to perform fish resource assessments, hydrographic and trawl surveys, geological bottom-sediment sampling and acoustic registrations of the sediment layers below the seabed. The main characteristics of the research vessel are described in the table below (Table 2) (Marine Traffic [1]).

Table 2. Main characteristics of the R/V "Johan Ruud"

Name	Calling signal	Length o.a	Length p.p	Beam mid	Draught	Speed	Gross tonnage	Class
Johan Ruud	LEDR	30.50m	27.20m	8.50m	3.75m	11.5(max) -10 knots	332	DnV+1A1 stern trawler

Figure 2: R/V Johan Ruud (Source: Marine Traffic)

3.3 Study area

3.3.1 Balsfjord

The study was carried out on the Norwegian Prawn fishery and performed on the protected area of Balsfjord (69°20'N, 19°0'E). The fjord (Figure 3) is located south of the city of Tromsø and arises approximately 40km inside the Norwegian mainland. It is separated from open coastal waters by not very deep sounds, being Tromsøysund 10m depth and Rystraumen 35m. The maximum depth of 195m is reached in the central part of the fjord and forms a deep basin, between 180 and 195m depth, of more or less 12km long (Finne & Gade, 1990). The bottom of the fjord is quite flat and made of grained mud (Oug & Høisoeter, 2000). The waters of the fjord do not have a wintery ice-cover (Finne & Gade, 1990) being like that productive during all the year (Eilerstsen & Taasen, 1984). Deep-water prawns *Pandalus borealis* (Krøyer, 1838) are abundant in Balsfjord and were the basis for a small commercial fishery until 1983 when the fishery was discontinued because of a ban introduced in prawn trawling in many Norwegian fjords (Hopkins & Nilssen, 1990).

Figure 3. Balsfjord location in Norway (in dark colour) (Source: Store Norske Leksikon)

3.3.2 Bay of Biscay

The study in bycatch made by AZTI-Tecnalia was located on the Bay of Biscay (ICES VIIIabd) which is situated (Figure 4) in temperate latitudes (between 48ºN and 43.5ºN and 1º40’W and 9º 20’ W). The inflow of oceanic water from the Atlantic Ocean has a big influence in the climate and especially during winter months large storms occur (Onandia, 2012). The southern part of the Bay presents a narrower continental shelf (between 12 and 40km) then the northern part, which has an extensive continental shelf (150-180 km on average) (Koutsikopoulus & Le Cann, 1996).

Figure 4. Map of the Bay of Biscay (Source: Lloyds Maritime Map: Bay Biscay; Gironde Bordeaux, 1971)

3.4 Experimental designs

3.4.1 Size selectivity and Selection Curve in bottom trawls

In trawl fishery, size selectivity refers to the measurement of the difference between the fish size, the size distribution available of fish in a fished population, and the fish size distribution that is retained in the trawl (Sistiaga, 2010). Most part of the trawls selectivity studies are focus on species or size selection. The main size selectivity process normally happens in the last part of the trawl (Beverton, 1963) and especially in the codend (Wileman et al, 1996). It is assumed that from all the fish population entering the trawl, each individual will have a possibility of escaping or being retained by the gear. This possibility can be defined as the probability of being retained *(r(l)),* that equal 1 minus the probability of escaping. This probability depends on the size of the fish, the behaviour and the properties of the selectivity device applied in the trawl (Sistiaga, 2010).

The selection curve usually has an S-shaped figure, looking similar to an ogive. It represents the probability that a fish has to be retained by the gear with a certain length when it enters the net (Onandia, 2012). It is normally assumed that the data has a normal distribution and that the selection curve equals the cumulative function of a curve with normal distribution :(Wileman et al, 1996). The curve of fish length *(l)* against retention *r(l)* is defined as:

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

Being also possible to express as:

$$r(l; \alpha, \beta) = \frac{\exp(\alpha + \beta(l))}{1 + \exp(\alpha + \beta(l))}$$

Where α, the intercept, and β, the slope, (or a and b) are parameters estimated using a maximum plausible fit of the model (Sistiaga, 2010). The right side of the curve (Figure 5) represents retention of fish *r(l)* and the left side represents the one that escape 1-*r(l)*.

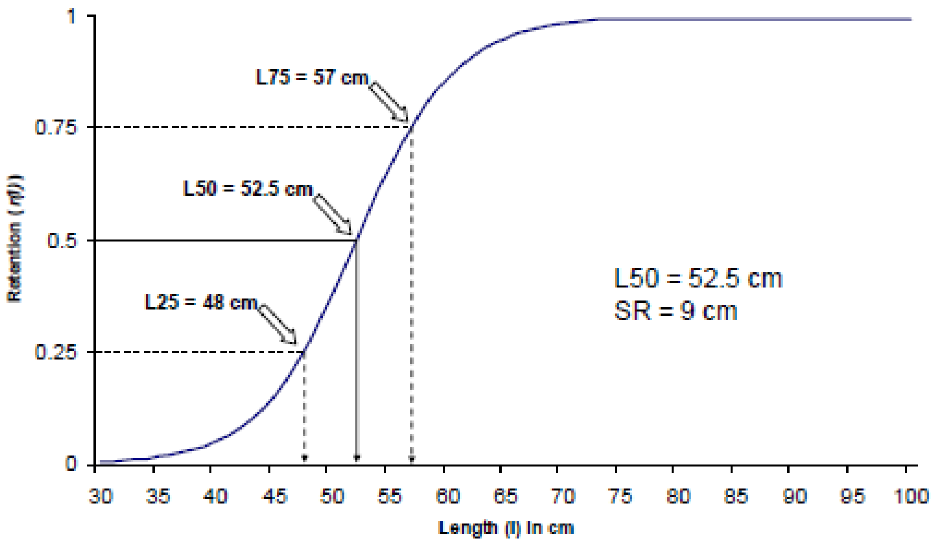


Figure 5. Example of a typical selection curve for cod and haddock in the Barents Sea (Sistiaga, 2010)

From the selection curve, two important and useful parameters can be obtained to describe the size selectivity in the gear, and to calculate the effect of selectivity on fish populations. The first one is the middle selection point (L50%) that represents the length at which a fish has 50% probability to be retained, and it is called L50. The other parameter is the Selection Range (SR) that is calculated from the difference between the L75, 75% of probability to be retained, and the L25, 25% of probability to be retained. Both L50 and SR (see formulas below) define the curve mathematically (Onandia, 2012).

$$r(l_{50}) = 0.5; this\ is: l_{50} = -a/b = -\frac{\alpha}{\beta}.$$

$$Selection\ range = L_{75} - L_{25} = \frac{2\ln(3)}{\beta}$$

Logistic and normal selection curves are symmetric around the L50 (see Figure 5). Curves that do not take into account normal distribution and are not symmetric around the L50 are flexible generalisations of the logistic curve. The studied Richards curve uses an asymmetry parameter (δ) that determines the nature of the asymmetry in the form (Wileman et al, 1996)

$$r(l) = \left(\frac{\exp(a + bl)}{1 + \exp(a + bl)}\right)^{1/\delta}$$

In this case, the longer tail depends on the value of the asymmetry parameter. If this parameter is bigger than 1 the curve has a longer tail to the left and if the curve is between 0 and 1 will have a longer tail to the right. If the value equals 1, the curve will show a logistic trend (Wileman et al, 1996).

In addition to these two parameters, another element used in the description of gear selection is the selection factor (SF). This factor equals the ratio between the L50 and the codend mesh size. This last term refers normally to the inside mesh size or the lumen opening of the mesh (Wileman et al, 1996). The parameter is useful when comparing gears. Furthermore, a given SF helps to predict the effect on L50% with a change in the mesh size, or in other way, to find the accurate mesh size for a given L50%.

$$Selection\ factor = \frac{50\%\ retention\ length}{codend\ mesh\ size}$$

3.4.2 Sorting grid

The idea of using a separator grid is to retain all small specimens; in the case of prawn fishery, all prawns, excluding large specimen through an exit (opening) in the upper part of the trawl, allowing them to escape (Larsen, 2006). In this report, a Nordmøre-grid (Figure 6), classified as a by-catch excluder, was used. It consists on a guiding funnel located before the codend that guides the catch to the base of a grid. This grid is made of obliquely oriented bars with 19mm spaces. The operational idea is that all the organisms smaller than the spaces go through the device and be retained in the codend, whilst larger individuals were guided upwards and escaped through an opening located on top of the trawl (Broadhurst, 2000).

The grid was installed in the end of the trawl before the cod-end inside an especial net section called grid section (Figure 9). The grid section is 7.77m long (119.5 meshes (#), being each mesh 65mm) and 0.905m (21#) wide. The grid is installed at an angle of 48 degrees inside the grid section at a distance of 5.7m. The grid is composed of 19 bars with a 20mm diameter (Ø20) leading to 20 gaps that offer a 0.43m^2 lumen area. The area of the grid is 1,17m^2 being 1,35m long and 0,865m wide. It is divided in 3 sections of 0.37m, 0,39m and 0,37m respectively by 2 supporting bars (Ø55mm). The lastridge rope crosses the grid from the middle, creating two sections of 27# each. Inside the grid section and 0.5m before the grid a guiding funnel was installed composed of 150 bars with a 3.5 to 4.0cm diameter to direct fishes to the grid.

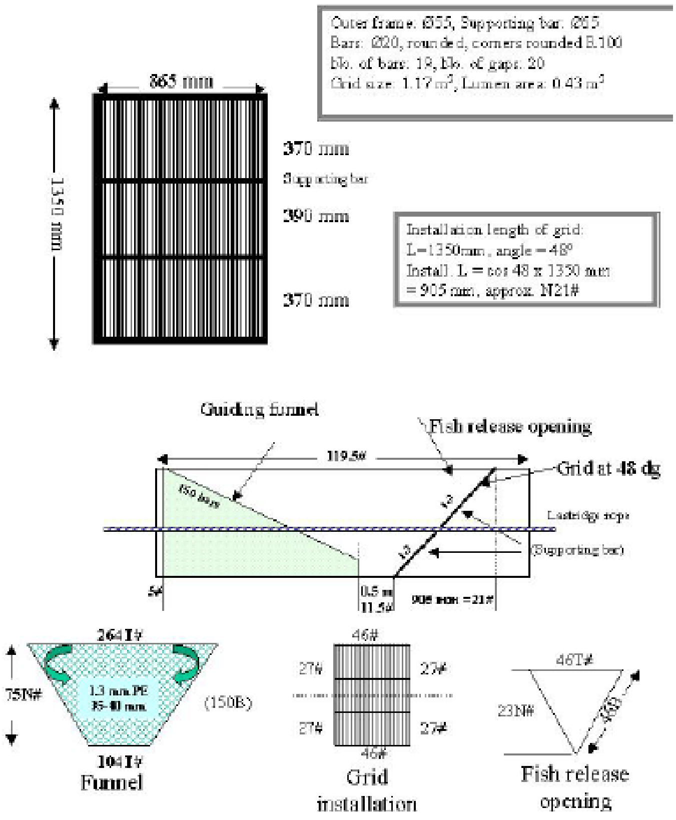
3.4.3 Square mesh window

The functioning of the SMW (Figure 7) is to allow the escape of fish by providing a larger area of open meshes (Zuur et al, 2001). The window takes into account behavioural differences between prawns and fish, based on the principle that fish responded differently to trawls, because of their slower movement and faster response to water flow changes inside the trawl, which made them able to maintain an escaping activity (Broadhurst, 2000).

Following the design of AZTI-Tecnalia in this report, a 125mm mesh size SMW was used with polyethylene (PE) braided knotless Ø5.1mm and with a mesh length of 130,1mm. The window is 1,95m long and 0,975m wide. It has a frame reinforcement of Ø4mm PE twine. It is located in front of the codend at a 5 meshes distance from the limit (Figure 9).

3.4.4 Cover net

We used a small-meshed cover (Figure 8 and Figure 9) with similar mesh size as the codend to retain catches passing through the selectivity device. The method is used to retain all escapees. It is assumed that this cover does not affect the ordinary escape process of the trawl. The top cover was made of Ø1.8mm PE with a 48mm mesh size with and 8mm mesh codend. It is 15,5m long and in the upper part it has plastic floats of Ø200mm.



The original Nordmøre-grid design with outer dimensions 648x1350mm; aluminium and 19 mm bar spacing, as used February 2014 in Balsfjord (Source: Larsen, RB. 1991)

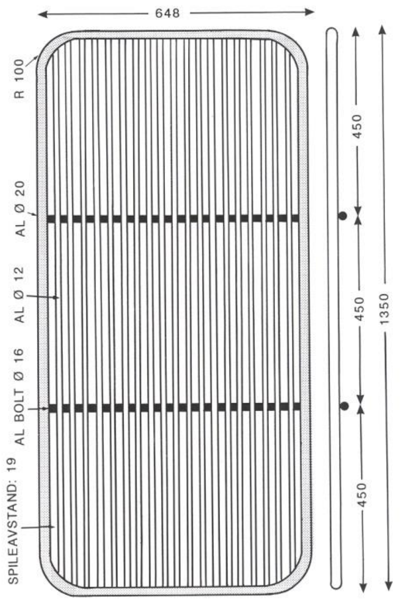


Figure 6. Small scale prawn trawl selective HDPE device (Source: Larsen, R. B., UiT, 2001)

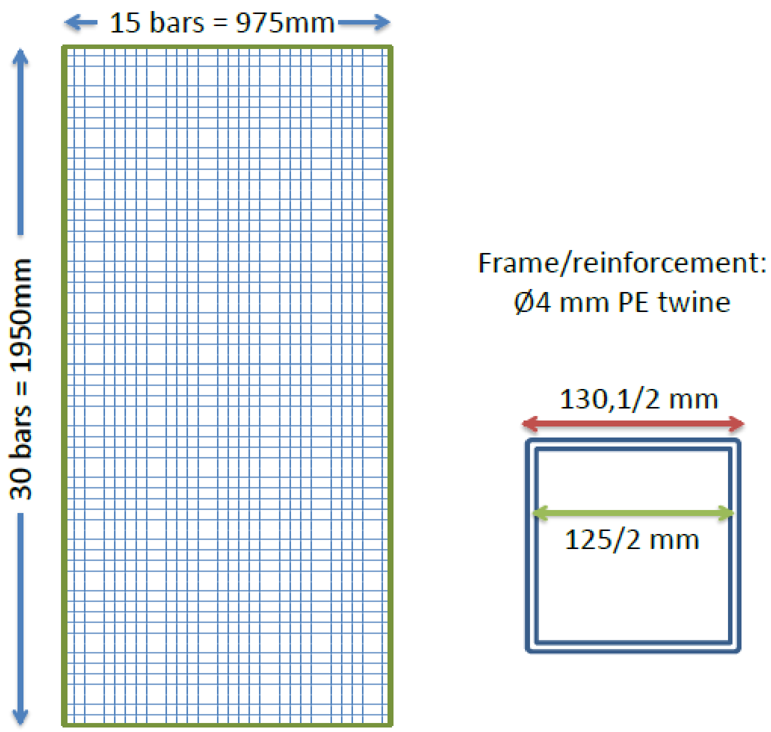


Figure 7. Square mesh window built from 125mm mesh size (Source: Larsen, R. B., UiT, 2001)

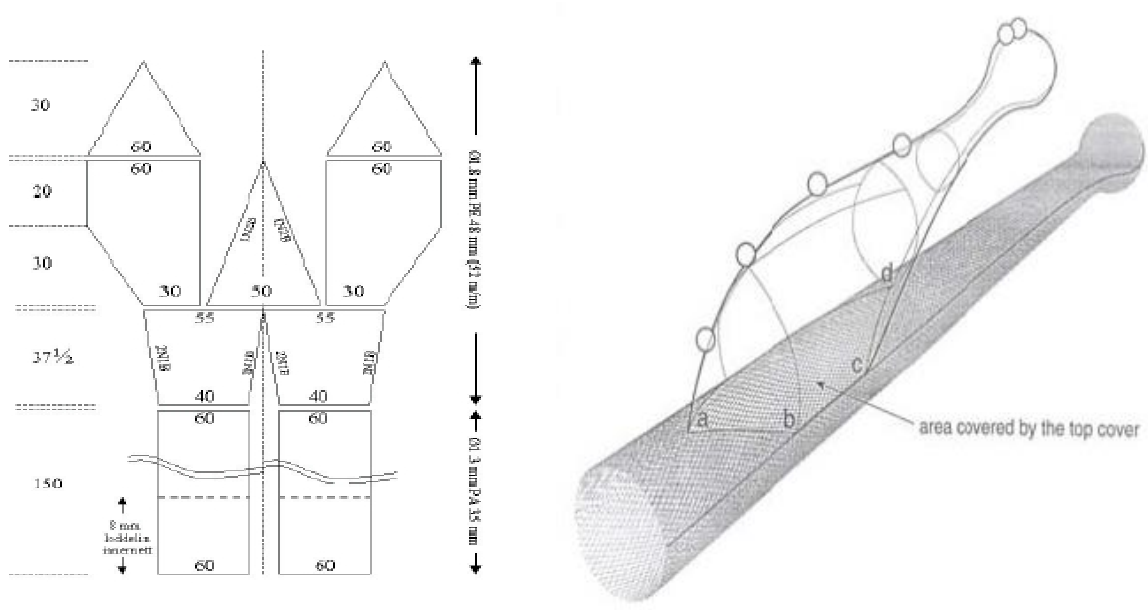


Figure 8. Construction and attachment of a small meshed cover over grid or window (Larsen, R.B. 2013 and Wileman et al. 1996)

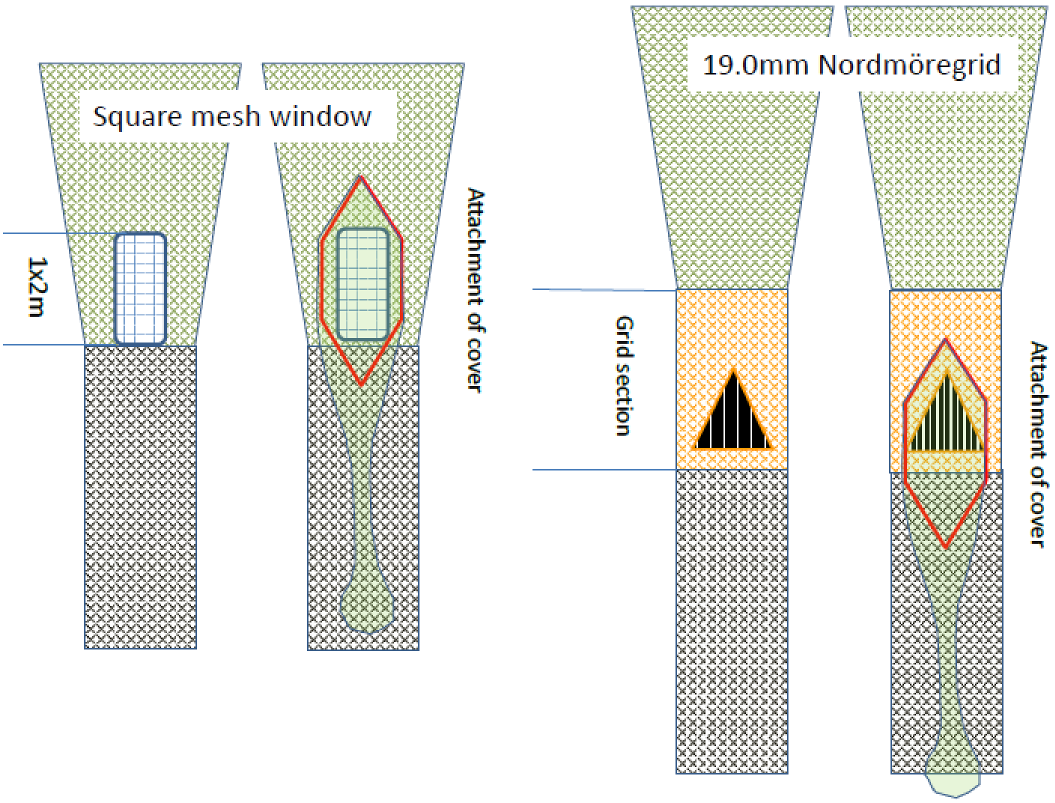


Figure 9. Locations of the selective devices and attachment of cover during experiments in 2014 (Larsen, R.B., UiT, 2013)

3.5 Key species

3.5.1 Species in Balsfjord

In the study made in Balsfjord, together with the prawns, the main key species were to be cod, haddock, and long rough dab.

3.5.1.1 Prawns

Pandalus borealis (Krøyer, 1838) or northern prawn, as defined by FAO, (1980) is a species of caridean prawn found in cold areas of the Atlantic and Pacific Oceans. It lives in depths between 20 and 1330m with muddy bottoms inside of a temperature range of 2 to 14ºC. In the Arctic-Atlantic area, the species is distributed from southern and eastern Greenland to areas as far south as the English Channel covering Iceland, Svalbard, Norway, and the North Sea water (FAO, 1980).

It is one of the most commercially important carideans of the North Atlantic, together with the Common Prawn (*Crangon crangon*), and it is considered the principal product of the prawn fishery of the northeastern Atlantic (FAO, 2012).

3.5.1.2 Atlantic Cod

The Atlantic Cod (*Gadus morhua*, Linnaeus, 1758), is one of the most widely consumed fish species. In the eastern Atlantic, it can be found from the Bay of Biscay up to the north inside the Arctic Ocean including the North Sea, Baltic Sea, and Sea of the Hebrides as well as in areas around Iceland and the Barents Sea (Whiteman, 2000).

Generally considered a demersal fish with pelagic feeding and spawning habits depending on prey distribution, Atlantic cod is distributed in a variety of habitats covering from the shoreline to the bottom of the continental shelf in depths over 600m (FAO, 1990). Cod populations are characterized by having big migratory movements. The Arctic-Norwegian cod spends most of the year inside the Barents Sea, migrating seasonally along the Norwegian coast to spawn (FAO Fisheries and Aquaculture Department, 2004).

Considered as the “beef of the sea” for being one of the most important commercial fish, cod has been exploited since the humans start fishing in the seas of Europe. It is a very valuable fish as a prime food and it commonly both salted and dried for export or storage for wintertime. It is mainly caught with bottom otter trawls and pelagic trawls. Nowadays devices such as handlines and cod traps are being replaced by gillnet (FAO, 2012). The major fishing grounds in Europe are located around Iceland, in the Barents Sea, off Newfoundland and West Greenland, in the Norwegian Sea, off Spitzbergen and around Bear Island. Norway and Iceland are the countries with larges catches (FAO, 2012).

3.5.1.3 Haddock

The haddock (*Melanogrammus aeglefinus*, Gill, T.N., 1862) it is distributed on both sides of the North Atlantic and is widely fished commercially for human consumption. It can be easily recognized by a black lateral line along the white side and a distinctive dark blotch over the pectoral fin. Commonly found in bottoms between 40 to 133m it has a maximum range of 300m, determinate by a temperature range of 2 to 10ºC. Juveniles tend to live in shallower waters while adults live in deeper water. The most important spawning grounds are middle Norway, southwester Iceland and Georges Bank (US) (FAO, 1990).

It is an important target species in North Atlantic fisheries. The most important fishing grounds are located around the European coast of Russia, around Iceland, in the Barents Sea, around Faeroe Islands, off western Norway and western Scotland, in the Celtic Sea, off Ireland, in the North Sea and in the English Channel (FAO, 2012). It is commonly fished with bottom trawls, longlines, gillnets, and traps being UK and Norway the countries with bigger catches. Marketed as fresh, chilled as fillets, frozen, smoked or canned fish it can be sometimes used as fishmeal (FAO, 2012).

3.5.1.4 Long rough dab

The long rough dab, also known as sole, (*Hippoglossoides platessoides,* O. Fabricius, 1780) is a flatfish that lives in the Atlantic Ocean off eastern Greenland and from the English Channel to the coast of Murmansk, Russia (Froese & Pauli, 2003). Living on soft bottoms on depths between 10-400m is more abundant in depths between 90 to 250m depending on bottom temperatures of -0.5 to 2.5ºC (Nielsen, 1986).

With a maximum total catch of 130000 tonnes reported in 1969, annual catches of long rough dab has decreased to levels around the 10000 tonnes. The countries with the biggest catches are the Russian Federation and Iceland (FAO, 2012).

Although in this report the common name used for *Hippoglossoides platessoides* is going to be long rough dab since 2003 the FAO recommends the use of American plaice as common nomenclature for international works (Froese, R., and D. Pauly, 2003). However, since both nomenclatures are accepted as trade names and in the lack of an Official Trade name for the species, long rough dab was chosen for this report due to it is commonly used in European markets.

3.5.2 Species on the Bay of Biscay

Being a mixed fishery, with more than 100 species, the main target species are, together with a big range of others, hake, anglerfish, and megrims. The Basque trawling fleet lands 13000 tonnes of fish annually (Iriondo et al., 2008). Fishing in a mixed species fishery is always related with high levels of bycatch that could reach above 50% of the total catch, and include non-commercial species such as Atlantic argentine or boarfish and commercial species with low market place or no quota like mackerel or blue whiting (Perez et al., 2005).

3.6 Data analysis

After being collected, the data was plotted in Excel and analysed descriptively. For the statistical analysis correlation, analyses were done by comparing the selectivity devices between them and the data from the Bay of Biscay. For that correlation analyses, a series of ANOVA's were made, using both Excel and SPSS for a better statistical result.

To test the selection system, data from the two-compartment, cover and codend, of each selectivity device was analysed using the selectivity data analyses software SELNET (developed by Dr. Bent Herrmann, SINTEF fisheries and aquaculture). With this program, we were able to analyse data obtained from sea trials using a two-compartment experimental sampling setup. The software also enables the analyses and simulations of data for experimental designs involving multiple compartment-designs by means of complex selection models. For that the program handles collection and analysis of data for a number of different experimental designs like covered codend, catch comparison, paired gear or catch data (Herrmann, 2009). The estimation of the selectivity parameters of the two-compartment system (i.e. cover and codend) is implemented in SELNET with numerical methods that use the definition for L50 as the length where 50% of the catch is retained. SELNET is a developing program and because of that, a beta version was used in my thesis.

4 Results

4.1 Sea trials

4.1.1 Bay of Biscay

In the study made by AZTI-Tecnalia in the Bay of Biscay 28 hauls were performed with the SMW as selectivity device (Table 3). The towing time and fishing speed were standardised to 15 minutes and 3 knots. Haul were made during day light time starting around 9:00. Depths varied between 23 and 377m changing because of the depth variations between fishing places.

Table 3. Haul description showing number, date, start and finish hour, depth and speed (Arregi, L., 2013, unpublished)

Day	Haul	Starting Time	Depth (m)	Speed (knots)	Finish Time	Time Fishing
25/06/2013	1	08:40:00	234.8	3.3	08:55:08	15:08
25/06/2013	2	11.00:40	169.1	3.3	11:16:53	15:13
25/06/2013	3	13:25:00	156.0	3.3	13:40:14	15:14
25/06/2013	4	17:01:30	178.7	3.4	17:16:45	15:15
25/06/2013	5	19:21:00	93.0	3.7	19:36:13	15:13
26/06/2013	6	09:16:00	371.1	3.0	09:31:16	15:16
26/06/2013	7	10:52:46	269.0	3.2	11:08:00	15:14
26/06/2013	8	12:22:00	134.3	3.6	12:37:10	15:10
26/06/2013	9	13:55:45	116.5	3.7	14:11:00	15:15
26/06/2013	10	15:41:00	127.4	3.7	15:56:09	15:09
27/06/2013	11	09:15:00	180.7	3.4	09:19:00	15:11
27/06/2013	12	13:05:00	23.7	3.6	13:20:00	15:05
27/06/2013	13	14:43:00	28.9	3.8	14:58:00	15:09
27/06/2013	14	17:10:00	53.5	3.7	17:25:00	15:12
28/06/2013	15	08:14:00	95.6	3.8	08:29:00	15:12
28/06/2013	16	13:52:00	90.6	3.8	14:11:00	15:07
29/06/2013	17	08:51:00	101.6	3.7	09:06:00	15:09
29/06/2013	18	10:45:00	33.5	3.8	11:00:00	15:08
29/06/2013	19	13:09:00	65.5	3.8	13:24:00	15:13
29/06/2013	20	14:45:00	92.5	3.8	15:00:00	15:04
30/06/2013	21	07:51:00	70.4	3.8	08:06:00	15:22
30/06/2013	22	10:00:00	50.4	3.8	10:15:00	15:05
30/06/2013	23	11:43:00	34.8	3.9	11:58:00	15:14
30/06/2013	24	14:16:00	198.4	3.3	14:31:00	15:10
01/07/2013	25	08:50:00	135.0	3.6	09:05:00	15:09
01/07/2013	26	11:43:00	122.9	3.6	11:58:00	15:07
01/07/2013	27	14:18:00	129.9	3.8	14:33:00	15:00
01/07/2013	28	16:06:00	112.8	3.8	16:21:00	15:03

4.1.2 Balsfjord

During the cruise, a total of 30 hauls were performed and the use of the selectivity devices was distributed using the sorting grid in 14 hauls (numbered as 1 to 14) and the SMW in 16 hauls (numbered as 16 to 30). From the 14 hauls performed with the sorting grid, 13 were valid and in the case of the SMW, 14 of the 16 hauls were valid. The non-valid hauls were caused because of accumulation of mud, both in the cover net and in the codend hampering the entry of the fish to the net. The hauls were performed during daylight starting around 8:00 and finishing around 16:00 due to fish behaviour and distribution. The towing time (i.e. gear at the seabed) was standardized to 20 minutes and the fishing speed was around 3 knots. Figure 10 shows the start point of all the hauls inside of Balsfjord.

Inside of Balsfjord, the hauls were made in two different fishing grounds, one located in the middle of the fjord, around 69º 22,0N 19º 04,0E, and the other one in the bottom of the fjord around 69º 19,6N 19º 22,0E. The depth in the middle of the fjord was around 185m and in the bottom of the fjord was around 125m. Two fishing places were used to avoid overexploitation of the fishing ground and to test both devices in two different depths and locations to avoid selection bias in the experiment. Each selectivity device was used the same number of times in both fishing places. Sorting grid was used 7 times and the SMW was used 8 times in each place. In Table 4 haul information is given showing starting and fishing places, depth, used device and speeds among other information.

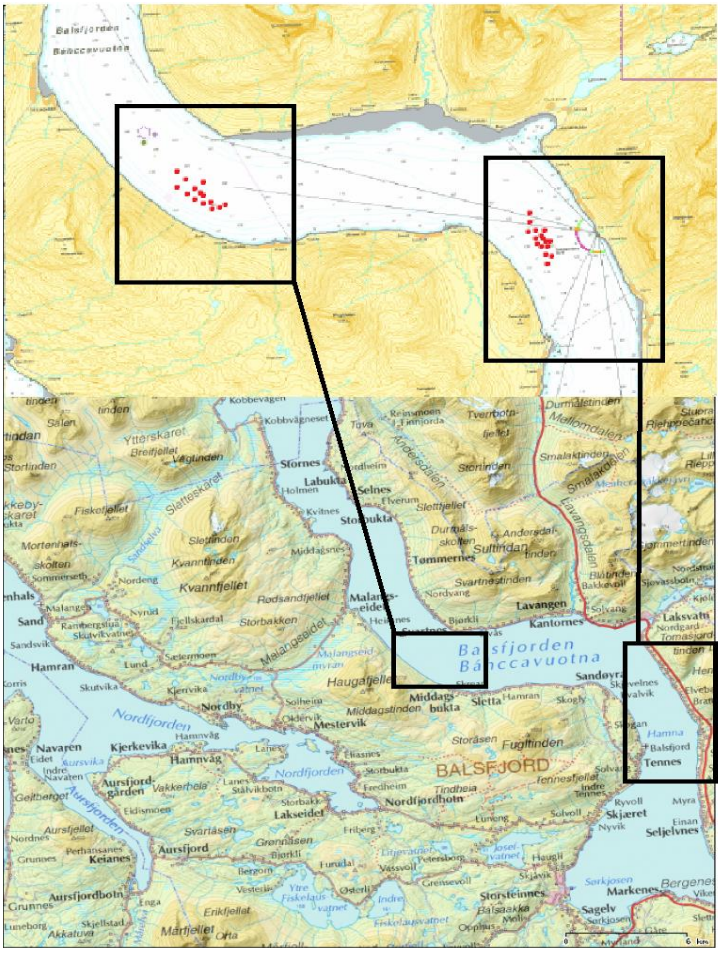


Figure 10. Plotted hauls for the two devices inside of Balsfjord

Table 4. Haul description showing number, date, start and finish hour, trawling time, start and finish position, start and finish depth, wind speed, state and used selectivity device.

Haul nr	Date	Start	Finish	Time (m)	Pos start	Pos finish	Depth Start (m)	Depth Finish (m)	WindSpeed (m/s)	State	Device
1	27/01/2014	12:40	13:01	21	N69º 22.2 , E19º 03.8	N69º 21.6 , E19º 04.8	188	186	14	Valid	Grid
2	27/01/2014	15:14	15:36	21	N69º 22.3 , E19º 04.2	N69º 21.6 , E19º 05.3	186	184	15	Invalid	Grid
3	27/01/2014	16:58	17:18	20	N69º 22.1 , E19º 04.8	N69º 21.5 , E19º 05.2	187	185	14	Valid	Grid
4	28/01/2014	08:40	09:00	20	N69º 22.1 , E19º 04.3	N69º 21.5 , E19º 05.3	187	186	14	Valid	Grid
5	28/01/2014	10:00	10:21	21	N69º 21.9 , E19º 04.7	N69º 21.3 , E19º 05.8	187	184	16	Valid	Grid
6	28/01/2014	11:56	12:16	20	N69º 19.8 , E19º 22.1	N69º 19.2 , E19º 22.7	126	123	12	Valid	Grid
7	28/01/2014	12:55	13:15	20	N69º 19.9 , E19º 21.7	N69º 19.3 , E19º 22.5	126	123	10	Valid	Grid
8	28/01/2014	14:50	15:11	21	N69º 19.8 , E19º 21.9	N69º 19.2 , E19º 22.6	126	122	7	Valid	Grid
9	29/01/2014	08:35	08:55	20	N69º 19.5 , E19º 22.2	N69º 20.1 , E19º 21.7	124	126	5	Valid	Grid
10	29/01/2014	09:22	09:42	20	N69º 20.0 , E19º 21.7	N69º 19.4 , E19º 22.5	127	124	6	Valid	Grid
11	29/01/2014	10:27	10:47	20	N69º 19.5 , E19º 22.2	N69º 20.2 , E19º 21.5	125	127	6	Valid	Grid
12	29/01/2014	11:47	12:07	20	N69º 21.8 , E19º 05.2	N69º 22.2 , E19º 03.7	185	190	7	Valid	Grid
13	29/01/2014	12:43	13:03	20	N69º 22.2 , E19º 04.2	N69º 21.6 , E19º 05.4	188	187	8	Valid	Grid
14	29/01/2014	13:36	14:00	24	N69º 22.0 , E19º 04.5	N69º 22.5 , E19º 03.3	187	188	7	Valid	Grid
15	30/01/2014	08:51	09:01	10	N69º 22.0 , E19º 04.3	N69º 21.8 , E19º 04.9	187	186	7	Invalid	Square Mesh
16	30/01/2014	10:36	10:56	20	N69º 21.8 , E19º 04.8	N69º 21.4 , E19º 06.3	187	185	6	Valid	Square Mesh
17	30/01/2014	11:41	12:01	20	N69º 21.9 , E19º 04.6	N69º 21.4 , E19º 06.1	188	186	7	Valid	Square Mesh
18	30/01/2014	13:18	13:38	20	N69º 19.9 , E19º 21.8	N69º 19.3 , E19º 22.4	127	125	6	Valid	Square Mesh
19	30/01/2014	14:22	14:42	20	N69º 19.6 , E19º 22.2	N69º 20.2 , E19º 21.5	125	126	4	Valid	Square Mesh
20	31/01/2014	08:38	08:58	20	N69º 19.6 , E19º 22.3	N69º 20.2 , E19º 21.5	123	125	4	Valid	Square Mesh
21	31/01/2014	09:48	10:09	21	N69º 19.9 , E19º 21.7	N69º 19.3 , E19º 2.6	126	123	6	Valid	Square Mesh
22	31/01/2014	10:38	10:58	20	N69º 19.6 , E19º 22.3	N69º 21.6 , E19º 05.8	124	126	7	Valid	Square Mesh
23	03/02/2014	09:30	09:42	12	N69º 21.8 , E19º 05.0	N69º 21.6 , E19º 05.8	185	184	9	Invalid	Square Mesh
24	03/02/2014	11:08	11:28	20	N69º 19.6 , E19º 22.2	N69º 19.2 , E19º 22.5	125	122	5	Valid	Square Mesh
25	03/02/2014	11:58	12:18	20	N69º 19.5 , E19º 22.3	N69º 20.2 , E19º 21.5	122	126	7	Valid	Square Mesh
26	03/02/2014	12:45	13:05	20	N69º 19.9 , E19º 21.7	N69º 19.2 , E19º 22.4	126	123	6	Valid	Square Mesh
27	03/02/2014	14:10	14:30	20	N69º 19.5 , E19º 22.2	N69º 20.2 , E19º 21.5	125	127	6	Valid	Square Mesh
28	04/02/2014	08:49	09:09	20	N69º 21.9 , E19º 04.7	N69º 22.4 , E19º 03.5	185	188	3	Valid	Square Mesh
29	04/02/2014	09:48	10:08	20	N69º 21.8 , E19º 05.0	N69º 21.4 , E19º 06.4	185	184	3	Valid	Square Mesh
30	04/02/2014	10:41	11:02	21	N69º 21.8 , E19º 05.2	N69º 22.3 , E19º 03.7	184	188	3	Valid	Square Mesh

In addition to the three species considered as target, i.e. cod, haddock, and long rough dab, all the other species caught were also sorted and measured. The size distribution for the three target species in the different compartments for each device was analysed (section 4.2). Prawns were studied separately according to the measured weight in section 4.3.

4.2 Numbers of fish and their size distribution

In this section, the size distribution of the selected species is analysed for the codend and the cover net of each selectivity device. In (Table 5) the catches of the selected species per haul, per device and per compartment are described. The non-selected species were marked as other species In Figure 11 & Figure 12, the number of individuals can be observed. In the hauls where the grid was used, the number of fish retained by the cover was higher than in the codend. With the square mesh panel, the opposite is recorded.

The recorded number of long rough dab was obtained from calculations using the total weight of the sample and estimating the total number of individuals from measured subsamples.

Regarding to other species with minor interest in this research the length distribution was also measured for both devices. In total, 14 more species were caught being the most abundant capelin (*Mallotus villosus*), witch flounder (*Glyptocephalus cynoglossus*) and Atlantic herring (*Clupea harengus*).

Table 5. Numbers of fish measured and recorded per species, haul nr. and compartment (i.e. cover and codend) of both selectivity devices.

		Cod		Haddock		Long rough dab		Other Sp	
	Haul	Cover	Codend	Cover	Codend	Cover	Codend	Cover	Codend
Grid	1	41	5	4	0	85	10	4	36
	3	92	0	3	0	55	6	11	20
	4	23	2	1	0	106	18	70	167
	5	38	6	11	0	65	19	5	73
	6	13	7	11	0	18	9	10	126
	7	10	1	20	0	25	26	3	96
	8	38	4	51	0	131	52	9	81
	9	6	1	10	0	29	41	1	13
	10	34	4	24	0	108	39	25	125
	11	10	1	15	0	30	14	6	120
	12	13	3	1	0	59	22	1	61
	13	23	1	2	0	56	12	7	318
	14	20	1	1	0	69	12	7	28
	Total Grid	361	36	154	0	836	280	159	1265
Square Mesh Window	16	0	54	0	1	1	97	4	31
	17	0	49	0	2	0	60	5	18
	18	0	18	0	13	0	148	0	43
	19	0	26	0	16	1	41	4	45
	20	0	6	0	9	0	75	1	30
	21	1	18	0	21	1	160	10	20
	22	1	13	0	16	1	315	8	27
	24	0	42	0	19	1	186	4	44
	25	0	4	0	3	0	12	0	38
	26	0	46	1	15	0	214	6	16
	27	0	6	0	4	0	113	0	13
	28	0	7	0	0	0	16	7	36
	29	0	39	0	0	2	106	13	53
	30	0	9	0	0	0	2	0	15
	Total SMW	2	337	1	119	7	1544	62	430
Total Hauls		363	373	155	119	843	1824	221	1694

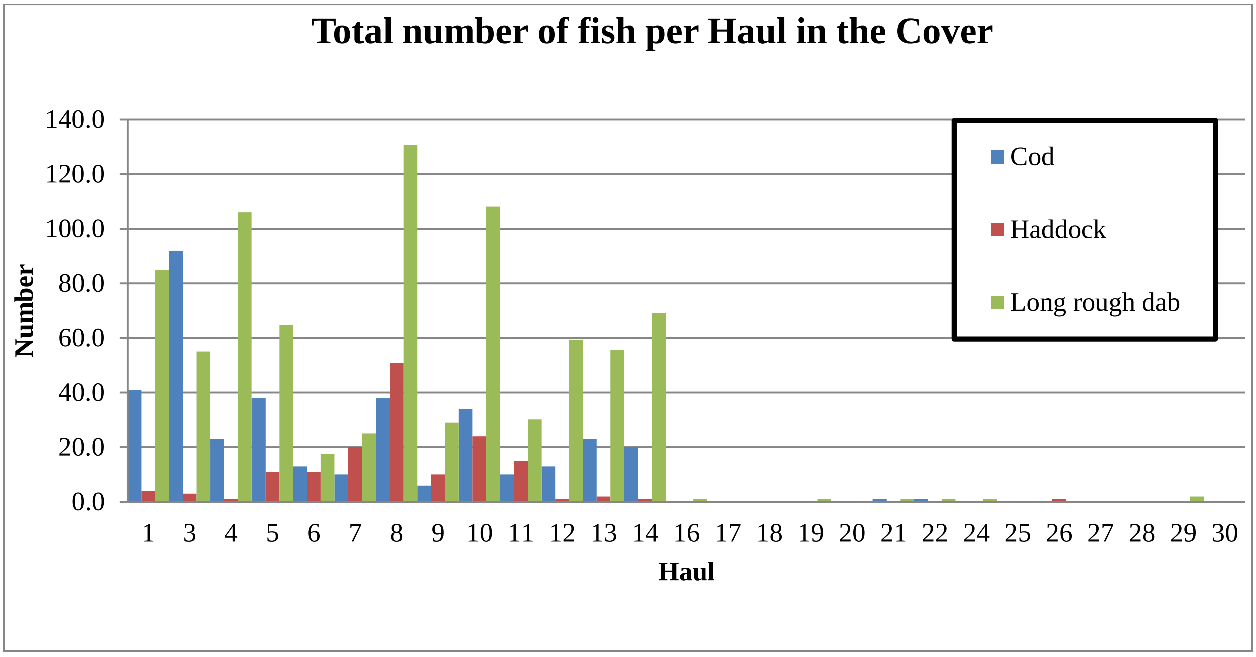


Figure 11. Total number of Fish in the Cover per Haul

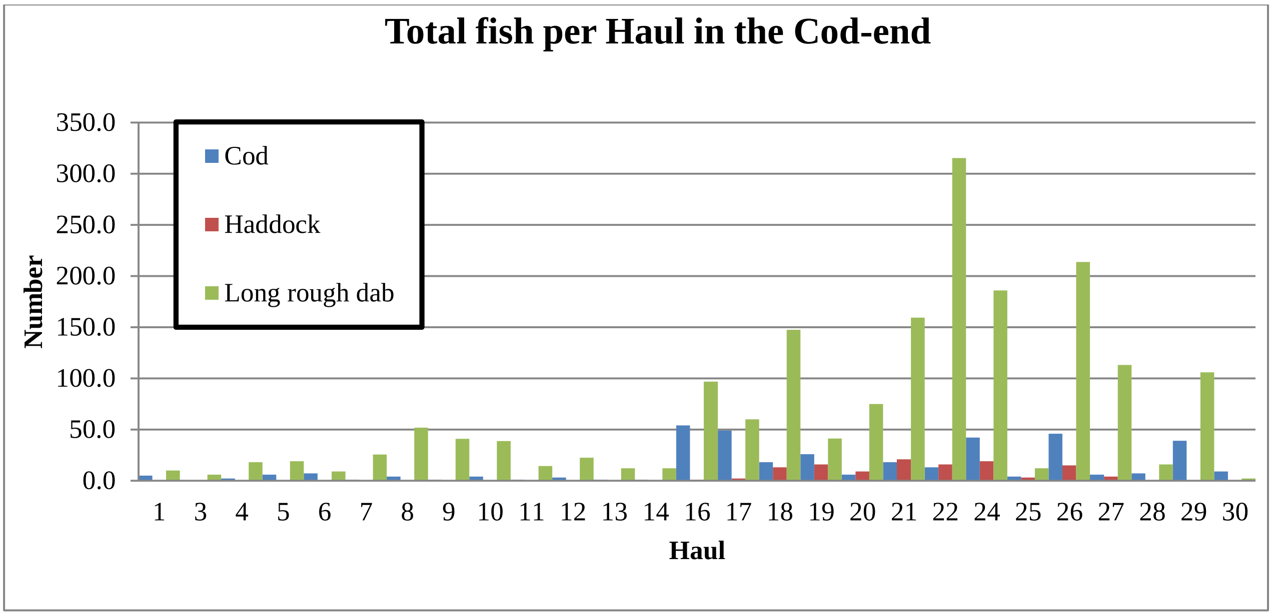


Figure 12. Total number of Fish in the Codend per Haul

With the obtained total number of fish per device the retention, fish in the codend, and the exclusion, fish escaping through the device, rates were calculated for each species. The following figures show the retention and exclusion rates per selectivity device of each species taking in account the total number of individuals caught during the hauls.

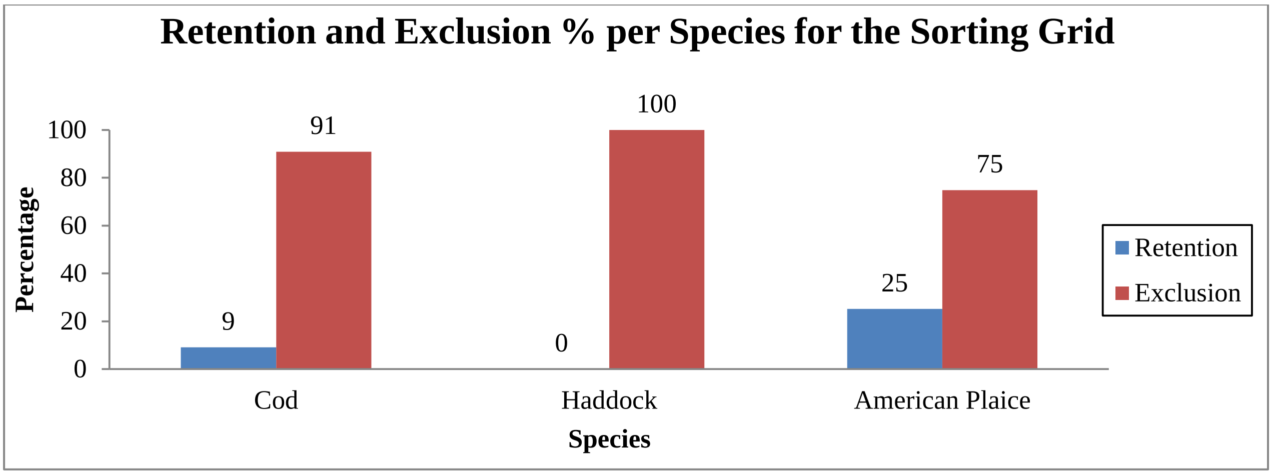


Figure 13. Retention and Exclusion rates for each species using the Sorting Grid as selectivity device.

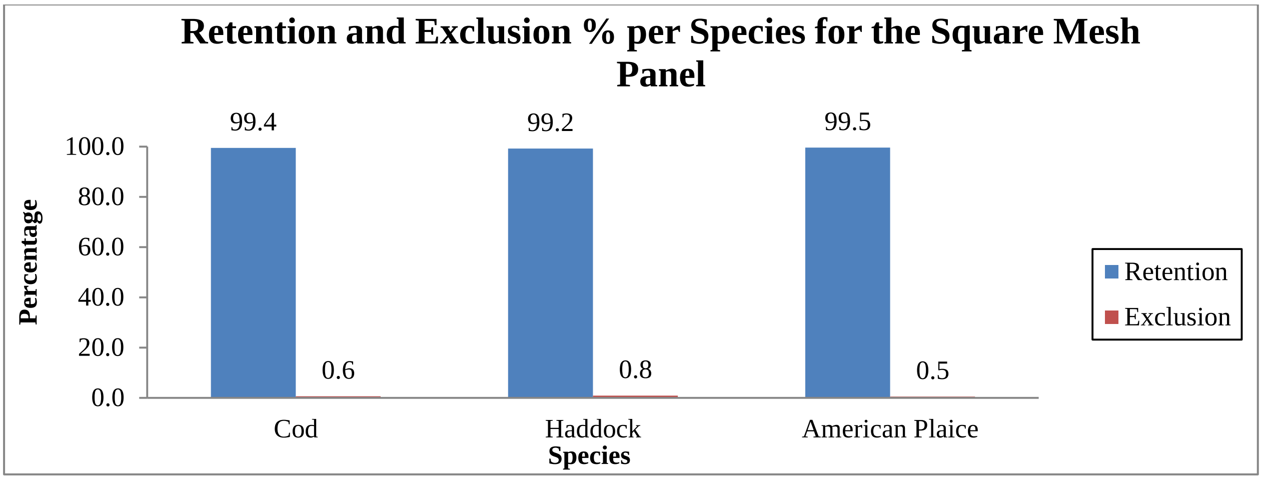


Figure 14. Retention and Exclusion rates for each species using the Square Mesh Panel as selectivity device.

In Figure 13, it can be observed that for all the species, the exclusion rate using the sorting grid is higher than the retention rate. This means that the most part of the fish was escaping through the device. In the case of the Square Mesh Panel (Figure 14), it can be observed that for all the species almost all fish were retained in the codend and that very few individuals were escaping through the device.

In the following subsections, the size distribution of all the obtained individuals of each species per haul and selectivity device is analysed. Each selectivity device i.e. sorting grid and SMW is separately studied for a better view of the results in terms to analyse the selectivity of both of them. The figures presented show the relative proportion retained in the codend and in the cover.

4.2.1 Cod (Gadus morhua) size distribution

During the sorting grid hauls (Figure 15), the length range for cod was between 7 and 100cm, having only one individual of 120cm. In the codend, we found individuals between 7 and 17cm. In the cover, the full size range was found, and there is an overlap with the codend in the size range 7-17 cm. This overlap represents the size selection area (see section 4.4). The cover catch represents almost all of the individuals of the population, from juveniles to big adults. The few individuals of juvenile cod that passes between the bars of the grid were retained in the codend.

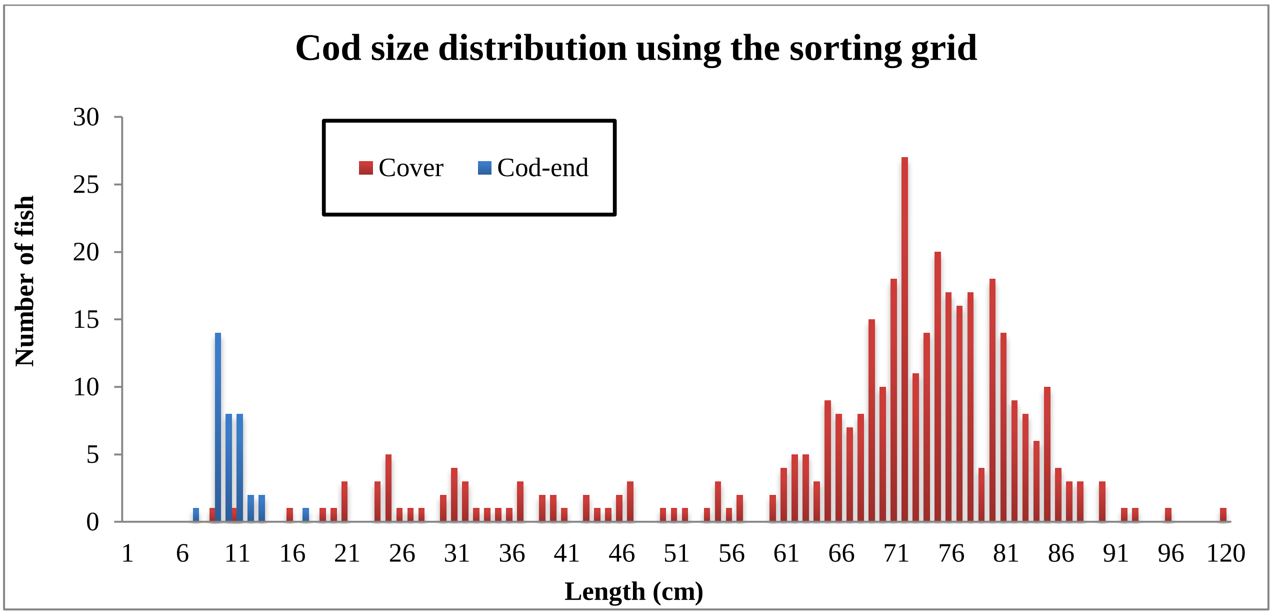


Figure 15. Size distribution of cod in the codend and the cover for the sorting grid

In the case of the hauls, where the SMW was used, (Figure 16) the length range was between 9 and 100cm in addition to one bigger individual of 104cm. The codend catch represents all the individuals of the population from juveniles to big adults, with sizes between 9 and 104cm. In the case of the cover, just two small individuals of 16 and 21cm were found. These two individuals were the only ones able to escape through the device.

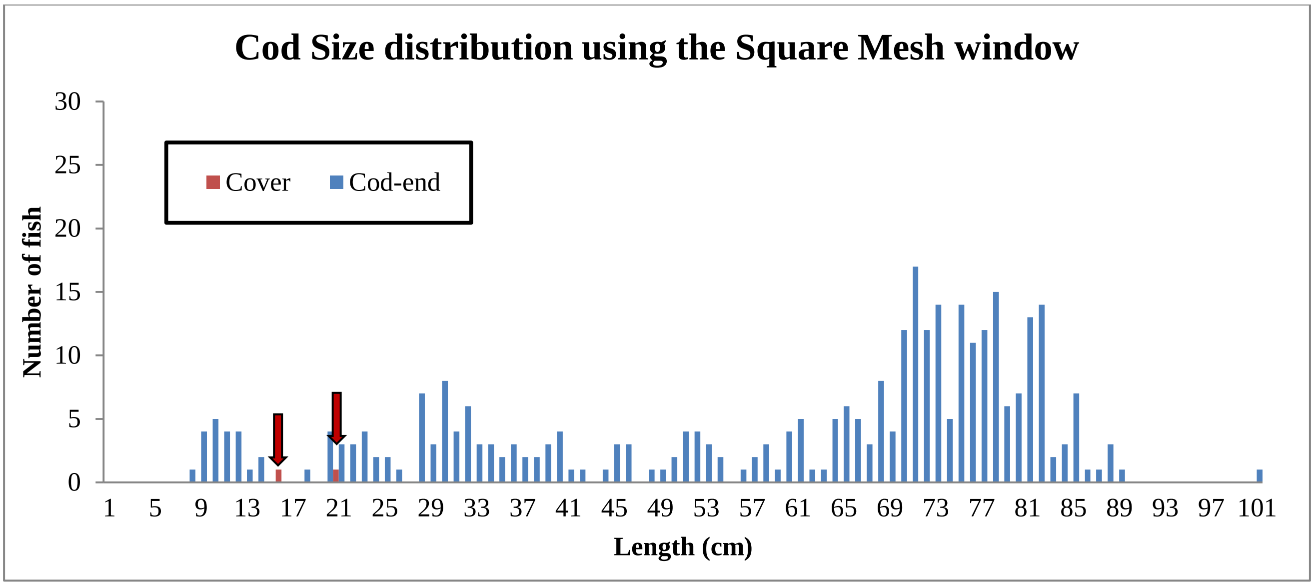


Figure 16. Size distribution of cod in the codend and in the cover for the square mesh window. Appointed with arrows the only two individuals found in the cover.

4.2.2 Haddock (Melanogrammus aeglefinus) size distribution

The length range for haddock, using the sorting grid (Figure 17) was between 19 and 94cm. There were no individuals caught in the codend, meaning that all the individuals escape through the device and that the catch found in the cover represents all of the individuals of the population, from juveniles to big adults.

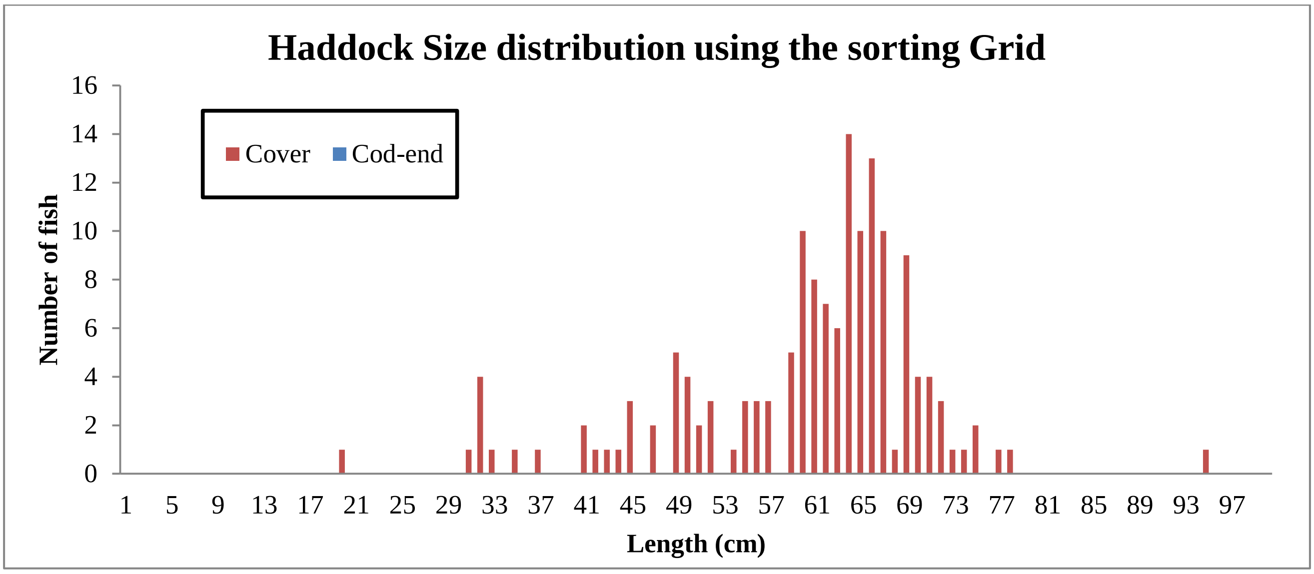


Figure 17. Size distribution of haddock in the codend and the cover for the sorting grid

The length range for haddock, using the SMW, (Figure 18) was between 30 and 75cm, having one individual of 85cm. In the cover, just one individual of 31cm was found. It can be assumed that the catch found in the codend represents all of the individuals of the population, from juveniles to big adults. The individual found in the cover was the only one able to escape through the device.

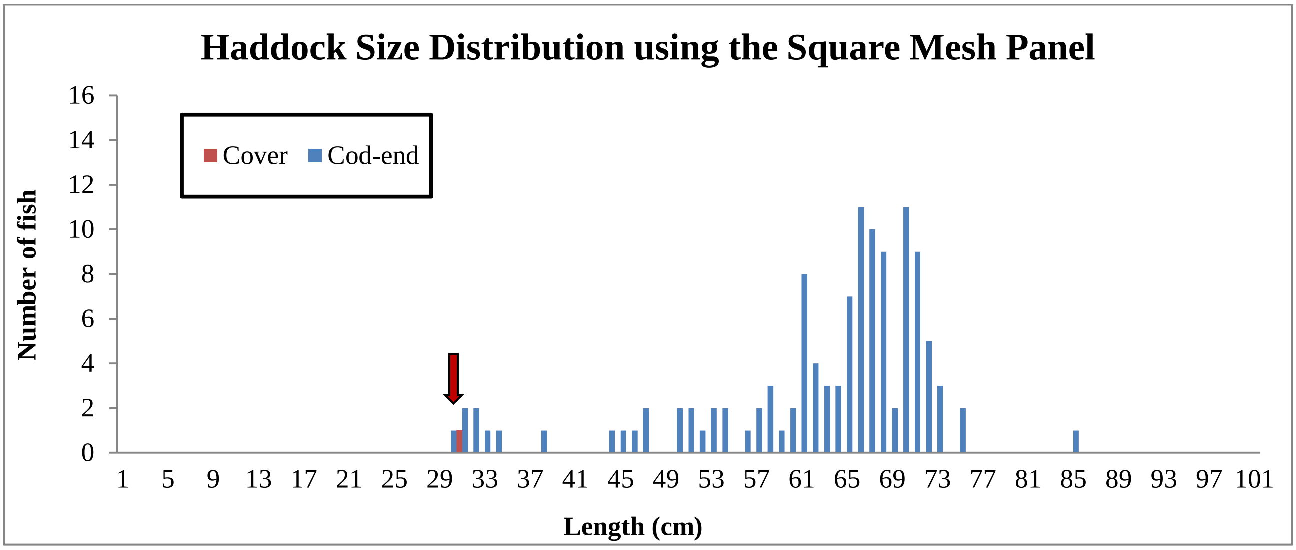


Figure 18. Size distribution of haddock in the codend and in the cover for the SMW. Appointed with an arrow the only individual found in the cover

4.2.3 Long rough dab (Hippoglossoides platessoides) size distribution

For those hauls where the sorting grid (Figure 19) was used, the length range of long rough dab was between 9 and 41cm. In the cover, individuals between 11 and 41cm were caught and, in the codend, the size distribution was between 9 and 33cm. Between sizes of 9 and 33cm, there is an overlap of sizes that represents the size selectivity range (section 4.4). The big individuals found inside the cover, those bigger than 33cm, represent the adult population able to escape through the device.

The length range for long rough dab using the SMW (Figure 20) was between 11 and 38cm. The codend catch represents almost all of the individuals of the population, from juveniles to big adults, because in the cover just 7 individuals were found after all the hauls with sizes between 14 and 20cm. Despite they were able to escape through the device these 7 individuals do not give enough data to study the selectivity and cannot be explained as an overlap of sizes.

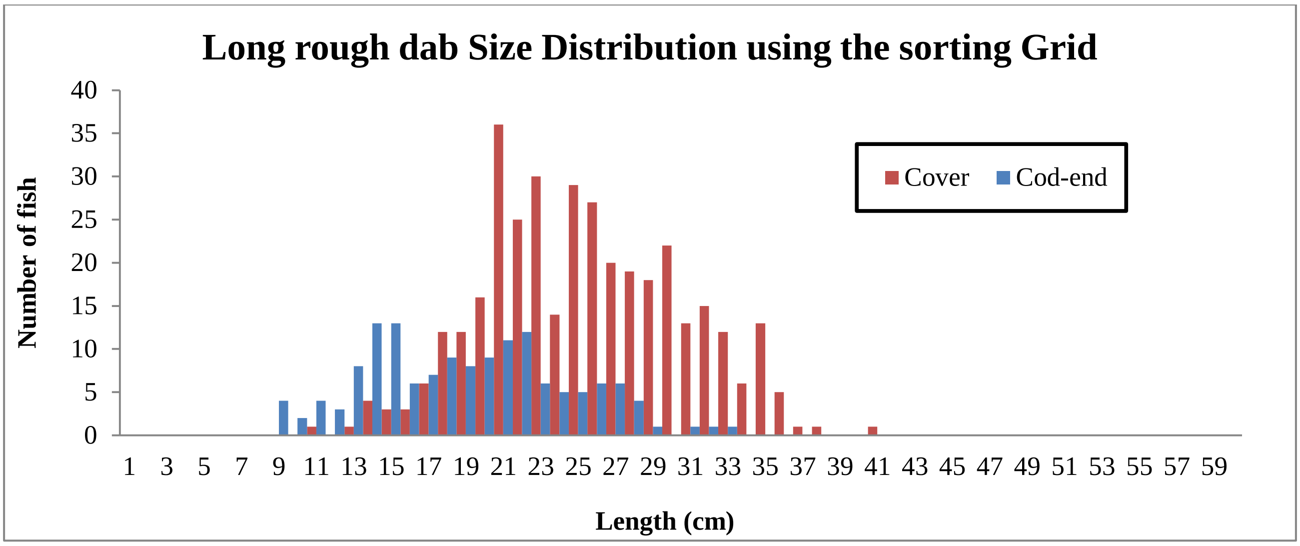


Figure 19. Size distribution of long rough dab in the codend and the cover for the sorting grid

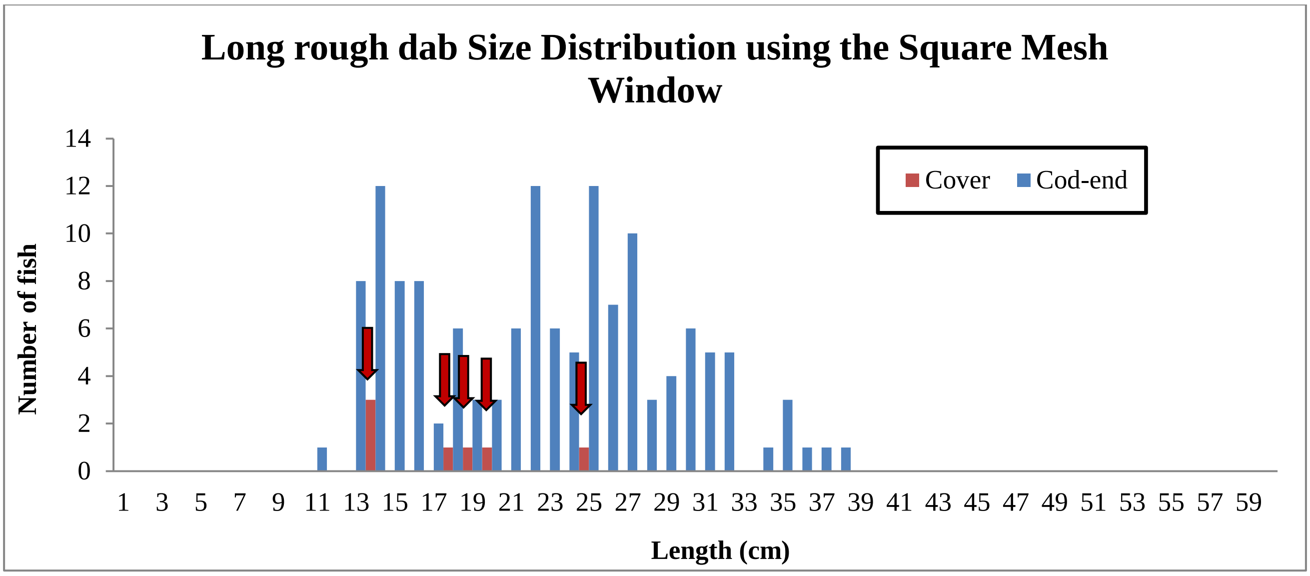


Figure 20. Size distribution of long rough dab in the codend and in the cover for the SMW. Appointed with arrows the only 5 length classes found in the cover

4.3 Prawns

In this section, the weight distribution of prawns (*Pandalus borealis*) is analysed for the codend and the cover net of each selectivity device. From each haul, the total weight of all the caught prawns was calculated and the number of prawns per kilogram (kg) was counted to estimate the number of individuals caught. In Table 6 it can be observe all the obtained data for prawns.

The Nordmøre-grid (with maximum 19.0 mm bar distance) is compulsory in the commercial northern prawn fishery in Norway. Fishermen are looking for two effects by this bycatch-reducing device, i.e. maximum reduction of fish and minimum loss of prawns to maximize profits. It is significant to limit the loss of prawns during fishing operations. For this reason, it is important to calculate the retention (and exclusion) rates in these experiments.

For a standardization of the number of prawn, the average amount of prawns per kg was counted from each haul. The average number of prawn per kilogram was calculated to 209 prawns per kg. This number of prawn per kg was used to calculate the total number of prawn of each haul (Table 6) from the total weight measured on board.

Table 6. Obtained data for each haul and device of prawn

		Cod-end		Cover		Total Prawn	
Haul n	Method	Total Weight	Total Prawn	Total Weight	Total Prawn	Total Weight	Total Prawn
1	Grid	47.3	9885.7	0.000	0	47.300	9885.7
2	Grid	0	0	0.000	0	0.000	0
3	Grid	19.9	4159.1	0.260	68	20.160	4227.1
4	Grid	26.1	5454.9	2.700	564.3	28.800	6019.2
5	Grid	63	13167	0.000	0	63.000	13167
6	Grid	11.1	2319.9	0.000	0	11.100	2319.9
7	Grid	11.5	2403.5	0.000	0	11.500	2403.5
8	Grid	42.6	8903.4	0.015	9	42.615	8912.4
9	Grid	7.02	1467.18	0.036	15	7.056	1482.18
10	Grid	31.7	6625.3	0.039	17	31.739	6642.3
11	Grid	7.93	1657.37	0.006	4	7.936	1661.37
12	Grid	68.38	14291.42	0.025	21	68.405	14312.42
13	Grid	66.74	13948.66	1.580	330.22	68.320	14278.88
14	Grid	89.62	18730.58	0.000	0	89.620	18730.58
15	Square Mesh	0	0	0.000	0	0.000	0
16	Square Mesh	71.05	14849.45	0.600	125.4	71.650	14974.85
17	Square Mesh	36.97	7726.73	0.000	0	36.970	7726.73
18	Square Mesh	21.37	4466.33	0.000	0	21.370	4466.33
19	Square Mesh	29.475	6160.275	0.088	15	29.563	6175.275
20	Square Mesh	46.35	9687.15	0.000	0	46.350	9687.15
21	Square Mesh	24.165	5050.485	0.106	23	24.271	5073.485
22	Square Mesh	15.18	3172.62	0.020	4	15.200	3176.62
23	Square Mesh	0	0	0.000	0	0.000	0
24	Square Mesh	20.89	4366.01	0.000	0	20.890	4366.01
25	Square Mesh	2.39	499.51	0.000	0	2.390	499.51
26	Square Mesh	17.39	3634.51	0.015	3	17.405	3637.51
27	Square Mesh	7.925	1656.325	0.000	0	7.925	1656.325
28	Square Mesh	8.65	1807.85	0.060	14	8.710	1821.85
29	Square Mesh	50.24	10500.16	0.364	68	50.604	10568.16
30	Square Mesh	0.013	0.013	0.008	5	0.021	5.013

Comparing the total obtained weight of prawns per haul, it can be very clearly observed that the weight of caught prawns in the cover (Figure 21) were almost inexistent, with a maximum weight in Haul 4 of 3kg. In a clear contrast in all the hauls, almost the entire catch of prawn was found in the codend (Figure 22) having a maximum weight of 90 kg in Haul 14.

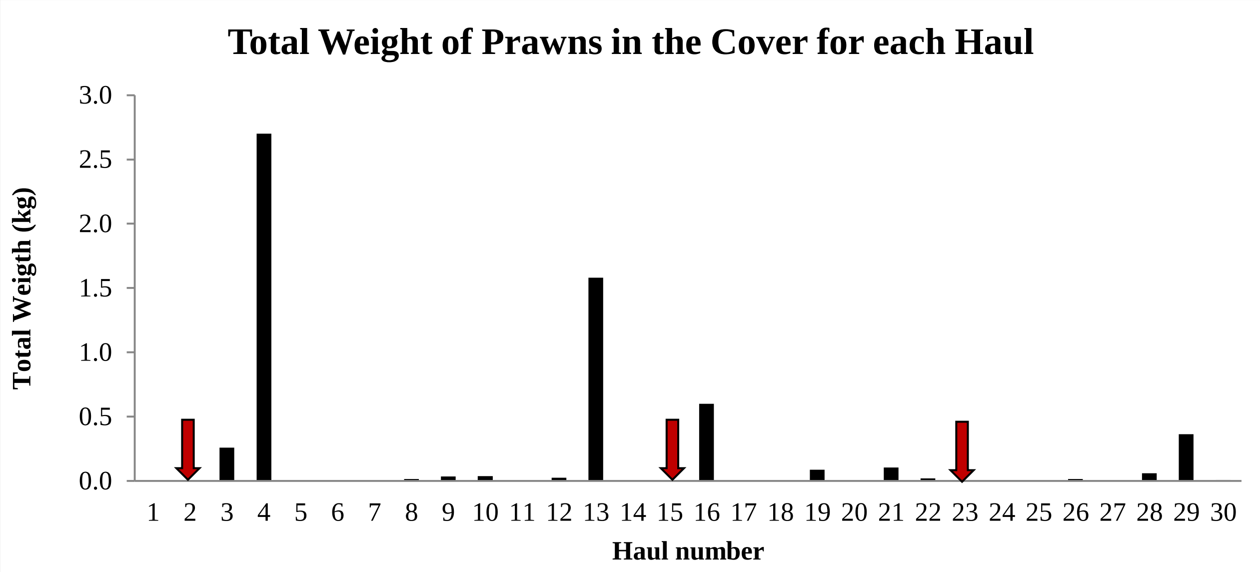


Figure 21. Total weight of prawns in the Cover. The null hauls are pointed with an arrow.

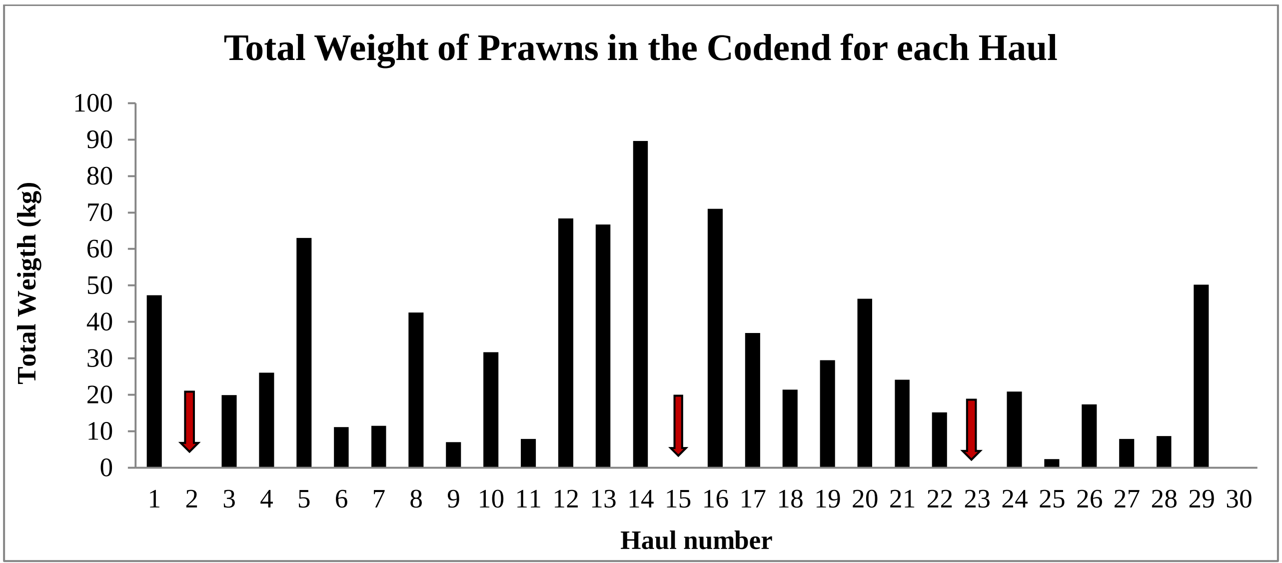


Figure 22. Total weight of prawns in the Codend. The null hauls are pointed with an arrow.

Based on the obtained results for both selectivity devices and focusing on the total weight of prawns, the retention, prawns in the codend, and the exclusion, prawns escaping through the device, rates were calculated. As it can be seen in Figure 21 and Figure 22, both devices has similar results in the cover and in the codend and because of that all the hauls are going to be analysed together, taking into account all the total weight of prawns caught. As can be observed in Figure 23 from the total obtained weight of prawns, 99,3% of the prawns were retained and just the 0.7% was able to escape through the device being excluded from the catch.

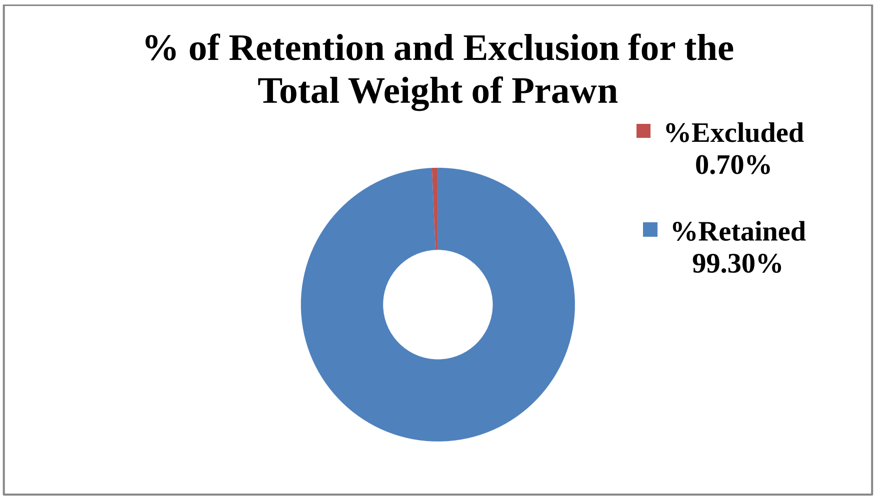


Figure 23. Percentage of Retention and Exclusion for the Total Weight of Prawn for all the hauls

4.4 Selectivity analyses with the software SELNET

The SELNET software has several options for model choices for performing selectivity data analyses. Normally, the obtained data have a normal distribution and the *logit*-function would fit the raw data. SELNET also includes a function to determine the degree of grid-contact (the CLogit-function), which is essential to the selection results when grids and other selective devices are used showing the proportion of individuals contacting the selection device.

In the performed experiments, it is obvious that selectivity data were obtained only during hauls with the grid device. Moreover, sufficient data were obtained for only two of the recorded species, i.e. cod and long rough dab. In addition, it is seen from the data that the numbers of fish inside the selection area were very small in most hauls. To find a correct model we tested several options in the SELNET software and the best-fitted model was the *Richard's curve*. This model is a special version of the logistic curve that takes into account that the shape is different from the cumulative distribution of a normal curve. This means that the model is used for samples that are not normally distributed, and that does not take in account that the curve is mirrored around the L50% length. Because of that for this analysis, the *CRichard* model was selected in SELNET to study the data.

Table 7 shows the L50, i.e. the length where there is a 50% chance of being retained, and the Selection Range, that shows the distance between probabilities at 25% and 75% chance of being retained. (The SR is an expression for the steepness of the selection curve, i.e. short SR equals a steep curve). The p-value, the probability of obtaining a result at least as extreme as the one that was actually observed, measures the fitness of the model. Deviance is the equivalent to the likelihood ratio test statistic and usually, when the sum of deviance exceeds DOF it is due to a lack of model-fit. Contact refers to the proportion of fish that actually interact with the device and has a real opportunity to escape through the device. This parameter covers a range from 0, no contact, to 1, all individuals contact the device, for each species. AIC or the Akaike information criterion, is a measure of the relative quality of the model for the given set of data, i.e. AIC gives a means for model selection. The obtained values show a very big difference due to the obtained results. In the case of cod, the AIC is relatively low because almost all the fish escapes. Long rough dab, on the other way, shows a high AIC value because the overlap on sizes, that gives more uncertainty to the model. The degrees of freedom or DOF are the number of values in the final calculation of a statistic that are free to vary. Normally, they are calculated from the number of length classes present in the data minus the number of parameters. Finally the R^2 value (R square) or coefficient of determination, indicates how well data points fit the model, providing a measure of how well observed outcomes are replicated by the model. The coefficient ranges from 0 to 1, being values near to 1 the ones that fit most.

Table 7. Sorting Grid retention analysis obtained values with SELNET

Sorting Grid retention analysis								
Specie	L50	SR	P-value	Deviance	Contact1	AIC	DOF	R2-Value
Cod	16,10	3,75	1	6.46	1	28.08	69	0.8793
Haddock	-	-	-	-	-	-	-	-
Long rough dab	17.72	7.83	0.9443	16.43	1	478.1	27	0.9737

The single haul analyses for cod (Figure 24) show large differences in L50% values for each haul and one outliner with respect to the selection range (SR). These results are due to the limited number of fish inside the selection range in single hauls. Because of that pooling the data (i.e. summarizing the numbers for each length-class), it is possible to establish the selection curve for cod with the grid-device (Figure 25).

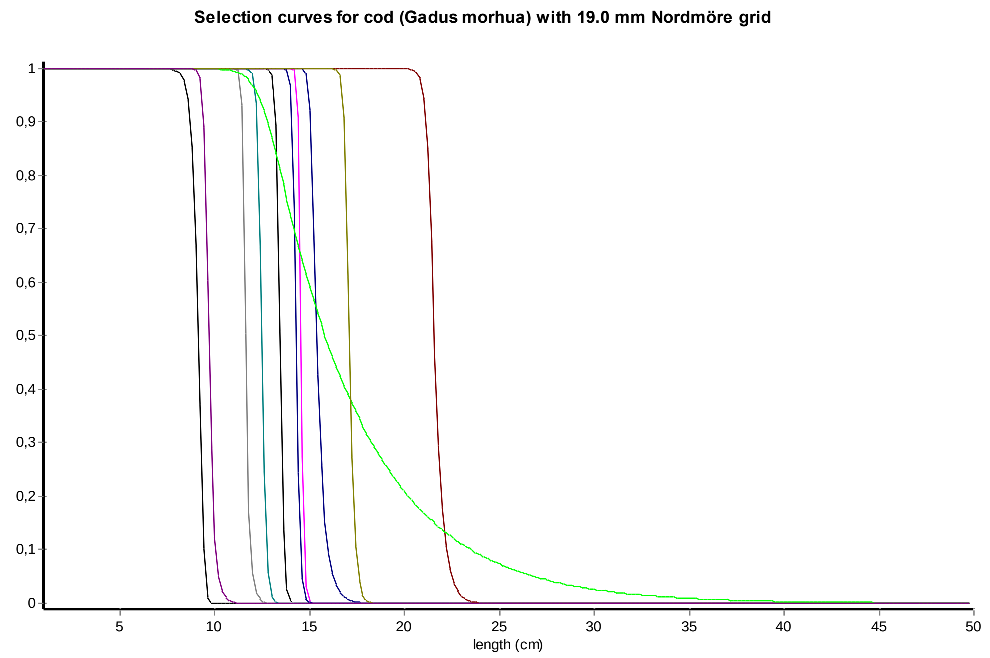


Figure 24. Single haul selection curves for cod (*Gadus morhua*) using the 19.0mm Nordmøre-grid

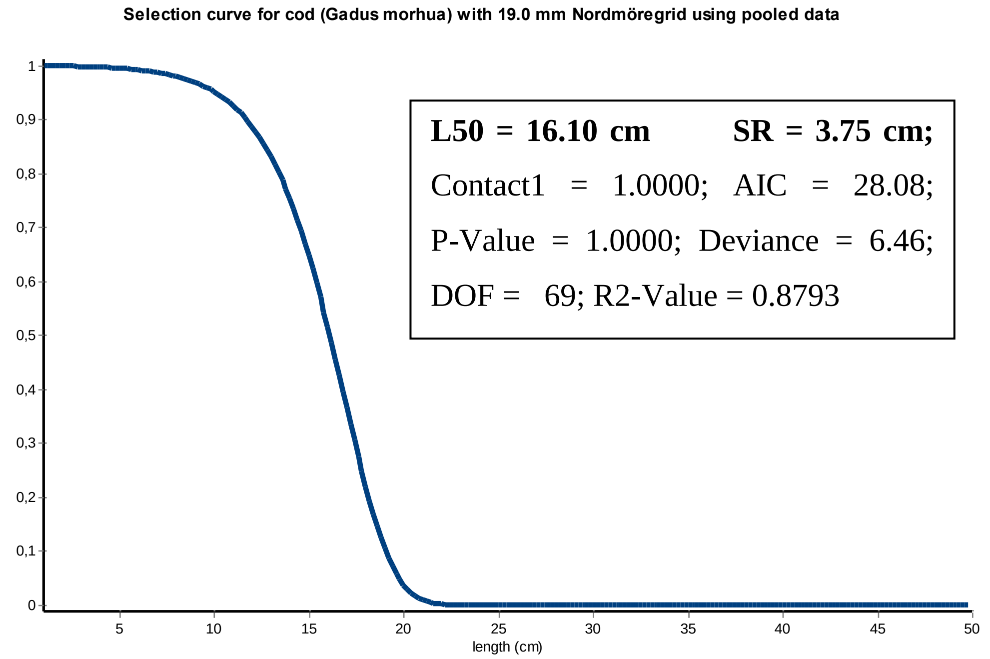


Figure 25. Selection curve for cod (*Gadus morhua*) obtained from pooled data using the 19mm Nordmøre-grid

The obtained pooled figure, confirms the results obtained in section 4.2, showing a size selectivity area in lengths between ca. 5 cm and 22 cm. In the size distribution analysis, the size overlap was between 9 and 17cm and that it can be clearly observed in the figure above. Individuals with lengths bigger than around 22cm have no probability to be retained by the device, while smaller individuals have some probability and around 9cm all the individuals are retained.

In the case of long rough dab, the single hauls analysis (Figure 26) shows that the differences between the L50 are bigger than in the case of cod and the obtained SR results are more different. The curves show very different patterns and complicate the study. In this case, it is also needed to use a pooled data set to study the retention curve properly (Figure 27).

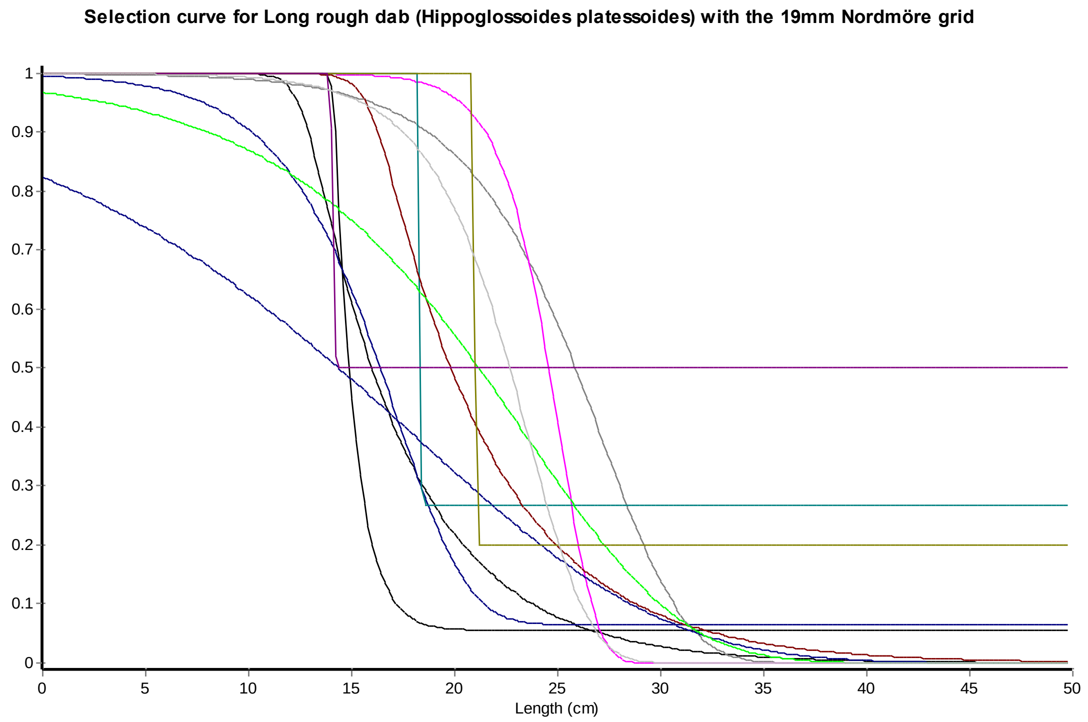


Figure 26. Single haul selection curves for Long rough dab (*Hippoglossoides platessoides*) using the 19.0mm Nordmøre-grid.

Figure 27, shows that the overlap between sizes observed in section 4.2 is real being observed in the figure as the area behind the curve. Individuals inside this area will have some probability to be retained by the device. Smaller individuals will have bigger opportunity than large individuals.

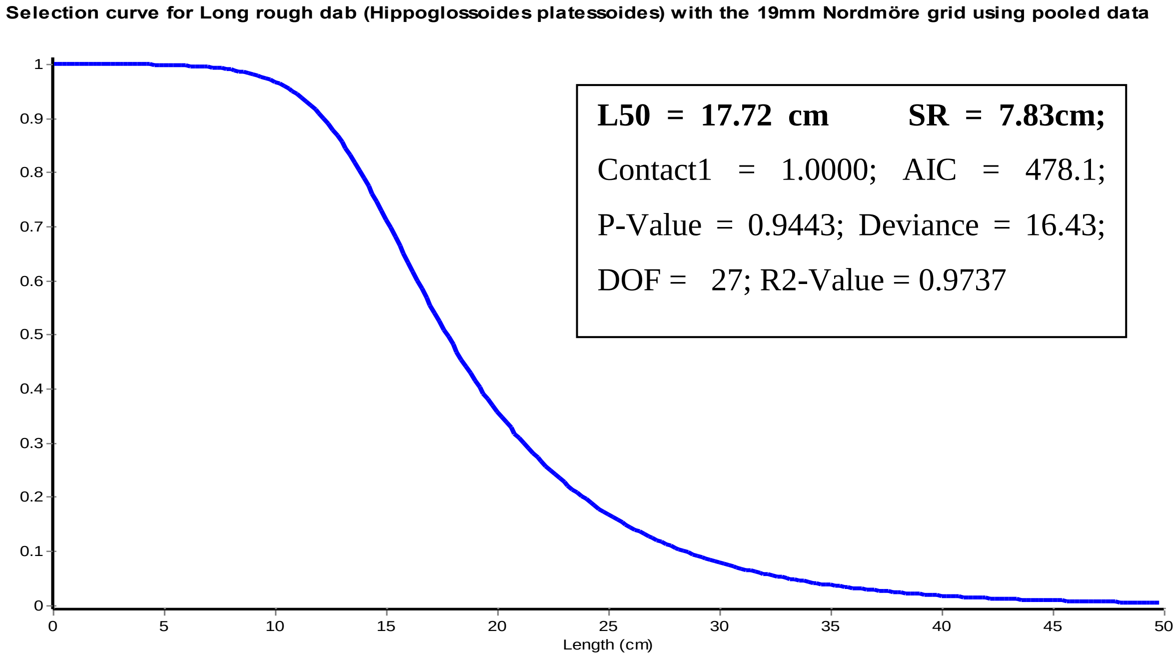


Figure 27. Selection curve for long rough dab (*Hippoglossoides platessoides*) obtained from pooled data using the 19mm Nordmøre-grid

4.5 Number of fish and size distribution of Bay of Biscay

In this section, the number of fish and the size distribution of the species of the Bay of Biscay are to going be presented and analysed. However, due to the high number of species caught i.e. 57 species, for this size distribution analysis 3 species were chosen, which is comparable to the Balsfjord data. The species were chosen according to similarities in behaviour and biological characteristics with the ones used in section 4.2. European hake (*Merluccius merluccius*) was chosen to compare it with cod (*Gadus morhua*). Haddock (*Melanogrammus aeglefinus*) was compared with blue whiting (*Micromesistius poutassou*). Long rough dab (*Hippoglossoides platessoides*) was compared with the four-spot megrim (*Lepidorhombus boscii*).

4.5.1 European hake (Merluccius merluccius) size distribution

The catches of European hake obtained in the Bay of Biscay using the SMW as selectivity device show sizes between 6 and 85cm (Figure 28). Almost all of the individuals were found inside the codend. Inside the cover, few individuals were found covering lengths between 9 and 46cm. However, the overlapping of sizes of both compartments was too small in numbers to perform valid selectivity analyses.

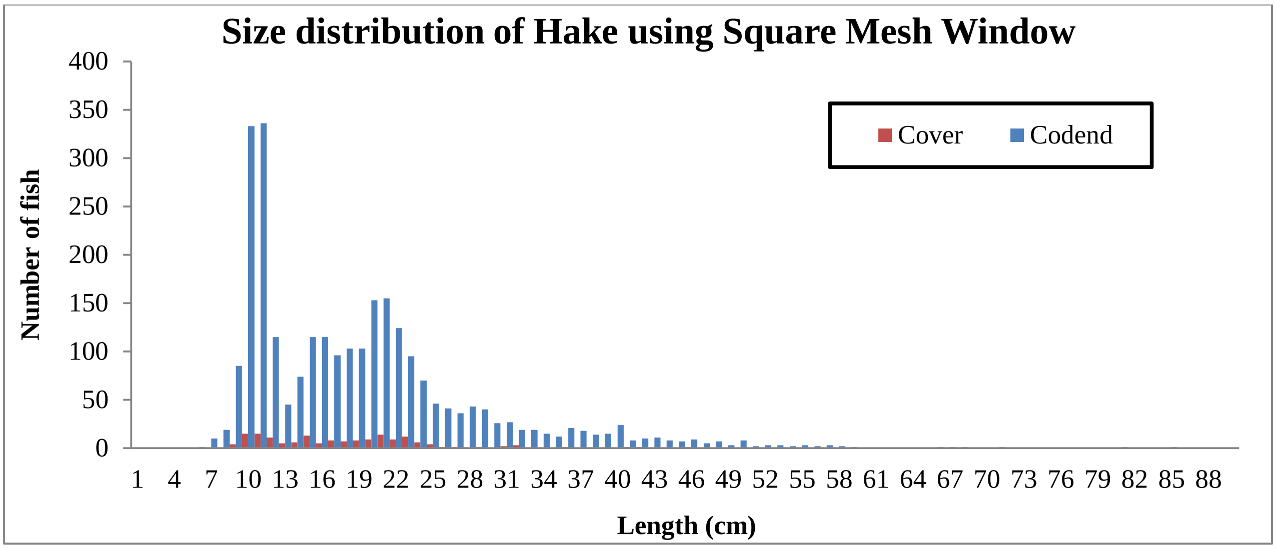


Figure 28. Size distribution of Hake (*Merluccius merluccius*) using the SMW in the Bay of Biscay

4.5.2 Blue whiting (Micromesistius poutassou) size distribution

In Figure 29, the size distribution for blue whiting using SMW is shown. Sizes go from 9cm to 39cm and despite more fish were found in the cover, there is an overlap of lengths in all size-groups.

The higher number of individuals in the cover, compared with the codend, shows that the device is effective for this species. However, the overlapping, and the very similar amounts of fish in both compartments demonstrates that the device is not totally effective because not all individuals are retained or escape.

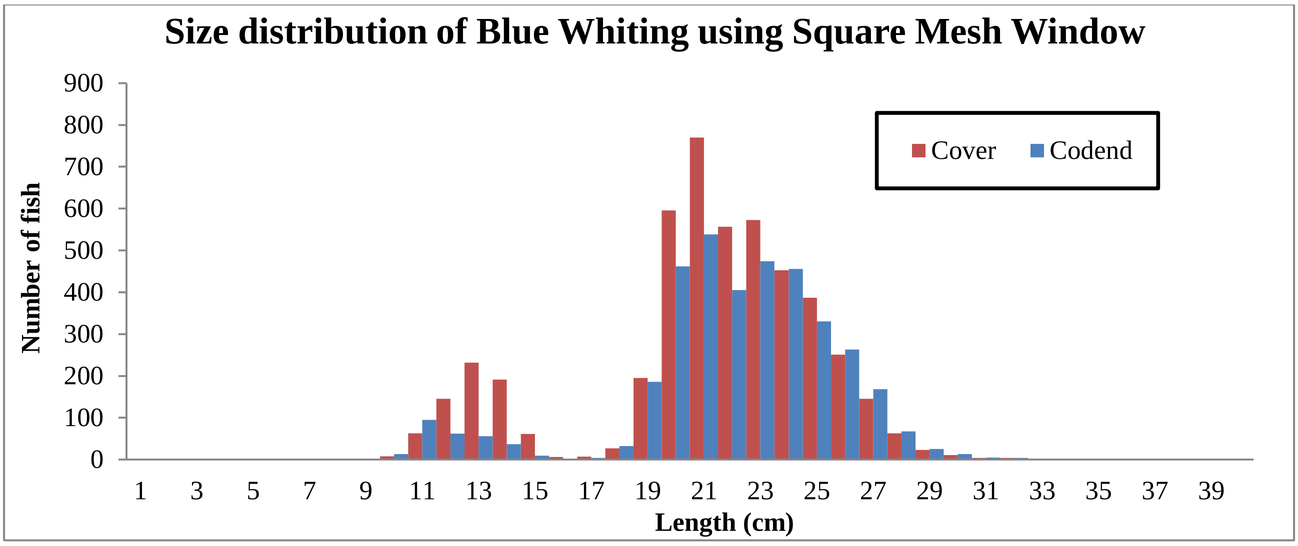


Figure 29. Size distribution of Blue Whiting (*Micromesistius poutassou*) using the SMW in the Bay of Biscay

4.5.3 *Four-spot Megrim (Lepidorhombus boscii) size distribution*

The size distribution that can be observed (Figure 30) for the four-spot megrim shows that all the sizes, going from 10 to 45cm, can be found in the codend. In the cover, just a few individuals were retained; with sizes of 18 and 27cm. Individuals caught in the codend represent all the different lengths of the population from young individuals to adults. The individuals caught in the cover were the only ones able to escape through the device.

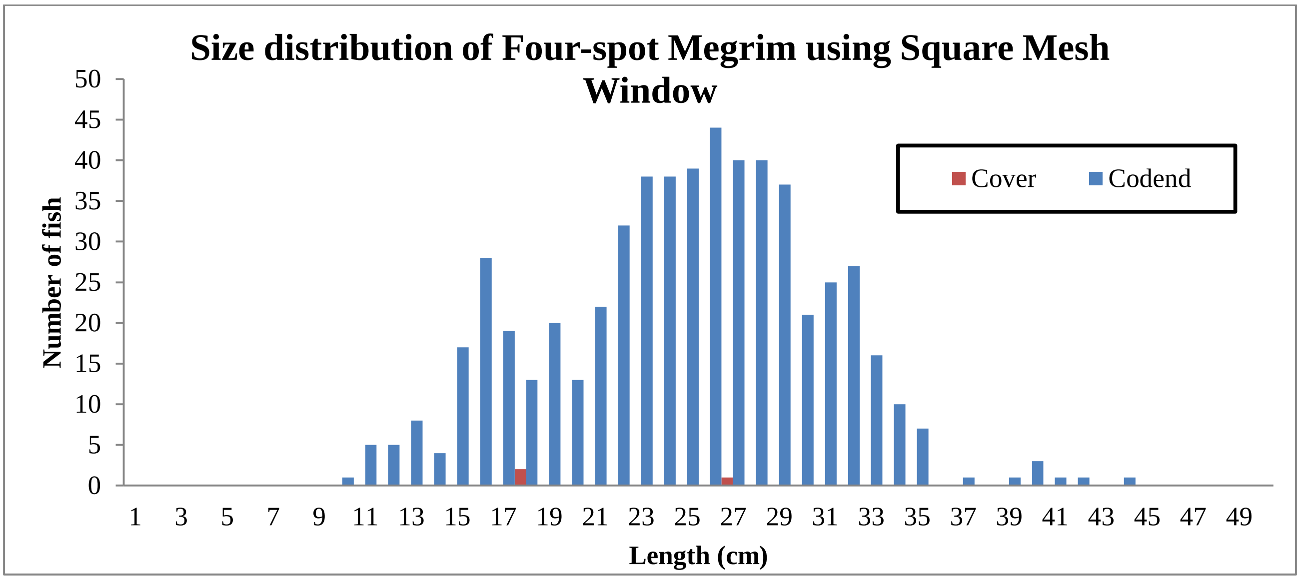


Figure 30. Size distribution of Four-spot Megrim (*Lepidorhombus boscii*) using the SMW in the Bay of Biscay

4.6 Statistical analysis

The idea of this section was to compare and statistically study the existent differences between the selectivity devices i.e. sorting grid and SMW. It was also planned to study the differences in size selectivity by the SMW between a target species fishery of Norway (i.e. the coastal prawn fishery) and a mixed species fishery from the Bay of Biscay fishery. However, the obtained graphical analysis, sections 4.2 and 4.5, show very clearly the differences and similarities.

The study of size distribution made in section 4.2 shows a clear difference in selectivity between the two selectivity devices. The use of sorting grid is very efficient and almost all the fish escape. In the case of SMW, it is very clear that the device is not working because almost all the fish are retained in the codend. Because this can be clearly observed in section

4.2, we are not going to perform additional statistical analyses (other than the selectivity analyses in section 4.4).

The obtained graphical results for target fishery and the mixed species fishery in the use of the SMW, section 4.2 and section 4.5, show that in both cases the device was not effective. Because of that, we do not consider the need of making any statistical analysis to prove any difference or similarity.

Picture taken by Ixai Salvo Borda on board R/V Johan Ruud, Feb 2014

5 Discussion

5.1 New Common Fisheries Policy

In the European Union (EU), technical improvement of fishing selectivity measures (such as rules on gear design, mesh sizes, selectivity devices) or the improvement of fishing ground management tools (e.g. access limit to some fishing grounds or closing seasons) is a very complex topic (Weissenberger, J. 2013). The main idea of the EU Commissionaires is that the discard ban will suppose a strong incentive to increase selectivity fishing practices and that it will help to develop the use of selectivity devices (Condie et al, 2014). However, as shown by Condie et al. 2013 a discard ban in isolation without any kind of management tools will not improve the need of more selective fishing. The ban generates small or no economic incentive for increasing the selectivity of fishing techniques. When, as in the new CFP, the discard ban is applied in addition to other management measures, i.e. landing obligation, it plays a strong role as an incentive for fishermen to increase the selectivity of the fishing gear. The ban also helps to improve fisheries management, making it possible to obtain full catch data and improve a more direct control on bycatch. Norway can be a good example of success in the implementation of discard bans. They applied it since 1983 to all significant commercial species. The ban increased the need for a rapid development of new selectivity devices and helped to motivate the creation of the Nordmøre-grid that has being mandatory since 1991 together with sorting grids, that became mandatory since 1997 in fish trawls (Salomon et al, 2014).

One of the facts that can be considered as a weakness on the discard ban is that the landing obligation refers only to important commercial species. In terms of biodiversity, the measure uncovers plenty of fish and untargeted species, playing an important role in the decision making of fishermen when applying new selectivity measures (Condie et al, 2013). If the CFP, instead of protecting only the commercially important species, would cover all the species of the ecosystem, fishermen would be obliged to increase the selectivity of the fishing gears and the practices to protect all the species. In addition, a total landing obligation tends to be easier to control than a partial one. Mostly because in a partial landing obligation fishermen can disguise some species with others that are not protected and discard them as bycatch (Condie et al, 2014)

The new CFP also proposed a system of catch quotas and incentivises for selective fishing (European Commission, 2011). The CFP gives the fishermen the freedom to choose the way that they would like to apply the selectivity measurement according to the particularity of the vessels. The first studies made around these new applications in Scotland show a positive response from the fishermen that apply the selectivity devices (Condie et al, 2014). These changes made by the Scottish fishermen in the North Sea cod fishery were related to the implementation of more selective gears, making changes in structure and mesh size. For that, they increase the mesh size in the body and in the codend and change the use of bigger rock-hoppers on the footrope. They also lift the footrope of the net and use a bigger mesh in the mouth of the net (Marine Scotland, 2011). These changes result in a 52% of reduction of discards (Condie et al, 2014).

If the EU wants to reach the goal of a non-discard, policy it should take into account that, in some cases, the improvement of the selectivity can be very difficult to achieve. In addition, it has to take in account the big differences between fishing stocks and grounds in the EU waters. This problem can be solved by the regionalisation of the common pond. In the European Commission’s Green Paper of 2009, the possibility of an internal governance of the marine regions was stated by delegating power in the area of fisheries away from a general ruling from the European Commission. This internal governance will be based in the ability of taking decisions and applying some regulations, such as adapting the fleet capacity to the resource availability or regulating the best selective measurements according to the characteristics of the stocks. This gives to the Member States the right to take decisions on some regulations and enables an implementation on the local specification of each country stocks. The new CFP analyses the regionalisation in Art. 18 stating that all Member States will have cooperation on specific management questions (The European Parliament and The European Council, 2013). This regional governance of fisheries activities opens a new way to manage European stocks. The new measurements include control of landing and discarding activities inside territorial waters and on vessels that land in national ports. The willingness of each Member State to cooperate will determine a more “coherent regional strategy for sustainable fisheries” (Salomon et al, 2014).

The new Common Fisheries Policy supposes an important change for a more sustainable fisheries policy in the European Union. The discard ban and the landing obligation suppose an important step to stop the waste of valuable natural resources and to protect the marine biodiversity of the European waters. It can be considered as a strong incentive for fishermen to improve the efficiency of their fishing activities and gears, allowing the implementation of more selective fishing techniques to reduce bycatch. The exemption of 5% for some fisheries will complicate the implementation of this measurements and it can still be considered a big issue in terms of monitoring fishing activities. However, the big step that supposes the application of the CFP to 22 of the 28 Member States (Salomon et al, 2014) finishes with many problems that the EU was facing since they started regulating fisheries. It also encourages the development of a more efficient and protective fishing industry and finishes the “vicious circle” where European fisheries were trapped in the last decades (European Commission, 2009).

5.2 Study of the Square Mesh Window

5.2.1 Use of the SMW in target species fisheries

The obtained results with the SMW show that the device does not work at all for any of the chosen species because almost all the individuals were retained in the codend. Retention rates with the SMW were around 99% for all the chosen species, and length distribution results show that there were no size differences in the retention of individuals. In the case of the SMW, any individuals of the population were able to escape through the device in clear contrast with the Nordmøre-grid. These results prove the inefficiency of the device for a target species fishery.

In contrast, and as it was expected from previous literature, the obtained results with Nordmøre-grid were totally expected. In 2006 Larsen was stating that on average more than 95% of the bycatch volume was excluded with the Nordmøre-grid and Silva et al. 2012 state exclusion rates for non-target species in prawn fishery around 75-97%. The obtained retention and exclusion results show an almost complete exclusion of the unwanted species meaning that the device is fully efficient as a bycatch excluder system. Exclusion rates for cod, haddock and long rough dab are 91%, 100%, and 75% respectively. In the case of haddock there were no small individuals in the catches, i.e. no haddock inside the selection range of the device. The size distribution of the other 2 studied species shows that most of the individuals were sorted out (escaped) by the device.

The overlap in sizes observed for long rough dab between 9 and 33cm means that individuals between those lengths were able to escape or to go through the device. This phenomenon can be because of the different shape comparing with cod and haddock. Flat fishes, i.e. long rough dab, act differently than rounded fishes, i.e. cod and haddock, when encountering the device. Due to their slim body-shape, they could pass through the 19mm grid if oriented properly, i.e. sideways. Collete and Klein-MacPhee conducted similar studies in 2002 on Witch flounder and by Isaksen et al. in 1992 and by Richards & Hendrickson in 2006 on halibut.

Selectivity calculations made with SELNET show a fast decrease in the retention length for cod (i.e. narrow SR) and a less sharp one for long rough dab (i.e. a wider SR). These calculations in the case of cod confirm the obtained results in the size distribution studied and in the case of long rough dab, the obtained retention curve explains the overlapping of sizes.

Retention rates for Prawn and the Total Weight per Haul results obtained for both devices show a clear efficiency in the selectivity of prawn as target species in Balsfjord. Both devices show high retention rates achieving an overall retention in the codend rate of 99.3%. These results were expected, taking into account previous literature like Silva et al. 2012 that states a retention rate of prawns of 97-99% by weight.

5.2.2 Use of the SMW in mixed species fisheries

The obtained results with the SMW in the Bay of Biscay also prove the inefficiency of the device for mixed species fisheries. Size distribution results from the data provided by AZTI-Tecnalia show that almost all the individuals of hake and megrim were retained by the device. In the case of blue whiting, the size distribution results show that device does not work as a selectivity device, but excludes a certain proportion of the catch no matter the size range. Meaning that individuals of any length being either retained or excluded as they were found in both compartments.

The results obtained with the SMW for the Bay of Biscay were also expected, taking into account previous published data and experiments made by Sala et al. in 2008. They state poor selectivity results for different models and modifications of the SMW in mixed fisheries (Sala et al. 2008).

5.2.3 Analysis of the SMW as selectivity device

Results prove that the grids perform better than the SMW as bycatch excluders in target fisheries, i.e. prawn (deep-water shrimp) fishery in the Norwegian waters. The objective of using a selectivity device in this fishery is to exclude all the unwanted fish and to increase the retention and quality of the target species. Nordmøre-grid proves to be very efficient and it is explained by the working principle of the device. After going through the funnel, larger fish encounter the device and escape through the opening in the upper panel of the trawl net. Smaller fish that are able to pass through the grid and prawns continue until they are retained in the codend. The SMW working principle is based on the behaviour of the fish more than in the characteristics of the device. Fishes entering the net have to be in contact with the device to be excluded, as it always happens with the grid. In the case of SMW, there is an obvious lack of contact resulting in inefficient selectivity results. The efficiency of the contact is based both in the visibility of the device and in the swimming behaviour of the fish inside the net. The SMW is located on top of the net and, unless the fish are directed to it, it is not clearly certain that the fish will see the device. This visibility depends also on the turbidity of the water and in the trawling speed especially in the final section of the trawl (Onandia, 2012). Visibility and contact can be improved with funnels and different inclinations to increase the positive angle of attack, improving the contact of the fish with the device. Unless these improvements are done, the contact is totally determined by the behaviour of the fish. Fish that tend to swim or move around the top of the net has more chances to contact the device, e.g. haddock, than species that tend to stay in the bottom of the net, as cod or prawns. However, obtained results show that none of the species escapes through the SMW device. This means that even if they contact with it they are not able to escape through the openings or that the fishes do not show escaping behaviours. Similar conclusions can be obtained with the experiments made in the Bay of Biscay proving that SMW was not efficient as a selectivity device in mixed species fisheries.

The position of the SMW is also important. Most of the experiments with SMW located in the codend and square mesh codends prove to have positive results in selectivity of haddock, cod, and pollock (e.g. Graham and Kynoch, 2001 and Grimaldo et al., 2007). The position of the SMW in the codend allows species with passive behaviour, e.g. hake, to escape easily and fish in the lower section to contact the device. Contrary, if the SMW is located in the front of the codend (i.e. the aft section of the belly); fishes have less chance to contact with the device. On the other hand, the use of SMWs located before the codend does not give any improvement to the selectivity of the trawling activity. Because of the lack of previous studies with the SMW before the codend, it can be recommended the need of more research with various modifications such as the increase of the mesh size, the use of guiding funnels, etc.

The conflicting results obtained with the SMW device when is located in different parts of the trawl, encourages more research in the field. Being one of the advantages of the SMW the possibility to easily move and install it in any place of the trawl, further research with the device located in different parts of the trawl should be done. Attending to the observed natural behaviour of cod inside the trawl, for example, locating the device in the bottom of the trawl can maybe give better results. In addition, the performance of the SMW located in other sections of the trawl should be compared with the use of size separator grids, to observe if a simpler device as the SMW can show similar results as with the grids. If this happens and the SMW show similar or better performance than separator grids, a mandatory installation of the window would be recommended for mixed fisheries.

To avoid the observed inefficiency of the SMW and to increase the selectivity different devices can be applied. The development of fish size sorting grids as the sort-x, single grid or the flexi-grid (Larsen, 2006), which also are located in the section before the codend, can improve the size selectivity more than the SMW. These devices have a similar working principle as the SMW but work in a reverse way compared to the Nordmøre-grid, allowing the escape of small individuals retaining bigger ones. With this type of sorting grids, individuals with active swimming behaviour will find their way out of the trawl and they facilitate more passive swimmers to find the way out (Sistiaga, 2010).

5.3 Selectivity devices in EU in the frame of the new CFP

In the case of targeting small crustacean in trawl fisheries, the implementation of new sorting techniques, such as square mesh codend or grid are quite necessary, especially for EU stocks where the bycatch level is around 34-70% of the total catch (Sardà et al, 2006). The implementation of new selectivity techniques can really help in this kind of fisheries that work normally on stocks characterised of having a multi-species nature (e.g. Fonseca et al, 2005). The use of sorting grids allowing the escape of big individuals does not only decrease the number of unwanted fish and reduces bycatch, but also increases the quality of the catch because it mostly is the clean catches of the target species being retained. This reduces the on-board sorting time and preserves the quality of the catch. The use of full square mesh codends allows the escape of fishes that normally have a more active swimming behaviour and fight for escaping through the mesh.

For multispecies fisheries, the implementation of size-selection measurements seems to be quite complicated. Studies made in the Mediterranean by Sardà et al, during 2006, suggest that the use of square mesh codends and sorting grids will help to reduce discards and that it will carry benefits to the general community of the stocks. However, seasonal variations that happen on the target species will force to apply changes on more than one way because "one solution will not work in all conditions" (Krag et al, 2014). The same mesh size or sorting grid spacing will not work for all the species being too large for some and too small for others achieving the optimal selection just with few of them. The requirement of using one mesh size, or grid spacing, to catch all the different species during the all year in various fishing grounds and depths will result in a high level of discards or in high level of catch losses (Sardà et al, 2006). Recent studies suggest that for the improvement of selectivity in multi-species fisheries, a multiple selection system should be improved where first the different type of species will be separate from each other and afterwards sorted by size (Krag et al, 2014).

With the aim of providing measurements of the most important factors that affect to the variability in trawl size selectivity and in an attempt to develop practical codend designs, Suuronen et al in 2000 developed the BACOMA project. This project improves the technical management in Baltic Cod Fishery and evaluates the potential short and long-term economic effects that an increase on the selectivity will have in the Baltic cod trawl fishery (Suuronen et al, 2000). Results of this experiment show that increasing size selectivity would allow the increase of recruitment and bring a substantial economic increase to the fishery (Suuronen et al, 2007). This study proves that a good understanding of the ecosystem and of the fishery helps to introduce better managements tools, i.e. increase selectivity, that in the long run bring benefits to the fishery. Nowadays, the BACOMA codend is mandatory in the Baltic trawl fisheries (Suuronen et al, 2007).

5.4 Advices for further developments of selective EU trawl fisheries

In general, it can be stated that the application of selectivity devices in the EU fisheries need further studies. European fishing grounds are very diverse and involve many different fishing traditions that need to be deeply studied, to observe, and achieve a knowledge that will allow the development of a proper device for each fishery. However, this could be also difficult because of the seasonal variation and because the big amount of different target species in each fishery. Regarding to the fishery of the Bay of Biscay, the situation is also complicated due to the different stock fished in the same place. It can be said, in addition to the development of new selectivity techniques, that a deeper understanding of the fishing grounds is needed, far away from the current scientific assessment. This analysis should take into account more and more the opinion of fishermen and direct workers of the industry. This will change the way of approaching fishing and fisheries allowing the achievement of a better understanding of some conditions that can be underestimate when researching (Salomon et al, 2014).

The introduction of a selective fishery is complicated for several reasons. For the EU fisheries, the mixed species and size-ranges, with various landing sizes makes it very complicated to find the "correct" device. In fact, none of the solutions as listed in Table 8 would fit for all conditions at sea. Additionally, the introduction of one or multiple devices creates several practical disadvantages fishermen needs to solve or come to terms with. The trawl gear gets more difficult to handle and it introduces new or additional costs of operation. Moreover, the industry seems to worry over the fact that a certain proportions of marketable fish will be lost in a selective fishery.

The EU fisheries could take lessons from the Barents Sea fisheries and the Norwegian-Russian management where an exclusion ban on commercial species led to a rapid (and necessary) development of selective fisheries. Similar strategies have been chosen for instance in the Alaskan ground fisheries. The fishers had to accept some reduction in marketable and legal sizes of fish in order to stay in business. In the beginning the use of separator and sorting grids were disputed, while 20 years later the industry fully acknowledge the technical changes of their fisheries.

The example from the Scottish trawl fishery (Condie et al., 2014) by doing gear modifications to a more selective fisheries practise may be a first and simple attempt to reduce by-catches. This experience confirms that it is possible to alter the by-catch proportion significantly with minor and less disputed changes of the gear.

The results of this study show the inefficiency of the SMW as selectivity device to accomplish the objectives of the CFP. When located before the codend, the device is totally inefficient. Regarding to mixed species fishery it is obvious that the Norwegian Nordmøre-grid would not either solve the problem because the device excludes all big individuals. Regarding to future research, all the different selection techniques previously mentioned throughout the thesis (see drawings in Appendix 3) were evaluated in terms of advantages and disadvantages, to enable the comparison between them in the view of future work (Table 8). New developments of the SMW can be suggested together with the use of some combinations of other devices to achieve the objectives of the EU.

The SMW device is quite simple and can be located in various positions. Some studies suggest the efficiency of the device when locating in the codend (Graham and Kynoch, 2001). This seems to be related with the fact that the device seems to only work on active fish. Studies using underwater cameras, to observe fish behaviour, will allow an understanding why this happens and these studies will help to develop new strategies when applying the device. The lack of contact and the visibility of the device when located before the codend could be solved by using guiding funnels or other devices that will allow the fish to encounter the device. The size of the mesh could be also one of the limitations of the device. Maybe, the use of bigger meshes that change the inside water flow of the trawl, would allow the escape of more individuals. Size sorting grids seems to be quite effective, removing juvenile fish and most of the flatfish species. The use of this device in combination with BACOMA codends (Suuronen et al, 2007), now mandatory in the Baltic Sea, could also be one of the solutions. However, in very mixed species fisheries, both devices can suppose a problem, together with the full square mesh codend, to handle large and mixed catches. Size sorting grids (Larsen, 2006) can be also used in combination with separator trawls (Krag et al, 2014) facilitating the lack of contact that these last devices have. They will allow a "complete" escape of small individuals. A mesh size increase in a conventional diamond mesh codend could be useful because it will allow the escape of smaller individuals. However, as it happens with the full square mesh codends (Sala et al, 2008), big catches will supposedly decrease the efficiency of the device.

Table 8: Comparison of selectivity devices attending to Benefits and Drawbacks in selection of fish (Larsen et al, 2006; Sardà et al, 2006 & Sala et al, 2008).

Selective device	Benefits	Drawbacks
Square mesh window	Simple, inexpensive system. Can be located in various part of the belly and codend	Seems to work only on active fish showing clear attempts to seek towards the device
Nordmøre type Sorting grid (bycatch excluder)	Effective in removing all fish above a certain size	Loss of all larger fish, i.e. marketable sizes and sizes above MLS.
Size sorting grids	Effective in removing juvenile fish (and most of the flatfish species, including larger specimen)	Practical problems, complicate devices to use.
Full square mesh codends	Effective in removing active fish in the last section of the trawl. Effective removal of juvenile fish from rounded fish species.	Ineffective with large and mixed catches. Practical problems during handling and knot-slippage with large catches.
Separator trawls	Utilises natural behaviour of fish and enables the use of various compartments with unequal mesh sizes.	The split between species may vary and the use of two or more codends leads to handling problems.
Changed diamond mesh size in the codends	The most common and easiest method for altering size selectivity	Effective mesh opening depends on drag, twine thickness, etc. Possible mortality on those fish escaping at the surface.

6 Conclusion

This report proves that the Nordmøre-grid shows very different results on the exclusion of bycatch compared to the SMW in a target prawns fishery. The grid shows high exclusion rates in clear contrasts with the escape window that has very low exclusion rates.

Additionally, the study made in the Bay of Biscay confirms the discouraging results with SMW located before the codend. It proves that the device does not perform properly in both mixed or target species fisheries. These results show a clear contrast with studies where the SMW was applied directly in the codend (e.g. Graham and Kynoch, 2001 and Grimaldo et al., 2007).

Both studies, with the SMW, prove the inefficiency of the device to accomplish the bycatch regulation adopted through the new CFP. On the other hand, the Nordmøre-grids, as was expected, fully accomplish the regulation for target species fisheries.

Taking into account the actual development state of the different selective devices in the European fisheries, more selectivity studies are still needed, to achieve the European target of less than 5% bycatch to avoid discards in mixed fisheries. These studies should focus on the development of the SMW or in the application of a combination of different devices to solve the problems that mixed species fisheries have.

Picture taken by Ixai Salvo Borda on board R/V Johan Ruud, Feb 2014

7 References

Alverson, D.L., Freeberg, M.H., Murawski S.A. & Pope, J.G. (1994) A global assessment of fisheries bycatch and discards; FAO Fish. Tech. Pap. No. 339. 233 pp.

Andrew, N.L. & Pepperell, J.G. (1992) The by-catch of shrimp trawl fisheries; Oceanogr. Mar. Biol. Ann. Rev. 30, 527–565.

Beverton, R.J.H., (1963) Escape of fish through different parts of a codend; ICNAF Spec. Publ. 5, 9–11.

Booker, C. (2007) Fishing quotas are an ecological catastrophe; The Daily Telegraph (London), 25 Nov 2007

Link:

http://www.telegraph.co.uk/news/uknews/1570439/Fishing-quotas-are-an-ecological-catastrophe.html

Broadhurst, M.K. (2000) Modifications to reduce bycatch in prawn trawls: a review and framework for development; Rev. Fish Biol. Fish. 10: 27–60.

Bullough, L.W., Napier, I.R., Laurenson, C.H., Riley, D., Fryer, R.J., Ferro, R.S.T. & Kynoch, R.J., (2007) A year-long trial of a square mesh panel in a commercial demersal trawl; Fisheries. Research. 83: 105–112.

Caddy, J.F. (1982) Management of shrimp fisheries; In Fish Bycatch – Bonus from the Sea: Report of a Technical Consultation on Shrimp By-catch Utilization held in Georgetown, Guyana,

Catchpole, T.L. & Revill, A.S. (2007) Gear technology in Nephrops trawl fisheries; Rev Fish Biol Fisheries DOI 10.1007/s11160-007-9061-y

Collette B.B. & Klein-McPhee G. (2002) Bigelow and Schroeder fishes of the Gulf of Maine, 3rd edition. Washington: Smithsonian Institution Press

Commission of the European Communities (1976) Proposal for a Council Regulation (EEC) establishing a Community system for the conservation and management of fishery resources; COM (76) 535 Final

Committee of the Regions (1995) Draft Opinion of Commission 2 on the Regional Consequences of the Common Fisheries Policy; COR 318/95

Condie, H.M., Grant, A. & Catchpole, T. L., (2013) Does banning discards in an otter trawler fishery create incentives for more selective fishing?; Fisheries Research 148, 137-146.

Condie, H.M., Grant, A. & Catchpole, T.L. (2014) Incentivising selective fishing under a policy to ban discards; lessons from European and global fisheries; Marine Policy 45, 287-292

Davis, M. W. (2002) Key principles for understanding fish bycatch discard mortality; Can. J. Fish. Aquat. Sci 59: 1834-1843

Dayton, P.K., Thrush, S.F., Agardy, M.T. & Hofman, R.J. (1995) Environmental effects of marine fishing; Aquat. Cons.: Mar. Freshwater Eco. 5, 205–232.

Eilertsen, H.C., & Taasen, J.P. (1984) Investigations on the plankton community of Balsfjorden, northern Norway. The phytoplankton 1976-1978. Environmental factors, dynamics of growth, and primary production; Sarsia 69: 1-15.

Enever, R., Revill, A.S. & Grant, A., (2007) Discarding in the English Channel, Western approaches, Celtic and Irish seas (ICES subarea VII); Fisheries Research 86:143-152.

European Commission (2009) Green paper: reform of the Common Fisheries Policy; COM (2009)163 final. Brussels

European Commission (2011) Impact assessment. Commission Staff Working Paper; SEC 891. Brussels; 2011: p. 83.

European Commission (2011) Studies in the Field of the Common Fisheries Policy and Maritime Affairs; Impact Assessment of Discard Reducing Policies; EU Discard Annex. Project no ZF0926_S10

European Commission (2013), Fisheries and Aquaculture in Europe; No 62

European Council, Council of the European Union (2008) Consolidated versions of the treaty on European Union and The treaty on the functioning of the European Union; (OR. fr) 6655/08

European Council; Council of the European Union (2011) Resume of the discard ban European Commission Proposal for a regulation; COD 2011/0195

European Council; Council of the European Union (2013) The EU institutions provisionally agree on EU fisheries reform European 2015 regulation; abstract 10395/13 (OR. en) PRESSE 229

European Union (2008) On the implementation of the policy to reduce unwanted by-catch and eliminate discard in European fisheries; Commission non-paper, 13pp

FAO (Food and Agriculture Organisation) (1980) Shrimps and Prawns of the World. An Annotated Catalogue of Species of Interest to Fisheries; FAO CATALOGUE Vol.1.L.B. Holthuis. FAO Fisheries Synopsis No.125, Volume 1.

FAO (Food and Agriculture Organisation) (1990) FAO species catalogue. Vol.10. Gadiform Fishes of the world (Order Gadiformes). An Annotated and Illustrated Catalogue of Cods, Hakes, Grenadiers and other Gadiform Fishes Known to Date. Daniel M.Cohen Tadashi Inada Tomio Iwamoto Nadia Scialabba FAO Fisheries Synopsis. No. 125, Vol.10. Rome. 442p

FAO (Food and Agriculture Organisation) (1992) Yearbook of Fishery Statistics; Vol. 74. FAO, Rome, 677 pp

FAO (Food and Agriculture Organisation) (2001) Fishing Gear types. Trawl nets. Technology Fact Sheets; FAO Fisheries and Aquaculture Department Rome

FAO (Food and Agriculture Organisation) (2012), The state of World Fisheries and Aquaculture; Rome, ISBN 978-92-5-107225-7

FAO (Food and Agriculture Organisation) (2009) Expert consultation on international guidelines for bycatch management and reduction of discards Fisheries and Aquaculture Report No. 934 FIRO/R934 (En) ISSN 2070-6987

FAO (Food and Agriculture Organisation). (2005) Norway: fishery country profile; Rome.

FAO (Food and Agriculture Organisation) Fisheries and Aquaculture Department (2004) Cultured Aquatic Species Information Programme. Gadus morhua; Cultured Aquatic Species Information Programme. Text by Håkon Otterå Rome.

Finne K., & Gade H.G., (1990) A hydrographic description and qualitative analysis of physical processes in the Balsfjord based on data collected during the years 1980-1988; Bergen: University of Bergen, Dept. of Geophysics. 20 p.

Fonseca, P., Campos, A., Larsen, R.B., Borges, T.C. & Erzini, K., (2005) Using a modified Nordmöre grid for by-catch reduction in the Portuguese crustacean-trawl fishery; Fisheries Research 71, 223-239

Froese, R. and Pauly D., Editors. (2003) Fish Base. World Wide Web electronic publication. www.fishbase.org

Gillett, R., (2008) Global study of shrimp fisheries; FAO Consultant for FAO Fisheries Technical Paper. No. 475 Rome ISBN 978-92-5-106053-7

Graham N, & Kynoch R.J., (2001) Square mesh panels in demersal trawls: some data on haddock selectivity in relation to mesh size and position; Fisheries Research, Volume 49, Issue 3, January 2001, Pages 207-218, ISSN 0165-7836, 10.1016/S0165-7836(00)00211-3.

Gray, T. & Hatchard, J.; (2003) The 2002 reform of the Common Fisheries Policy's system of governance—rhetoric or reality?; School of Geography, Politics and Sociology, University of Newcastle, 40-42 Great North Road, Newcastle Upon Tyne NE1 7RU

Grimaldo, E., Larsen, R.B. & Holst, R., (2007) Exit windows as an alternative selective system for the Barents Sea Demersal Fishery for cod and haddock; Fisheries Research 85, 309–319.

Gulland, J.A. & Rothschild, B.J. (eds) (1984) Penaeid Shrimps – Their Biology and Management; Fishing News Books, Farnham, England, 308 pp.

Haig, N. (2008) EAE-ko arrantzarako plan estrategikoa 2008-2003 Plan estratégico de pesca de la CAPV; Sustrai: revista agropesquera, ISSN 0213-330X, Nº. 84, 2008, 42-46

Hall, M.A., Alverson, D.L., & Metuzals, K.I. (2000) By-catch: problems and solutions; Mar. Pollut. Bull. 41: 204–219

He, P., (2010) Behaviour of Marine Fishes Capture Processes and Conservation Challenges. ISBN: 978-0-8138-1536-7. Hardcover. 392 pages. June 2010, Wiley – Blackwell

Heikinheimo, O., Setala, J., Saarni, K. & Raitaniemi, J., (2006) Impacts of mesh-size regulation of gillnets on the pikeperch fisheries in the Archipelago Sea, Finland; Fisheries Research 77, 192-199.

Herrmann B, Madsen N, Sistiaga M & Grimaldo E. (2009) Modelling escapement during the fishing process as a dual sequence - Introducing SELNET; Poster session presented at ICES Working Group on Fishing Technology and Fish Behaviour (WGFTFB), Ancona, Italy,

Herrmann, B., (2005) Effect of catch size and shape on the selectivity of diamond mesh cod-ends I. Model development; Fisheries Research 71, 1–13.

High W.L., Ellis I.E., Lusz L.D. (1969) A progress report on the development of a shrimp trawl to separate shrimp from fish and bottom-dwelling animals; Commer. Fish. Rev. 31: 20–33.

Holden, M. (1994) The Common Fisheries Policy: Origin, Evaluation and Future; Blackwell Scientific Publications, Oxford.

Hopkins C.C.E. & Nilssen E.M.. (1990) Population biology of the deep-water prawn (Pandalus borealis) in Balsfjord, northern Norway: I. Abundance, mortality, and growth, 1979-1983; Journal du Conseil international pOllr {'exploration de la mer 47: 148-166.

Horwood, J. B. (1996) The fish stocks: status and advice; Paper presented at a Colloquium on the Politics of Fishing, Newcastle

Iriondo, A., Prellezo R., Santurtún M., García D. & Quincoces I., (2008) Basque trawl metier definition for 2003-2007; period. Revista de Investigación Marina, 3: 263-264.

Isaksen, B., Valdemarsen, J.W., Larsen, R.B. & Karlsen, L. (1992) Reduction of fish by-catch in shrimp trawl using a rigid separator grid in the aft belly; Fisheries Research 13, 335.352

Jensen, C. L., (1999) A critical review of the Common Fisheries Policy; Working Paper, Department of Environmental and Business Economics; University of Southern Denmark, No. 6

Jordan, A. & Jeppersen, T. (2000) EU Environmental policy: adapting to the principle of subsidiarity?; European Environment 10 (2): 64–74.

Jordan, L.K, Mandelman, J.W., McComb, D.M., Fordham, S.V., Carlson, J.K. & Werner, T.B. (2013) Linking sensory biology and fisheries bycatch reduction in elasmobranch fisheries: a review with new directions for research; Conservation Physiology 1

Karlsen L & Larsen R (1989) Progress in the selective shrimp trawls development in Norway, In: Campbell CM (ed). Proc. World Symp. Fishing Gear and Fishing Vessel Design. Marine Institute. St. John's 30–38.

Kelleher, K. (2005) Discards in the world's marine fisheries. An update. FAO Fisheries Technical Paper. No. 470. Rome, FAO. 131pp.

Kennelly, S.J. (1995) The issue of bycatch in Australia's demersal trawl fisheries; Rev. Fish Biol. Fish. 5, 213–234

Kennelly, S.J., Liggins, G.W. & Broadhurst, M.K. (1998) Retained and discarded by-catch from oceanic prawn trawling in New South Wales, Australia; Fisheries Research 36, 217–236.

King, M. (2007) Fisheries Biology, Assessment and Management¸ 2nd ed. p. cm, Blackwell Publishing ed ISBN 978-1-4051-5831-2 SH328.K55 pp 164 &165,

Koutsikopoulos, C. & Le Cann, B. (1996) Physical processes and hydrological structures related to the Bay of Biscay anchovy; SCI. MAR., 60 (Supl. 2): 9-19.

Krag, L. A., Herrmann, B. & Karlsen, J. D. (2014) Inferring Fish Escape Behaviour in Trawls Based of Catch Comparison Data: Model Development and Evaluation Based on Data from Skagerrak, Denmark; PLoS ONE 9(2) e88819. Doi: 10.1371/ journal.pone.088819

Kvamme, C. & Fröysa, K. G. (2004) Assessing the effects on stocks of selectivity changes in a fishery; Fisheries Research 69, 283-292.

Larsen, R.B. & Isaksen, B. (1993) Size selectivity of rigid sorting grids in bottom trawls for Atlantic cod (Gadus morhua) and haddock (Melanogrammus aeglefinus); ICES Mar. Sci. Symp. 196, 178–182.

Larsen, R.B. (2006): By-catch reducing trawls in the North East Atlantic fisheries; The Norwegian College of Fishery Science, University of Tromsø, N-9037 Tromsø, Norway

Longhurst, A. (1998) Cod: Perhaps if we all stood back a bit?; Fisheries Research 38, 101–108.

Macher, C., Guyader, O., Talidec, C. & Bertignac, M. (2008) A cost-benefit analysis of improving trawl selectivity in the case of discards: The *Nephrops norvegicus* fishery in the Bay of Biscay; Fisheries Research, Volume 92, Issue 1 pp 76-89

Marine Scotland (2011) Report on catch quota management using remote electronic monitoring (REM). Report to the Scottish Government. CQMS082011, Edinburgh, p.72.

Link

http://www.scotland.gov.uk/Topics/marine/Sea-Fisheries/17681/CQMS082011

Matsuoka, T. (2008) A review of bycatch and Discard Issue Toward Solution; Fisheries for Global Welfare and Environment, 5th World Fisheries Congress 2008, pp. 169–180. K. Tsukamoto, T. Kawamura, T. Takeuchi, T. D. Beard, Jr. and M. J. Kaiser, eds

Matsushita Y. (2000) Developments of by-catch reducing technologies in trawl fishery; Bull. Natl. Res. Inst. Fish. Eng 21: 1–57

MRAG (2007) Impact assessment of discard policy for specific fisheries: Final Report. European Commission Studies and Pilot Projects for Carrying Out the Common Fisheries Policy. No FISH/2006/17

Nielsen, J. (1986) Pleuronectidae; In: P.J.P. Whitehead et al., (eds.). Fishes of the North-eastern Atlantic and the Mediterranean (FNAM). Unesco, Paris, vol. III: 1299-1307.

Onandia, I. (2012) 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; Master's Degree Thesis in International Fisheries Management; Faculty of Biosciences, Fisheries and Economics, University of Tromsø

Oug, E. & Høisoeter, T., (2000) Soft-bottom macrofauna in the high-latitude ecosystem of Balsfjord, northern Norway: Species composition, community structure and temporal variability, Sarsia, 85:1, 1-13

Pascoe, S. (1997) Bycatch management and the economics of discarding; FAO (United Nations Food and Agriculture Organization) Fish. Tech. Pap. No. 370, Rome

Pérez N.; Santurtún M; Castro J, Ruiz J, &. Sainza M. (2005) Preliminary results on Northern hake from the "Spanish Discard Sampling Programme"; Working Document for the ICES WGHMM, Lisbon 2005.

Peterkin, F.A. (1982) Developing a shrimp by-catch utilization program; Proc. Gulf Caribbean Fish. Inst. 34, 112–119.

Prellezo, R., (2010) La Evolución de la Flota de Altura al Fresco en el Contexto del Marco Legislativo Español; Revista de Investigación Marina. 17(3): 21-27.

Revill, A.S., Catchpole, T.L. & Dunlin, G., (2007) Recent work to improve the efficacy of square-mesh panels used in a North Sea Nephrops norvegicus directed fishery; Fish. 85: 335–341.

Richards, A. & Hendrickson, L. (2006) Effectiveness of the Nordmöre grate in the Gulf of Maine Northern shrimp fishery; Fisheries Research 81, 100-106

Rulifin R.A., Murray J.D., Bahen J.J. (1992) Finfish catch reduction in South Atlantic shrimp trawls using three designs of by-catch reduction devices; Fish; 17: 9–20.

Saila, S.B. (1983) Importance and assessment of discards in commercial fisheries; FAO Fish. Circ. No. 765, 62 pp.

Sala, A., Lucchetti, A., Piccinetti, C. & Ferretti, M. (2008) Size selection by diamond-and square mesh codends in multi-species Mediterranean demersal trawl fisheries; Fisheries Research 93, 8-21

Salomon, M., Markus, T. & Dross, M. (2014) Masterstroke or paper tiger- The reform of the EU's Common Fisheries Policy; Marine Policy 47, 76-84

Sardà, F., Bahamon, N., Molí, B. & Sardà-Palomera, F. (2006) The use of a square mesh codend and sorting grids to reduce catches of Young fish and improve sustainability in a multispecies bottom trawl fishery in the Mediterranean; Scientia Marina 70, 347-353

Seidel W.R. (1975) A shrimp separator trawl for the southeast fisheries, In: Higman JB (ed). Proc. 27th Annu. Gulf Carib. Fish. Inst. Gulf and Caribbean Fisheries Institute, Miami. 66–76.

Sellke, P.; Dreyer, M. (2011) Enhancing Regionalisation of the Common Fisheries Policy: An Opportunity and Challenge for Participatory Fisheries Governance in the EU; Annual meeting of the International Studies Association, Annual Conference "Global Governance: Political Authority in Transition".

Silva, C. N.S., Broadhurst, M. K., Dias, J. H., Cattani, A. P. & Spach H. L., (2012) The effects of Nordmøre-grid bar spacing on catches in a Brazilian artisanal shrimp fishery; Fisheries Research 127–128 188–193

Sissenwine, M. & Symes, D. (2007) Reflections on the Common Fisheries Policy; EU commissioned report

Sistiaga, M. (2010) Selectivity studies in the Barents Sea bottom trawl gadoid fishery: Gear and methods; A dissertation for the degree of philosophiae doctor, University of Tromsø, Faculty of Biosciences, Fisheries and Economics, Norwegian College of Fishery Science

Sovik, G. and Thangstad, T. (2012) The Norwegian Fishery for Northern Shrimp (Pandalus borealis) in Skagerrak and the Norwegian Deep (ICES Division IIIA and Iva cast), 1970-2011; NAFO/ICES WG Pandalus Assessment group, Serial No N5994 NAFO SCR Doc. 11/068

STECF, (2006) Discard from community vessels. Report of the Subgroup on Research Needs (SGRN) of the Scientific, Technical and Economic Committee for Fisheries (STECF), SGRN-06-06, 46 pp. Stergiou, K.I., Economou, A., Papaconstantinou, C., Tsimenides, N., Kavadas, S., (1998) Estimates of discards in the Hellenic commercial trawl fishery. Rapp. Commun. Int. Mer. Medit. 35, 490–491.

Suuronen, P., Kuikka, S., Lehtonen, E., Tschernij, V., Madsen, N. & Holst, R. (2000) Improving technical management in Baltic cod fishery (BACOMA); Final Report (EC 4th Framework Programme, Contract FAIR CT 96–1994). 106 pp

Suuronen, P., Tschernij, V., Jounela, P., Valentinsson, D. & Larsson, P.O. (2007) Factors affecting rule compliance with mesh size regulations in the Baltic cod trawl fishery; ICES Journal of Marine Science 64, 1603-1606

Symes, D. & Crean, K., (1995) Historic prejudice and invisible boundaries: dilemmas for the development of the Common Fisheries Policy. In The Peaceful Management of Transboundary Resources, eds. G. H. Blake et al., pp. 395-411. Graham and Trotman, London.

Symes, D. & Phillipson, J. (2009) Whatever Became of Social Objectives in Fisheries Policy?; Fisheries Research 95 (1): 1–5.

Symes, D. (1997) The European Community´s Common Fisheries Policy Ocean & Coastal Management. Vol 35 Nos 2-3 pp 137-155

The European Parliament and The European Council (2013, 11 December); REGULATION (EU) No 1380/2013 on the Common Fisheries Policy, amending Council Regulations (EC) No 1954/2003 and (EC) No 1224/2009 and repealing Council Regulations (EC) No 2371/2002 and (EC) No 639/2004 and Council Decision 2004/585/EC

Thurstan, R. H., Brockington, S. & Roberts, C. M. (2010) The effects of 118 years of industrial fishing on British bottom trawl fisheries; Nature Communications 1 (15): 1.doi:10.1038/ncomms1013.

Valdemarsen J. W., (2005) World inventory of fisheries. Selectivity of gear. Issues Fact Sheets. In: FAO Fisheries and Aquaculture Department Rome.

Valdemarsen J.W. (2001) Technological trends in capture fisheries; Ocean Coast. Manage. 44: 635–651.

Waterfield, B. (2009) The human cost of the EU's fishing failure; The Daily Telegraph (London).

Watson J.W. & McVea C. (1977) Development of a selective shrimp trawl for the southeaster United States penaeid shrimp fisheries; Mar. Fish. Rev; 39: 18–24.

Watson J.W., Mitchell J.F. & Shah A.K.(1986) Trawling Efficiency Device: A new concept for selective shrimp trawling gear; Mar. Fish. Rev. 1986

Weissenberger, J. (2013) Discarding fish under the Common Fisheries Policy, Towards an end to mandated waste; Library of the European Parliament 130436REV1

Whiteman, K., (2000) World Encyclopedia of Fish & Shellfish. New York: Lorenz Books

Wileman, D.A., Ferro, R.S.T., Fonteyne, R. & Millar, R.B. (1996) Manual of methods of measuring the selectivity of towed fishing gears; ICES Coop. Res. Rep., no. 215: 1- 126.

Zuur, G., Fryer, R. J., Ferro, R. S. T. & Tokai, T. (2001) Modelling the size selectivity of a trawl codend and an associated square mesh panel; ICES Journal of Marine Science, 58: 657-671

Webpages:

[1]FF Johan Ruud in the Arctic University of Norway webpage: http://uit.no/ansatte/organisasjon/artikkel?p_document_id=151553&p_dimension_id=88172&p_menu=42374&p_lang=2

8 Appendix

8.1 Appendix 1: Data collection scheme

In this appendix the scheme (Table 9) used during the data collection is going to be presented. This scheme was prepared in collaboration with Ivan Tatone from the Arctic University of Tromsø to be used in the sea trials of this thesis.

Table 9. Scheme used during the data collection in the sea trials of this thesis

	Greed codend		Square mesh codend		Haul Nr
	Greed cover		Square mesh cover		Date / /
0		**0**		**0**	
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	
9		9		9	
0		**0**		**0**	
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	
9		9		9	
0		**0**		**0**	
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	
9		9		9	
0		**0**		**0**	
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	
9		9		9	
0		**0**		**0**	
1		1		1	
2		2		2	
3		3		3	
4		4		4	
5		5		5	
6		6		6	
7		7		7	
8		8		8	
9		9		9	

8.2 Appendix 2: Captain record scheme

In this appendix, the scheme (Table 10) that the Captain of the R/V Johan Ruud used to record the information of the hauls is going to be presented. For each haul, one of the presented tables was filled by the captain of the R/V Johan Ruud.

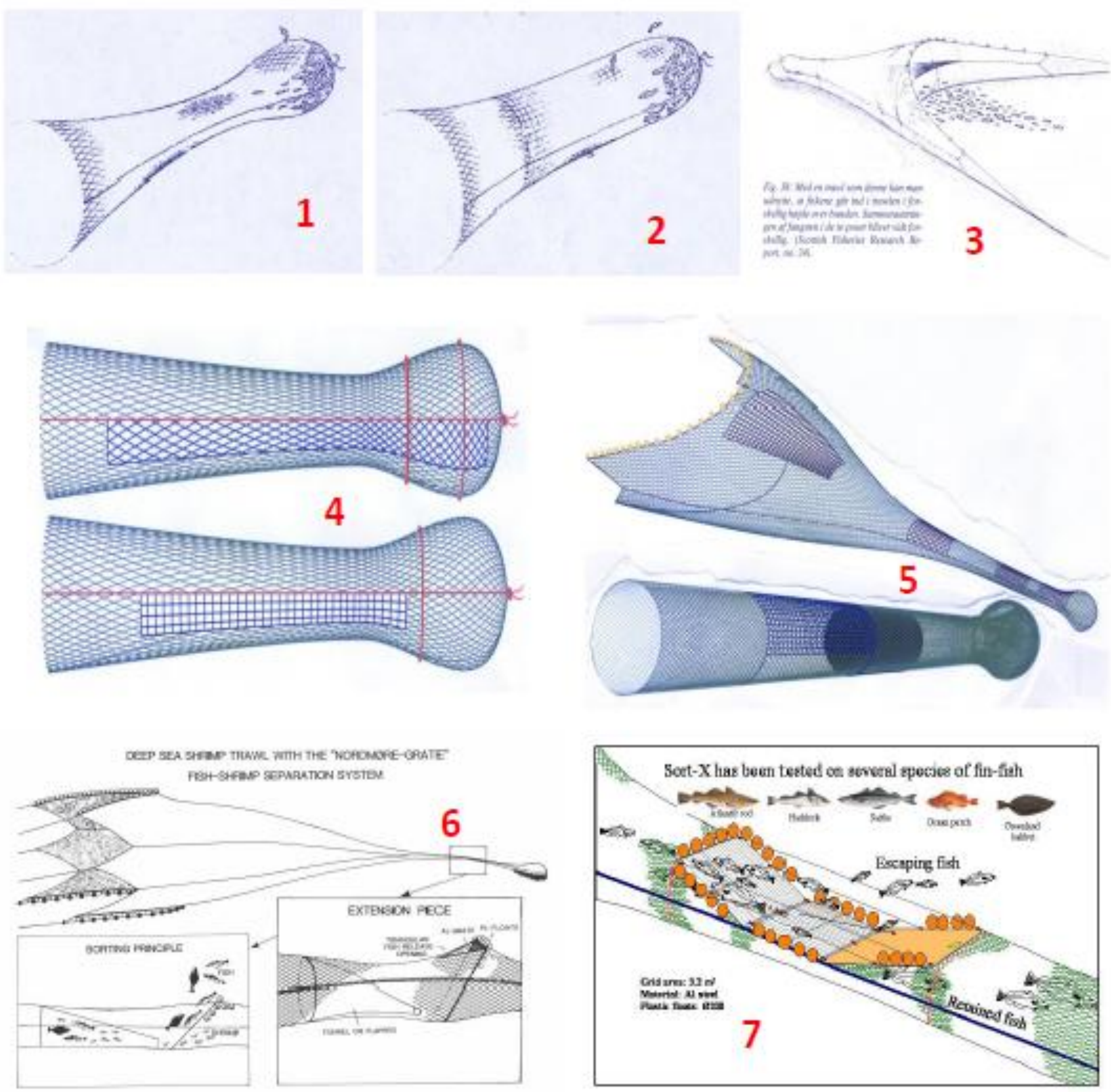
Table 10. Scheme of the parameters that the Captain records for each haul

Haul nr.		Date / /	
Avskutt Kl.		Hiver Kl.	
Trål tid minuter			
Posisjon start	N Ø	Posisjon slutt	N Ø
Dybde start	m	Dybde slutt	m
Vindstyrke m/s			
Fangst Kg			
Kommentarer			

- Translation of the terms of Table 10 from Norwegian to English:
  - Avskutt Kl. → Start time trawling (at seabed)
  - Hiver Kl. → Finish time (start hauling)
  - Trål tid → Trawl time
  - Posisjon start → Start Position
  - Posisjon slutt → End Position
  - Dybde → Depth
  - Vindstyrke → Wind speed
  - Fangst → Catch
  - Kommentarer → Comments

8.3 Appendix 3: Various devices described in Table 8.

Various selective devices used in bottom trawls (Source: RB Larsen, UIT)



1: The conventional diamond mesh codend
2: The full square mesh codend
3: The species separator trawls with two or more codends (not currently in use)
4: The Baltic windows (square mesh or T-90 mesh)
5: Square mesh windows inserted in various positions
6: The original Nordmöre fish-shrimp separator grid
7: The original Sort-X fish size sorting grid

(Separator/size sorting grids are made from steel, aluminum or various plastic materials)