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Possible technical measures that could be applied in NAFO 3M cod.

By

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Abstract

It has analyzed different technical measures that could be adopted in the NAFO 3M cod case to reduce the catches of cod below the Minimum Landing Size (MLS) and increase the Maximum Sustainable Yield (MSY). There is not so much information about technical measures in the NAFO cod fisheries. This analysis was mainly based on the Norwegian cod fisheries information. The adoption of the some studied technical measures seems to have a biological support because they would allow catching bigger fish minimizing the immature cod catches (length below the MLS) and the redfish by-catches in the NAFO 3M cod fishery. It was also studied the impact on Fmsy of some of these technical measures. These technical measures would increase slightly the current MSY but with a large increase in the fishing effort. The increase in the equilibrium yield with the selectivity change seems not to be very efficient. In NAFO, it should be studied the possibility of implementing technical measures to prevent the large catches of small immature individuals observed in 2013. These devices would prevent catches of individuals with length below MLS to avoid discards and will improve the exploitation pattern.

1. Introduction

An integral part of most fisheries management frameworks has been the regulation of technical aspects of fishing operations, through so-called technical measures. These define where, when and how the fishing fleets exploit commercial fish resources and interact with the wider marine ecosystem. Technical measures are part of a suite of input and output instruments. They are combined to influence both the exploitation rate and exploitation pattern with a primary goal of attaining sustainable exploitation of commercially exploited stocks and the provision of safeguards for ecosystem considerations. As such, they offer an objective tool for affecting several aspects of the interaction between fishing activity on exploited marine organisms and the broader marine environment. These include: affecting the distribution of fishing pressure; affecting the impact of fishing on both the physical and ecological environment; and providing an objective mechanism of defining fleet management units based on their gear type and selectivity patterns.

Technical regulations can be grouped into those that regulate the design characteristics of the gears that are deployed, such as the regulation of mesh size; those that regulate the operation of the gear such as setting maximum limits on how long or what type of gear can be deployed; those that set spatial and temporal controls such as closed/limited entry areas and seasonal closures; and those that define minimum sizes of fish and specify catch composition. Technical measures largely aimed to reduce catches of juveniles of commercial and non-commercial species, to improve species selectivity, to avoid catches of protected species, to reduce discards and minimize the impacts on the environment.

In terms of fishing pressure, technical measures can affect both exploitation pattern i.e. the distribution of fishing pressure across the demographic (age/length) spectrum of a given stock and the overall exploitation rate through the deployment of species selective gears which avoid the capture of specific species in a given gear. Scott and Sampson (2011) note that the exploitation pattern has a significant influence on the point estimates of Fmsy for a given exploitation rate and in general a higher age-at-capture (age at 50% selection) results in a higher Fmsy yield (MSY). Exploitation pattern is a composite result of a range of factors including the selectivity characteristics of the gears, the harvest ratios by different gears, as well as seasonal and spatial distribution of fishing effort relative to the seasonal and spatial distribution of the resource. Technical measures through adjustments in gear selectivity, and measures that set spatial and temporal controls can contribute significantly to changes in exploitation pattern and therefore changes in the potential yield that can be removed from a stock due to changes in Fmsy exploitation rates.

Effective implementation and enforcement of technical management measures can be extremely difficult. Fishers may resist in a variety of ways. Hence, a necessary condition for any successful implementation is the industry support.

The cod fishery on Flemish Cap (NAFO Division 3M) has traditionally been a directed fishery by Portuguese trawlers and gillnetters, Spanish pair trawlers and Faroese long-liners in the second half of the twentieth century. The fishery was closed in 1999 and this stock had been on fishing moratorium from year 1999 to 2009. The fishery was reopening in 2010 and nowadays is carried out mainly by trawlers from Faroe Islands (Denmark), Portugal, Spain, Russia, Estonia, United Kingdom and Norway at depths between 150-550 meters. The target species of this fishery is cod and the most important species in the by-catch is redfish.

The NAFO Conservation and Enforcement Measures (NCEM) in 2014 (NAFO/FC Doc. 14/1, Serial No. N6272) compile all the NAFO measures adopted by the Fisheries Commission to fishing in NAFO Regulatory Area (NRA). The 3M cod fishery is managed by total allowable catch (TAC) and quotas, shared mainly by European Union (57%), Denmark (22%), Norway (9%) and Russia (6%). Nowadays, there is not an effort allocation scheme for cod. The actual main technical measures for the 3M cod fishery are the general 130 mm trawl mesh size (Article 13) and the Minimum Landing Size (MLS) of 41 cm for cod (Article 17).

In the following sections possible technical measures that could be applied to the cod fishery will be analysed. It has also been analyzed the impact of some of these technical measures on the 3M cod Fmsy as well as in the model based Harvest Control Rule suggested for the 3M cod by the NAFO FC SC RBMS Working Group (NAFO, 2014).

2. Technical measures

2.1. Type of gear

All gears used to catch fished species are size/age selective to some degree. Mesh sizes, pot entrances, hook-size, as well as fishing season or location can be set to specifically target or select for different size/age classes of fish. Some fisheries can be highly selective, others less so. The actual 3M cod fishery is carried out mainly by trawlers. The change of the trawl gear for other with different selection characteristics would need a great economic investment to change the gear and to adapt the vessels. It is not clear that this investment can be economically recovered by improvements in the potential increase of yield. Therefore, it should be very well defined and proved the profitability of the investment, otherwise the industry would oppose to these large investments without a clear economic return.

2.2. Design characteristics of the gears (mesh size, sorting grids)

These types of technical measures are used to modify the gear selectivity and have a direct impact on the exploitation pattern of the fisheries. Traditionally, the selective properties of a trawl have been primarily related to the mesh size of the net (particularly in the codend), but in recent times have been developed different alternative selection measures, such as grids, escape windows, and square-mesh codend.

In the Northeast Atlantic trawl fisheries, several technical measures have been implemented in legislation (Suuronen and Sardà, 2007; Madsen, 2007). In 1997, the sort-X grid system became mandatory in the Barents

Sea to enhance sorting by size in the demersal trawl fisheries for Northeast Arctic cod. Kvamme and Frøysa (2004) showed by simulation that there would be substantial gains, in terms of both stock size and catches, from increasing the mean retention length by 5–8 cm relative to the estimated value of 47 cm prevailing before 1997.

There is not much information about the trawl cod selectivity in NAFO but there is available information about the trawl cod selectivity in other areas. Jørgensen et al (2006) compared the selectivity of a 135 mm codend with that of a trawl with a 135 mm codend and a 55 mm grid; they also estimated the selectivity of a 155 mm diamond mesh codend in Barents Sea. The results showed that similar selectivity can be obtained by using a 135 mm mesh codend in combination with 55 mm Sort-V grid and a codend with a 155 mm mesh size. The introduction of the grid in the Barents Sea cod fishery in 1997 in reality meant an increase in L50% (defined as the length of the fish that have a 50% probability of being retained by the gear on encounter) corresponding to an increase in mesh size from 135 to 155 mm.

Grimaldo et al. (2007) presented the results of the size selection of cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) in the Norway bottom trawl fishery with three different systems: a 135 mm diamond-mesh codend fitted with a 55 mm sorting grid (Sort-V); a 135 mm diamond-mesh codend fitted with two lateral exit windows; and a codend built entirely of 155 mm diamond mesh. The selectivity curves showed similar Selection Ranges (SR=L75%-L25%) for the three systems. Where L75% is the length of the fish where 75% of the fish is retained, and L25% is the length where 25% of the fish is retained. For cod, the mean SR was around 8 cm. All the estimated L50% values were far above the minimum landing sizes (MLS). For cod, the mean L50% was 56.1, 53.9 and 60.7 cm for the sorting grid, exit windows and diamond-mesh configurations, respectively, and was similar to the results obtained by Jørgensen et al. in 2006. From the point of view of fish behaviour, the sorting grid and the exit window setups presented a clear advantage over the diamond-mesh codend because they released fish at the fishing depth as soon as the fish reached the area of the selection device (grid or windows). The fish escaping from the diamond-mesh codend were exposed to far more stress, exhaustion, and physiological damage than fish that escaped from the other setups. The escape mechanism of the diamond-mesh codend raises the question of whether or not escaping fish survive.

One of the major problems in the NAFO 3M cod fishery is the decrease in the catches mean size observed in 2013 compare with previous years. Figure 1 shows the catches length distributions by country and Flemish Cap survey used in the 2013 and 2014 assessments (González-Troncoso *et al.*, 2013 and 2014). The mode observed in the length distribution of catches in the 2013 fishery was very close to the MLS (41cm) and it was quite different from 2012, when it was around 60 cm. In 2013, a 30% of cod individuals caught was below the MLS while in 2012 was 10%. Based on the Spanish Observer data, Iriondo *et al.* (2014) showed that in 2013 the fleet focused its effort in shallow areas where the small cod are more abundant. In previous years the fishing activity was focused on deeper waters catching bigger individuals. The main reason to this drop in the mode size of catches in 2013 seems to be due to market reasons rather than biological reasons.

Jørgensen *et al.* (2006) estimated the Barents Sea cod selectivity parameters assuming the logistic curve:

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

Where *r(l)* is the probability that a fish of length *l* will be retained in the test codend. *a* and *b* are the two generic selection parameters determining the mean selection length (L50%) and the selection range (SR=L75%-L25%) by the relationships:

$L_{50\%} = \frac{-a}{b}, \quad SR = \frac{\ln(9)}{b}$

These parameters were estimated for 135 mm codend (L50%= 43.89; SR=8.72), 135 mm codend with 55 mm sorting-grid (L50%= 55.02; SR=8.12) and 155 mm codend (L50%= 55.37; SR=14.01). For 135 mm codend case, which is very similar to the NAFO approved 130 mm minimum codend, the L50% would increase from 43.89 cm with the 135 mm codend to 55.2 cm with 135 mm codend and sorting-grid and this last was very similar to the 155 mm codend parameters values. Figure 2 presents the 3M cod selectivity age curves for 135 mm codend and 135 mm codend with 55 mm sorting-grid calculated with the Jørgensen *et al.* (2006) parameters values as well as the assessment Partial Recruitment (PR) estimated for 2013 for cod Div. 3M

(Gonzalez-Troncoso *et al.*, 2014). It can be observed that the introduction of the sorting-grids significantly decrease the fishing mortalities for ages 3 and 4, avoiding many immature juveniles catches.

In NAFO, it should be studied the possibility of implementing devices to prevent these large catches of small individuals. These devices would prevent catches of individuals less than MLS to avoid discards and will improve the exploitation pattern and the MSY. Good selection efficiency would reduce the pressure on undersized fish, and thereby increase the future size of exploitable stock (Armstrong *et al.*, 1990). The L50%= 55.2 cm would be a more appropriate value considering the NAFO cod MLS of 41 cm and the 3M cod biology. The estimated 50% maturity length and age for 3M cod in the last years were around 52 cm and 4 years (Table 1). Grimaldo *et al.* (2008) concluded that the sorting grids seem to have a bigger survival rate of the selected fish than the diamond meshes and the exit windows. The implementation of these devices would also reduce the redfish by-catch and discard rates in the cod fishery. They would improve the selectivity and the survival rate of the redfish catch in the cod fishery.

2.3. Spatial and temporal area closures

The exploitation pattern depends not only on the gear configuration but also on the spatial and temporal distribution of the fishery and underlying population. One way to improve the exploitation pattern is the spatial or temporal closures of areas with high concentrations of young fish.

There are few data available to study the 3M cod seasonal distribution. The fishery was closed until 2009 and there are not much data available to conduct a seasonal distribution study. Survey data do not provide too much information for such studies since the survey gives a fixed distribution picture in a particular season. Therefore this study will focus on the possibility of spatial closures rather than temporary closures.

Results of the spatial 3M cod length distribution based on Spanish Scientific Observers and Flemish Cap Surveys (Iriondo *et al.,* 2014) show a general increasing trend of the mean length with depth, with a bigger proportion of juvenile fishes in shallower waters. In Flemish Cap Survey the spatial distribution of hauls covers all the 3M area, and high abundance indices of juveniles are observed in shallower waters in the centre of Flemish Cap. However, before 2013 the commercial fishing activity focused their effort targeting cod in deeper areas where larger cod is more abundant but this pattern was different in 2013 when the fishing effort was more concentrated in the shallower waters of the Eastern part of Flemish Cap with smaller length distributions in catches. This change in the fishing pattern has been observed in other fleets as it can be deduced from the size distributions of commercial fleets in 2012 and 2013 (González-Troncoso *et al.*, 2013 and González-Troncoso *et al.*, 2014).

One solution to avoid the problem of large catches of juveniles that have occurred in 2013 could be the closure of the areas at less than 400 meters depth where these fish are more abundant as it can be concluded from the results of Iriondo *et al.* (2014). The effect in the exploitation pattern of this technical measure should be similar to the implementation of the 135 mm codend with sorting grids: prevent catches of individuals less than MLS to avoid cod discards and to improve the exploitation pattern and the MSY. But this measure could increase the by-catch of beaked redfish (*S. mentella* and *S. fasciatus*) as these species are more abundant in depths more than 400 meters (Avila de Melo *et al.*, 2013). Another problem of implementing these closures would be the effort concentration in small areas. The individuals bigger than the MLS are regularly distributed at all depths, although the proportion of cod larger than MLS is higher in deeper waters. If this measure is implemented, then a part of individuals larger than the MLS could not be fished with the consequent loss of fishing opportunities.

2.4. Minimum fish size and specify catch composition

Minimum Landing Size (MLS) for cod in NAFO is established in 41 cm. To establish the MLS should be taken into account the gear selectivity used in the fishery and the biology of the species that are intended to regulate, in our case the Flemish Cap Cod. The main objective is to establish the technical characteristics of the gear that allows catching the maximum biomass considering the growth tax and natural mortality of the species without endangering the reproductive potential of the stock. An efficient fishing gear in terms of selectivity should have a 50% retention probability (L50%) that is above the minimum landing size (MLS) and with very low probability of retention of the fish lower than the MLS to avoid discards.

In 3M cod fishery the MLS is quite well established taking into account that length of 50% maturity is around 54 cm in the last years and is larger than the MLS (41 cm). But considering the selectivity of the 135 mm codend mesh size parameters (L50%= 43.89; SR=8.72) estimated by Jørgensen *et al.* (2006) the mesh size used in the NAFO cod fishery (130 mm) is not the most adequate as it allows catching many individuals smaller than the MLS that should be discarded. The use of 130 mm mesh size catches fish of a wide size ranging from 20 to 120 cm based on the countries information. Considering that the MLS is 41 cm and the mean length of first maturation value for the last seven years is 54.27 cm, a percentage of around 73% in 2013 and 52% in 2012 of immature fish individuals were fished based on the total catch length distribution used in the assessment (Gonzalez-Troncoso *et al.*, 2014). To avoid this problem the characteristics of the gears should be changed to increase the size at first capture (L50%).

Taking into account that the fishery was re-opened four years ago, if the 2013 exploitation pattern fishing an important percentage of immature fish remains in the same line, some precautionary measures should be considered in the following years in the fishery. One solution could be the implementation of the 55 mm sorting grids in the current gear or the increase of the actual codend mesh size around 20 mm as it was discussed in the design characteristics of the gears section. These solutions have the advantage of minimizing the redfish by-catches in the 3M cod fishery and to catch bigger cod than the current catches minimizing the discards in the fishery.

3. Impact on Fmsy of a change in the exploitation pattern

It has been estimated a new Fmsy proxy considering the change in the exploitation pattern that could take place if the technical measures described above (sorting grids or mesh size change to 155 mm) are implemented in the Cod 3M NAFO fishery. The method used by González-Costas and González-Troncoso (2014) to estimate the approved 3M cod Fmsy proxy has been used to estimate a new value. The F30%SPR was chosen as the best Fmsy proxy for the 3M cod case. It was estimated a new F30%SPR with the same inputs used in 2014 but using the selection pattern for the 135 mm codend with sorting grids (Figure 2) estimated with the Jørgensen *et al.* (2006) parameters to see the differences between Fmsy proxies, the approved and the new one.

Table 2 and Figure 3 present the results for both Fmsy values as well as both estimated equilibrium yields and SSBs. The implementation of a selection pattern similar to the 135 mm codend with sorting grids would increase the current Fmsy value and the equilibrium catches but it should have a small impact in the equilibrium SSB. The increment of the equilibrium catches should be around 13% with an increase in the Fmsy of more than 100%. If we measure the efficiency of fishing (ef) as yield per unit fishing mortality (Y/F), the increase in the equilibrium yield with the selectivity change seems not to be very efficient. The efficiency of fishing would be reduced by 50% if we change the actual exploitation pattern with an ef = 169 699 to the new of the 135mm with sorting grids with an ef = 92 685.

These results are different from the obtained by Scott and Sampson (2011). They assumed similar selection patterns with a Ricker function for the recruitment whereas in our case we assume random recruitment. They found that as selectivid, maximum and minimum values of both MSY and Fmsy varied by about 30%.

4. Results of the implementation of Technical measures in the 3M model based HCR.

It was decided to simulate one 3M Cod Management Strategies Evaluation scenario (González-Costas *et al.*, 2014) of the model-based HCR suggested by the NAFO FC SC RBMS Working Group (NAFO, 2014) to study what would be the yield effects of a new Fmsy resulting of implementing a change in the selection pattern. It was chosen the scenario number 2 (M fix SR1 35%) to study the model-based HCR yields.

The model-based HCR tested was based on three different levels (20%, 35% and 50%) of exceeding the Fmsy proxy as Ftarget with a TAC constraint between years of 20%. The results showed that the projected catch and F levels depend on the value of this constraint (Gonzalez-Troncoso *et al.*, 2015). The M fix SR1 35% scenario was run without the TAC constraint with the current Fmsy proxy value and with the new Fmsy proxy estimated using the selection pattern for the 135 mm codend with sorting grids to see the effects of changing the selection pattern.

Figure 4 presents the median yield of the scenario 2 (M fix SR1 35%) with the model based HCR tested with the 20%TAC constraint, without TAC constraint and without TAC constraint and the new Ftarget estimated with the change in the exploitation pattern that could take place if the technical measures described above (sorting grids or mesh size change to 155 mm) are implemented. It can be observed three different periods in the projected time: first period (2014-2020) where the yield decreases in all cases in a similar trend and level; second period (2021-2028) where yields increase but this increase is more moderate in the case with the TAC constraint and is quite similar in the other two cases till 2024. Between 2024 and 2029 the case without TAC constraint and the new estimated Ftarget has clearly bigger yields than the other two cases. In the last period (2029-2033), the case with TAC constraint presents an increase trend while the other two cases (without TAC constraint) have a quite similar yield levels and variable trend.

Figure 5 shows the yearly median of the mean yield for the three scenarios in the medium (2014-2020) and long (2014-2033) periods. Results show that the implementation of gear devices as sorting grids or the enlargement of the current minimum cod-end mesh size till 155 mm does not lead to a big yield increase in the medium term period (2014-2020). In the long term period (2014-2033) the implementation of these technical measures leads to an increase in the yearly mean yield.

5. Conclusion

Considering the selectivity parameters of the 135 mm codend mesh size and the 3M cod biology, the mesh size used in the NAFO cod fishery (130 mm) is not the most adequate as it allows catching a lot of immature individuals with lengths below MLS that should be discarded. One solution could be the implementation of the 55 mm sorting grids in the actual gear or the increase of the actual codend mesh size around 20 mm. These solutions have the advantage of minimizing redfish catches in the 3M cod fishery and to catch bigger cod than in the current catches minimizing the discards in the fishery. Sorting grids seem to have a bigger survival rate of the selected fish than the diamond meshes and the exit windows.

Other technical solution to avoid the problem of large catches of juveniles could be the closure of the areas at less than 400 meters depth where these fish are more abundant. The effect in the exploitation pattern of this technical measure should be similar to the implementation of the 135 mm codend with sorting grids. But this measure could increase the by-catch of redfish as this species is more abundant in depths more than 400 meters. Another problem of implementing these closures would be the effort concentration in small areas.

The implementation of a selection pattern similar to the 135 mm codend with sorting grids or the enlargement of the actual minimum cod-end mesh size till 155 mm would increase the actual Fmsy value and the equilibrium catches but it should have a small impact in the equilibrium SSB. The increment of the equilibrium catches should be around 13% but with an increase in the Fmsy of more than 100%. This large increase of F would suppose a greater fishing effort and probably more economical operating expense for a small increase in catches. If we measure the efficiency of fishing (ef) as yield per unit fishing mortality (Y/F), the increase in the equilibrium yield with the selectivity change seems not to be very efficient. The efficiency of fishing would be reduced by 50% if we change the current exploitation pattern to the new.

The model based HCR applied with the new selection pattern have not a big yield increase in the medium term period (2014-2020). In the long term period (2014-2033) the implementation of these technical measures have an increase in the yearly mean yield.

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Table 1.- Age 50% maturity and length 50% maturity for cod 3M stock from the Flemish Cap Survey data.

Year	Age 50% maturity (years)	Length 50% maturity (cm)
2007	3.31	57.02
2008	3.37	58.98
2009	3.49	53.65
2010	3.52	53.13
2011	4.13	57.88
2012	3.93	52.43
2013	3.39	46.77
Mean	**3.59**	**54.27**

Table 2.- The F_{msy} proxies ($F_{30\%SPR}$), their equilibrium catches and SSB estimated with the 135 mm codend with sorting grids selection curve and the data used by González-Costas and González-Troncoso (2014) for 3M cod approved by the 2014 Scientific Council (SC), as well as the efficiency of fishing (ef)

Values approved by the 2014 SC

	$F_{30\%SPR}$	Yield (t)	SSB (t)	ef
10%	0.109	19995	176509	183440
50%	0.133	22570	126545	169699
90%	0.159	25726	91931	161799

New values with the 135 mm +SG selection

	$F_{30\%SPR}$	Yield (t)	SSB (t)	ef
10%	0.214	22667	175934	105921
50%	0.276	25604	126188	92768
90%	0.356	29043	91731	81581

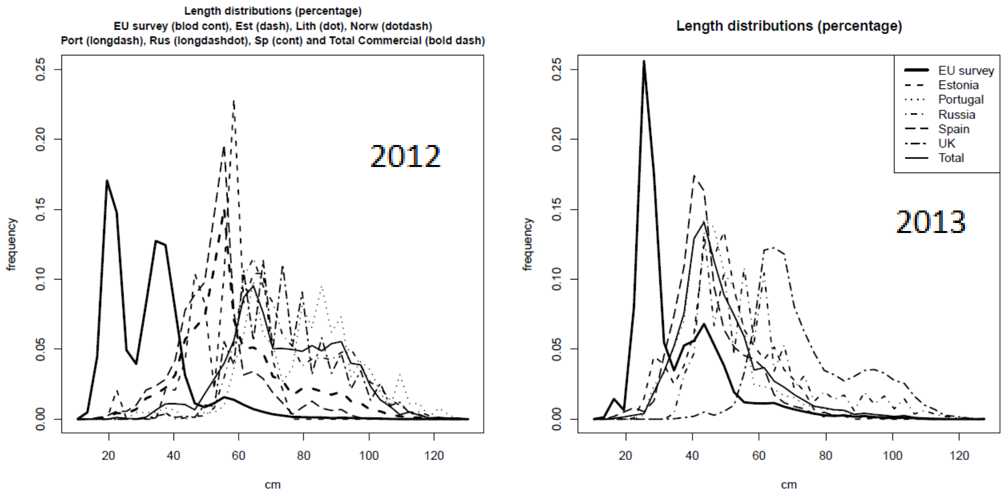

Figure 1.- NAFO 3M cod 2012 and 2013 catches length distributions by country (González-Troncoso *et al* 2013 and 2014).

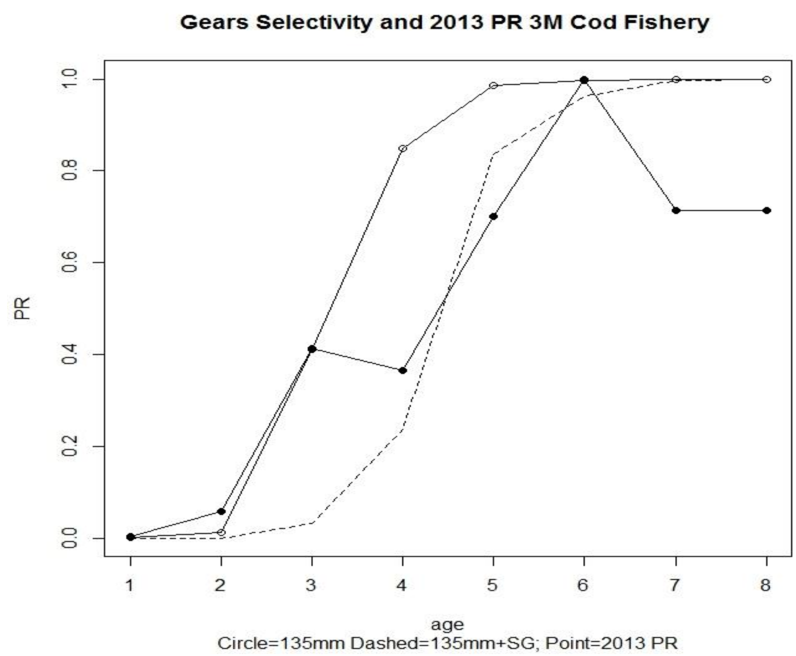

Figure 2.- The 135 mm codend, the 135 mm codend with sorting grids selection curves for 3M cod based on the Jørgensen et al. (2006) parameters and the NAFO 3M cod assessment Partial Recruitment (PR) estimated for 2013.

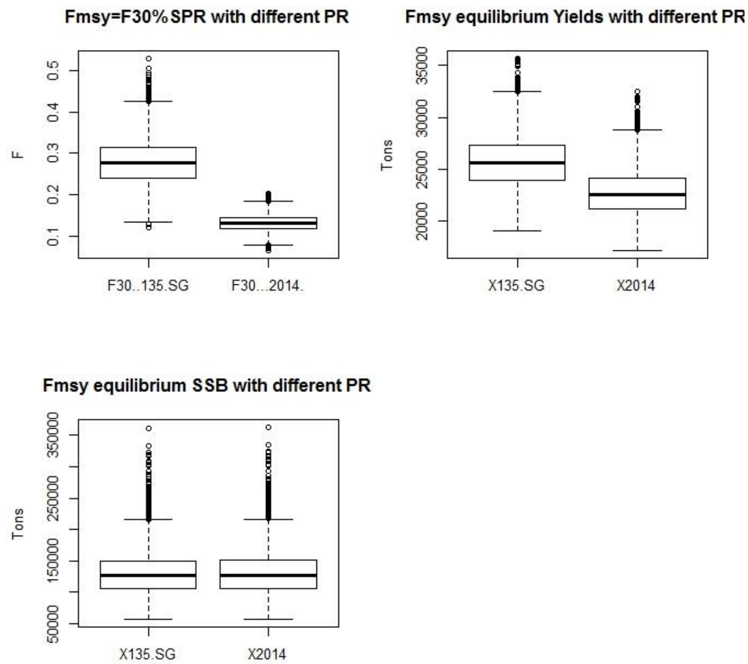

Figure 3.- F_{msy} proxies ($F_{30\%SPR}$) and their equilibrium catches and SSB estimated with the 135 mm codend with sorting grids selection curve (X135.SG) and the data used by González-Costas and González- Troncoso (2014) for 3M cod approved by the 2014 Scientific Council (X2014).

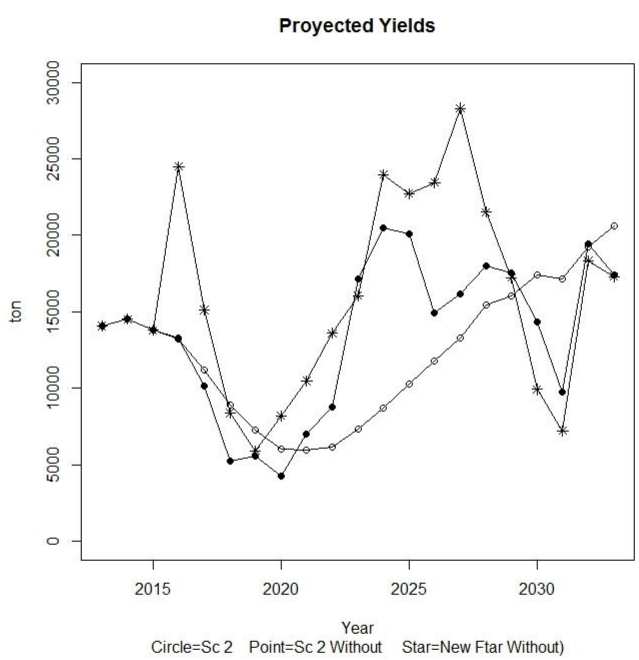

Figure 4.- Median yield by year for scenario 2 (M fix SR1 35%) with: Circles- the model-based HCR (with the 20% TAC constraint); points- the HCR without TAC constraint and stars- with the HCR without TAC constraint and the new F_{target} estimated with the change in the exploitation pattern that could take place if the sorting grids or mesh size change to 155 mm are implemented.

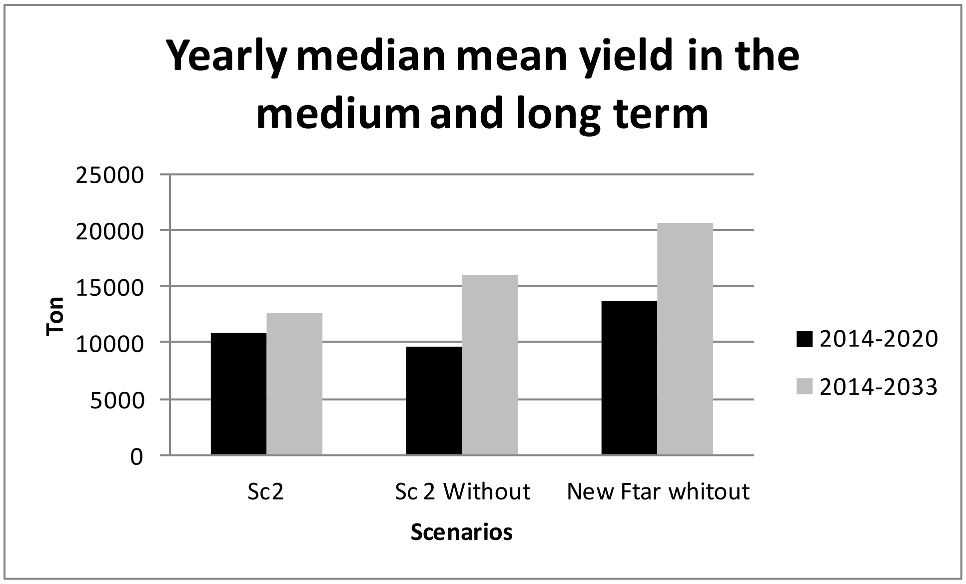

Figure 5.- Yearly median of the mean yield in the medium (2014-2020) and long term (2014-2033) period of the scenario 2 (M fix SR1 35%) with the model based HCR (with the 20% TAC constraint), with the HCR without TAC constraint and with the HCR without TAC constraint and the new F_{target} estimated with the change in the exploitation pattern that could take place if the sorting grids or mesh size change to 155