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Optimization of redfish fishery on the Flemish Cap Bank using biological target reference points

by

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Abstract

The objects to study are several redfish species from the Flemish Cap Bank in the NAFO Div. 3M of the Northwest Atlantic. The paper is aimed at the development of the proposals to optimize redfish fishery using biological reference points.

The estimation of biological reference points F_{max} and $F_{0.1}$ was made and the dynamics of the redfish stock and yield was calculated under the remained spawning biomass within 20-60 thousand t and different constant exploitation levels (F) ranged from 0.02 to 1.0. It was shown that the optimal mean long-term catch may be obtained with fishing mortality of about 0.2 and spawning biomass of around 40 thousand t.

Key words: redfish species, stock, abundance, simulation, fishing mortality.

Introduction

Three redfish species including beaked redfish (*Sebastes mentella*), golden redfish (*Sebastes marinus*) and Acadian redfish (*Sebastes fasciatus)* are studied as a single unit of the redfish stock on the Flemish Cap Bank.

Primary information to estimate redfish stock status in Div.3M is based on annual stratified bottom trawl surveys carried out by the European Union (EU) since 1989.

It was considered that the redfish stock from the Flemish Cap Bank was unsteady and its TAC was determined as 6.5 thousand t. At the same time, the EU survey data showed that the redfish commercial stock biomass ranged from 200.0 thousand t to 300.0 thousand t, that approximately corresponded to its state in the first fishing years.

The paper attempted to optimize redfish fishery using mathematical models and to determine a possible level of fishing mortality and yield.

Materials and methods

Statistical data of domestic and international redfish fishery on the Flemish Cap Bank for 1956-2014 were taken from the database of vessel daily reports of PINRO as well as from NAFO STATLANT21A and STATLANT21B databases on catch statistics.

Biomass and abundance indices, length-age composition of catches, mean weight of individuals by length and age, length-age keys to recalculate the catch in biomass to that one in abundance were derived from the working documents submitted to the annual meetings of NAFO Scientific Council (SC), annual reports of SC, as well as from the reports on the results of the EU bottom stratified trawl surveys.

In Div.3M, redfish abundance dynamics was estimated using XSA (Extended Survival Analysis) model [1]. Commercial stock recruitment dynamics was simulated by Ricker's stock-recruitment relationship [2]. To calculate $F_{0.1}$ and F_{max} biological reference points the YPR (yield per recruit) function was used [3]. The calculations of biological reference points were made with the aid of the software realized in Excel.

Dynamics of biomass stock and yield

On the Flemish Cap Bank, redfish species have been being harvested since autumn 1956. The XSA method was applied in the stock assessment of redfish species in 1956-2014; at that, only the data from EU surveys for 1989-2013 were used. During the exploitation period, yield, fishing and spawning biomasses, recruitment and fishing mortality varied much. Three periods during which the prolonged trends in fishing mortality (F_{bar} decrease or increase) were observed might be singled out; and the biomass of redfish stock varied accordingly in 1960-1968, 1970-1999, 2003-2012 (Fig. 1).

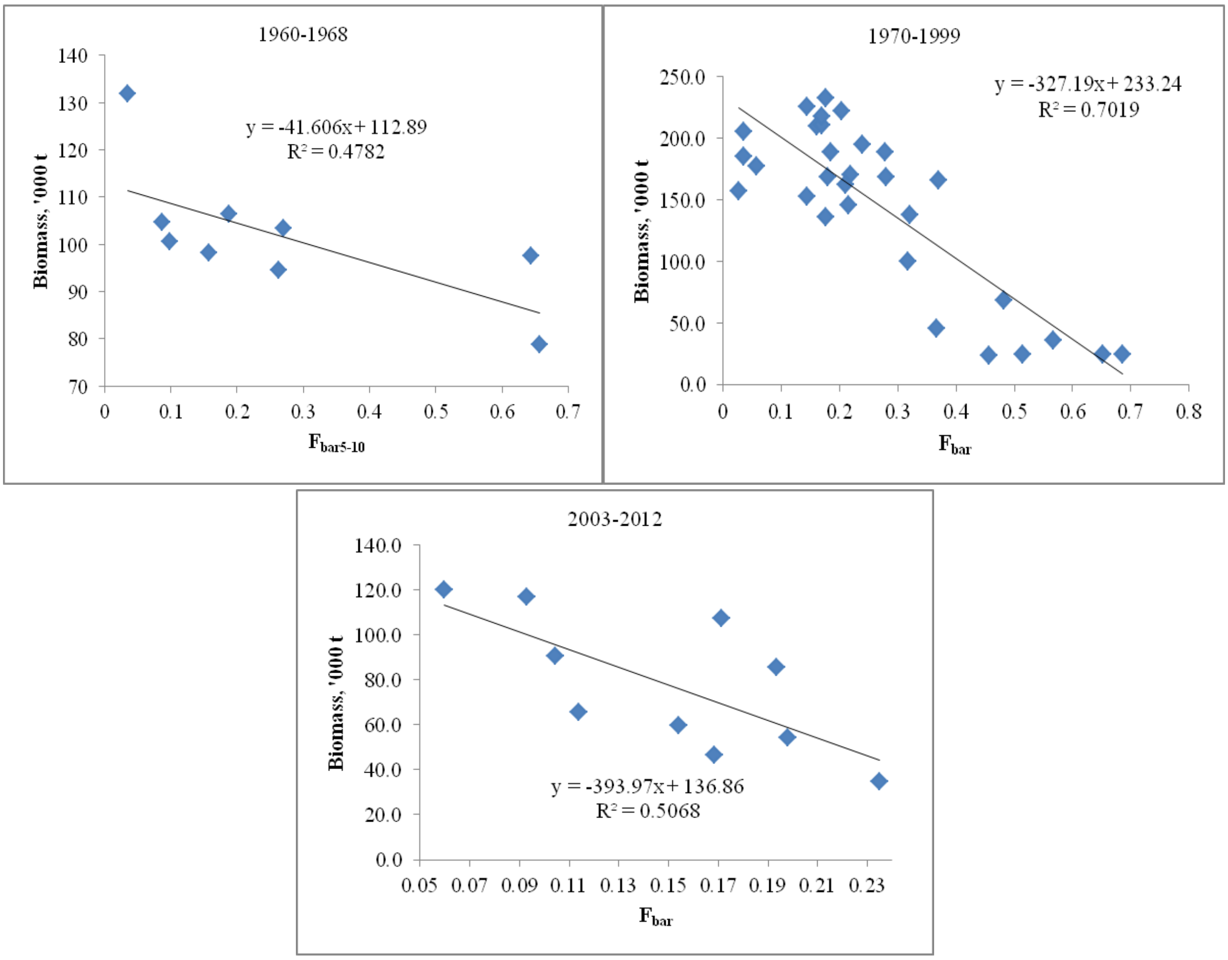


Fig. 1. Redfish biomass and fishing mortality relationship on the Flemish Cap Bank in 1960-2012

The trend of the stock size increase observed in 1960-1968, is closely connected with increase in fishing mortality from 0.66 to 0.056, and the reduction in the annual catch from 50.0 to 3.0 thousand t. In 1970-1999, there was an observed close correlation between redfish stock biomass and fishing mortality rate with a three year lag. A correlation coefficient showing the closeness equaled to 0.84. The third period of fishing mortality variation in redfish fishery goes back to 2003-2012. Then, fishing mortality gradually reduced from 0.14 to 0.07, and later it became stable at the level of 0.07-0.09. In that period, the stock biomass gradually increased and got stabilized at the level of 130.0-150.0 thousand t (by XSA calculations).

Yield per recruit

One of the approaches often used in fishery regulation for many fish species involves the analysis of yield per recruit and calculation of $F_{0.1}$ and F_{max}, which were the biological reference points [3]. The approach is based on certain hypotheses the primary of which are recruitment stability, growth parameters and natural mortality in the conditions of balanced fishery. The curve of the yield per recruitment (Y/R or YPR) is considered as the function of instantaneous fishing mortality rate (F). A reference point of $F_{0.1}$ is a point F, at which a Y/R curve slope is 10 % from its value at the zero point (in the origin of coordinates). F_{max} – is a value of fishing mortality at which the curve of the yield per recruit has a maximum.

Variability of biological reference points, $F_{0.1}$ and F_{max}, was studied using several historical periods of fishing characterized by different values of mean weight, maturation ogive and exploitation model (Table 1). Biological reference point $F_{0.1}$ varied slightly from 0.08 to 0.11, some changes, from 0.093 to 0.106, were also observed in the yield per recruit ($YPR_{F0.1}$). Parameter F_{max} ranged more widely, from 0.17 to 0.27, besides 1956-1966, when fishing mortality, F_{max}, was estimated at 1.025. However, the YPR-curve for this period is a curve with poorly expressed (flat-topped) maximum. The YPR-value being actually equal to the maximum, 0.12 kg/ind., is already reached under F=0.35. Further increase in fishing mortality, in fact, has no influence on yield per recruit. Hence, a value of 0.35 may be taken as F_{max} for this period.

In most of studied periods, actual fishing was characterized by fishing mortality, F_{bar}, exceeding F_{max} (Table 1). It was especially noticeable in 1989-2001, when F_{bar} equaled to 0.401, while F_{max} was estimated at 0.18. In our opinion, that was the reason of the abrupt reduction in redfish stock biomass in that period.

Table 1 Variation of biological reference points $F_{0.1}$ and F_{max}, fishing mortality F_{bar}, yield per recruit and mean annual yield in different periods of redfish fishery on the Flemish Cap Bank

Period	$F_{0.1}$	F_{max}	$YPR_{F0.1}$, kg/ind.	YPR_{Fmax}, kg/ind.	F_{bar}, registered	Mean annual catch registered in a period, t
1956-1966	0,082	1,025	0,094	0,118	0,228	19590
1967-2003	0,079	0,171	0,104	0,113	0,237	20191
2004-2014	0,112	0,274	0,093	0,103	0,137	5274
1989-2001	0,086	0,180	0,106	0,116	0,401	24720
1958-2014	0,078	0,177	0,102	0,112	0,216	17207
1989-2014	0,088	0,203	0,105	0,114	0,271	15150

Optimization of fishery

In order to optimize single species fishery of redfish on the Flemish Cap Bank the two approaches were applied:

1) determination of the maximal yield under the remained spawning biomass at the given level during the whole period of fishing (target size of the spawning stock);

2) determination of the maximal yield under maintaining the constant fishing mortality and exploitation model.

In the developed model of optimization, redfish abundance, commercial stock biomass and the biomass of mature fish and yield were calculated using the equations applied in the XSA method [1].

Estimation of model parameters

Recruitment. To simulate the recruitment of the Flemish Cap Bank redfish the model of Ricker [2], the parameters of which were estimated by recruitment abundance and spawning biomass from XSA was applied. Taking into account that Ricker's model badly described the redfish stock recruitment dynamics some variants of optimization were made using the actual recruitment. In that case, each year the recruitment was studied as normally distributed occasional value with mathematical expectation being equal to the recruitment value by surveys and dispersion being equal to 40 % from the mathematic expectation. The value of the dispersion was taken randomly in order to obtain wider range of recruitment.

Weight by age in the stock and catch. In simulating, mean weight the following approach was used. The data on redfish annually submitted to NAFO SC [4, 5] by experts were used to calculate the mean weight and dispersion for each age for 1989-2014. It was assumed that the weight of an individual at age was a normal distributed random value with known mathematical expectation and dispersion.

Maturation ogive. Recently, there are not many Russian investigations of the different Flemish Cap redfish species maturation rates (surveys and systematic researches were stopped in 2000). Therefore, in the calculations the data on redfish given by NAFO expert were applied [4, 5]. Allowing for that the redfish stock consisted of three distinct species having different maturation parameters the calculation of a unified maturation ogive resulted in big uncertainties that Figure 2 showed.

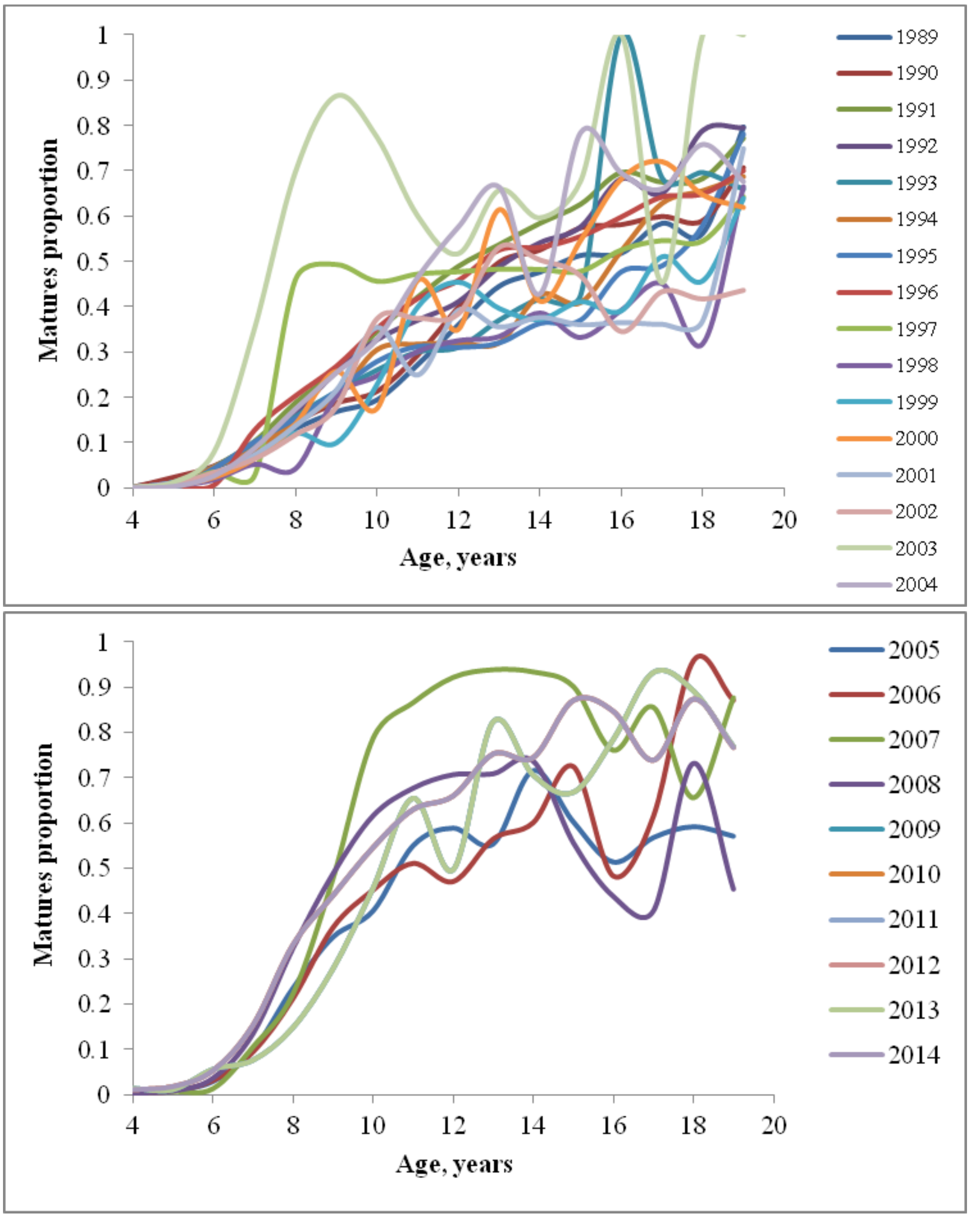


Fig. 2. Percentage of the Flemish Cap Bank redfish maturation by age used in redfish stock estimation in NAFO for 1989-2014, from [4, 5]

In the simulation the annual observed data on maturation were approximated by a curve:

$$Mat_a = \frac{b}{1+e^{-\lambda(a-a50\%)}} \quad , \qquad (1)$$

where Mat_a – percentage of mature fish at age a;
a 50% - fish age at which 50 % of individuals become mature;
λ and b - parameters.

For 2015-2045, the mean values of maturation percentage by age were calculated and their curve given in Fig. 3 was approximated.

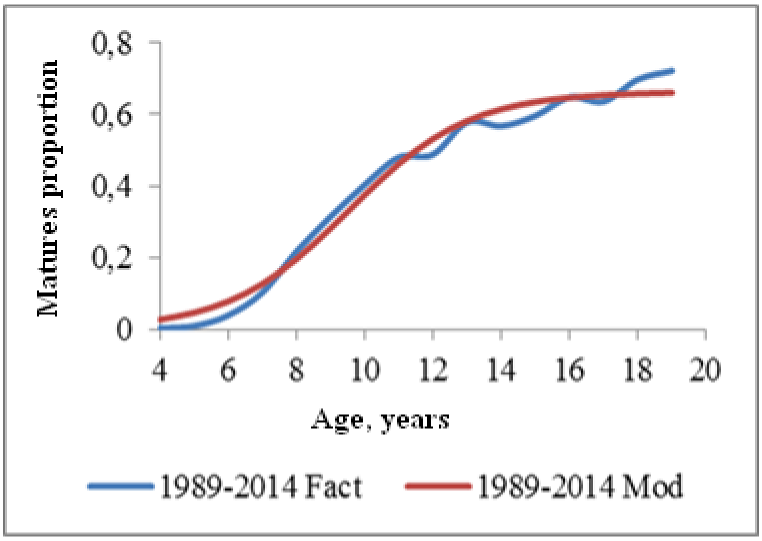


Fig. 3 Portion of the Flemish Cap Bank mature redfish by age obtained by averaging data for 1989-2014 and their maturation curve approximation

Exploitation model Distribution of fishing mortality by age was taken to be equal to the long-term means for 1989-2014. This way of choosing fishery selectivity allows for the up-to-date structure of fishing fleet and the fishing gear technical capabilities determining their selectivity.

To derive stable redfish stock estimates associated with the choice of random values of input parameters a stochastic approach was used. It included multiple calculations (5-10 thousand runs) by model with various generated recruitment, growth and sex maturation. The results of all the iterations were averaged; and the range of variability of the parameters was estimated by given percentiles (0.05, 0.5, 0.95).

Results

Fishing optimization under the criterion of maintaining spawning biomass. Calculations of the best average annual yield and average annual biomass of redfish fishing stocks were done maintaining the constant spawning biomass at 20,000 - 60,000 tons (with the pitch of 10,000 tons). It was proposed that indices of stock recruitment would correspond to the actual indices and were not connected with the population density.

The results of modelling for periods of 1958-2014 and 1989-2014 show an identic tendency in changing fishing biomass and yield and have some insignificant alterations in the absolute estimates (Table 2, 3). The average annual biomass for both periods at identical SSB values diverges by no more than 5%. Stock dynamics modelling with constant SSB for this period proves that the average annual best yield in the period of 1989-2014 is higher than the actual one at any constant SSB of 20,000 - 50,000 t.

Table 2 Average annual values for redfish biomass, yield and fishing mortality for the period of 1958-2014 on the Flemish Cap Bank along with fishing optimization by maintaining constant spawning biomass

Spawning biomass, t	Fishing biomass, t	Yield, t	Fishing mortality
20000	94420	16440	0,26
30000	117389	15650	0,18
40000	138189	14404	0,13
50000	156782	12664	0,10
60000	174332	10994	0,07
Actual	132624	17207	0,20

Table 3 Average annual values for redfish biomass, yield and fishing mortality for the period of 1989-2014 on the Flemish Cap Bank, along with fishing optimization by maintaining constant spawning biomass

Spawning biomass, t	Fishing biomass, t	Yield, t	Fishing mortality
20000	100217	20104	0,29
30000	124062	18906	0,20
40000	145743	17178	0,15
50000	165432	15305	0,11
60000	184420	13199	0,08
Actual	86751	14793	0,27

The analysis does not make it possible to pick out the best value for the spawning biomass. The largest average annual yield was obtained at SSB of 20,000 tons. However, formally speaking, this value seems to be quite low. We consider SSB value of 40,000 tons as more appropriate. If the spawning biomass was kept at 40,000 tons, the average annual yield would amount to 17,200 tons which is more than the actual yield of 14,800 tons. The forecast for 25 years with the average annual recruitment shows that with spawning biomass (SSB) being kept at 40,000 tons the fishing stock would amount to 150,000 tons and yield may be up to 16,500 tons which is considerably more than the yield of 7,000 tons currently advised by SC NAFO.

<u>Fishing optimization by regulating fishing mortality.</u> Calculations of the best average annual yield and average annual biomass of redfish fishing stock were done at the constant fishing mortality fixed at 0.02 to 1.0, with the pitch of 0.02.

Redfish recruitment abundance was calculated in accordance with “stock-recruitment” dependency [2]. Ricker’s equation parameters were estimated by values of recruitment and spawning biomass from the XSA calculations. Two periods of 1958-2014 and 1989-2014 were also analyzed. For each of those the forecasts of dynamics of stock biomass and yield were made up to 2045. For the period of 1958-2014 the maximum average annual yield is about 18,000 tons and corresponds to the best fishing mortality which is 0.2 (Fig. 4). A drastic decrease in redfish stock is observed when exploitation is effected at fishing mortality of more than 0.3. Fishing at constant fishing mortality F which, for instance, is equal to 0.5 would result in average yield for 1958-2014 falling to 13,000 tons. If fishing mortality was 0.5 up to 2045, the average yield for 1958-2014 would fall to 8,000 tons and the fishing biomass would amount to 50,000 tons and the spawning one – to 10,000 tons.

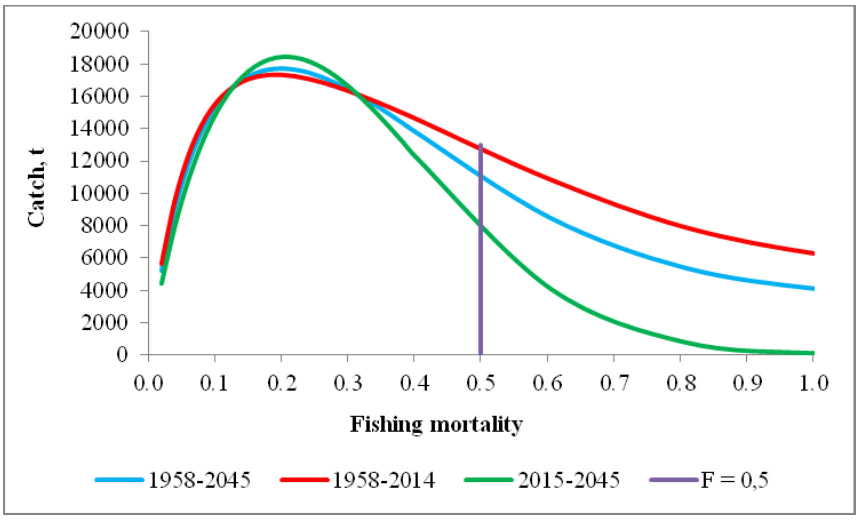
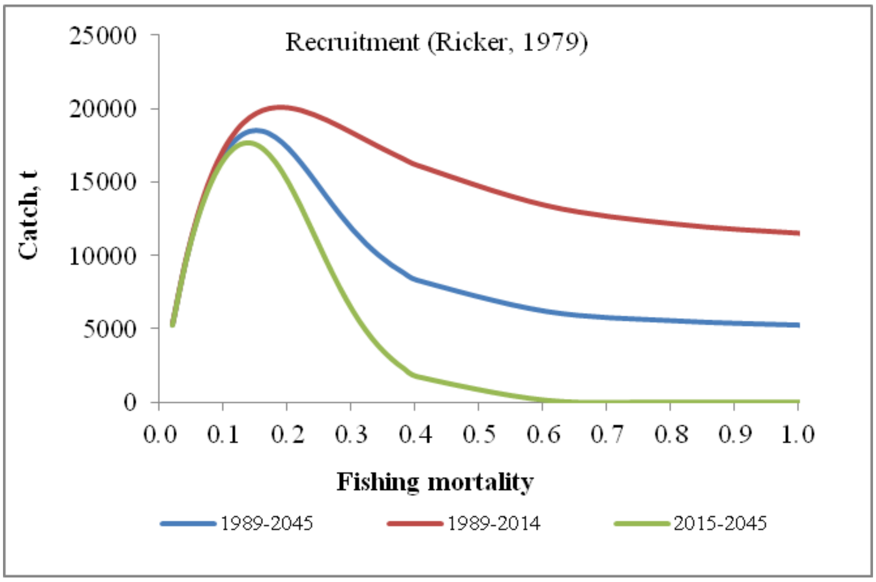


Fig. 4 Dynamics of average annual yield over different fishing periods in 1958-2045 depending on fishing mortality

Maximum average annual yield for 1989-2014 is about 20,000 tons and may be reached at fishing mortality equal to 0.21 (Fig. 5). This value is close to F_{max} value estimated by yield per recruit curve. For the forecasted period of 2015-2045 the largest yield (17,000 tons) corresponds to fishing mortality of 0.16.



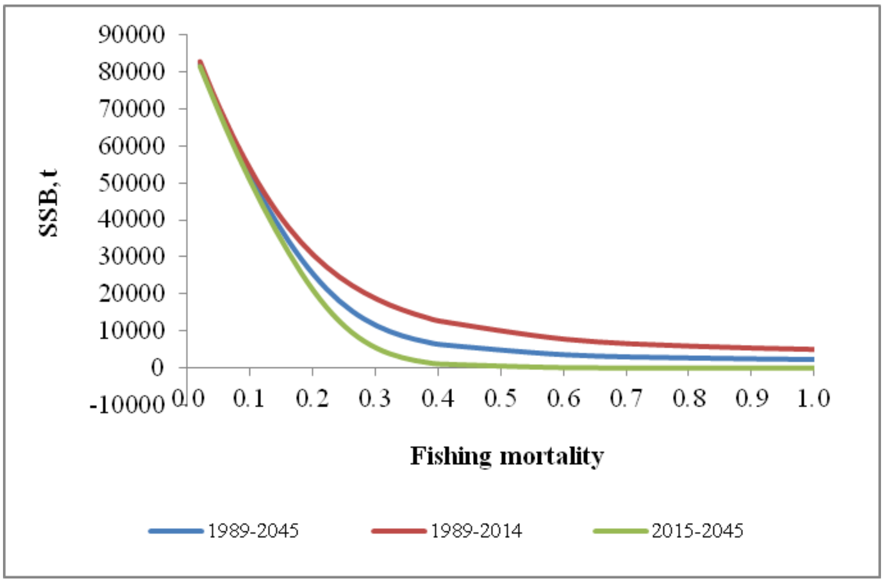


Fig. 5 Dynamics of redfish yield and spawning biomass on the Flemish Cap Bank for 1989-2045 with stock recruitment modelling by Beverton and Holt's and Ricker's curves

While choosing constant fishing mortality for rational fishing, it is necessary to allow for the character of the curves for fishing and spawning biomasses. Fishing at F=0.2 would keep the spawning biomass at 40,000 tons and the fishing one – at 120-130, 000 tons. As fishing mortality increases, fishing and spawning mortality decrease. In the forecasted period of 2015-2045, an increase in fishing mortality results in an abrupt decrease in spawning biomass. Spawning biomass would amount to no more than 5,000 tons already at F=0.3, and that may practically lead to stock collapse (Fig. 5).

Fig. 6 shows index dynamics for redfish stock per year for 1989-2045 when fishing at some constant fishing mortality values (at the actual recruitment values for 1989-2014 and average geometric value for 2015-2045). The following fishing mortality values were analyzed: F=0.09 corresponds to $F_{0.1;}$ F=0.20 corresponds to F_{max}; F=0.3 corresponds to, as we consider it, a marginal rate of fishing mortality at which stock abundance and biomass notably decrease; and F=0.55 corresponds to excessively high exploitation.

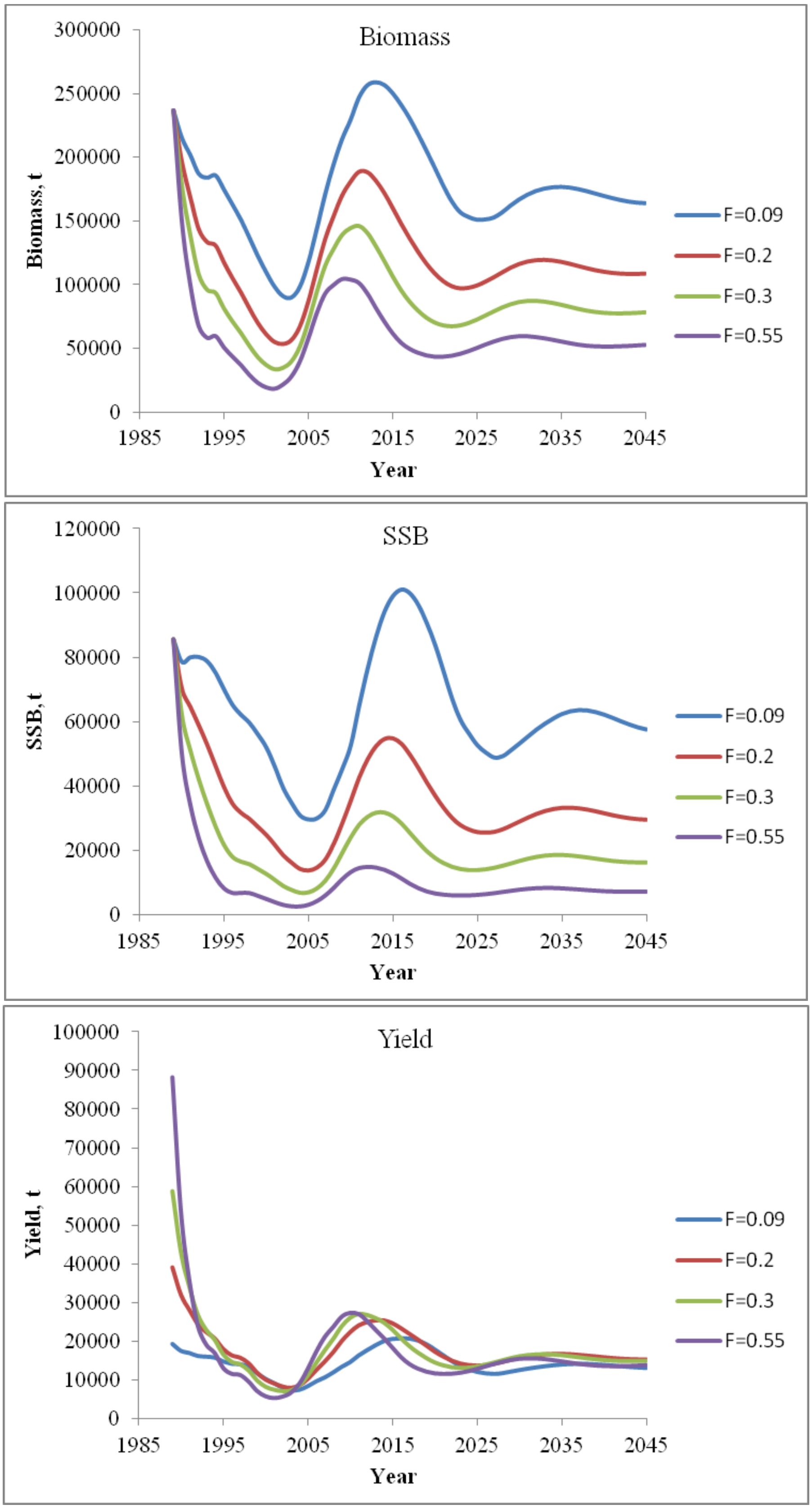


Fig. 6 Dynamics of total and spawning biomasses and yield for 1989-2045 when optimizing fishing by constant fishing mortality at actual (1989-2014) and average long-term recruitment for the forecasted period (2015-2045)

CONCLUSION

Analysis of yield per recruitment dependency as a function of fishing mortality for different exploitation periods of redfish stock on the Flemish Cap Bank, proved that estimations of biological references $F_{0.1}$ and F_{max} are stable and that there is an opportunity to use them while improving fishing. As of the calculations done, in any period of actual fishing going on at fishing mortality F that was higher than

F_{max}, redfish biomass would decrease. High fishing mortality in 1989-2001 caused an abrupt decrease in redfish biomass. Redfish fishing at F of 0.14-0.18 throughout all periods was a stabilizing redfish stock, and maintaining fishing mortality at 0.08-0.12 (close to $F_{0.1}$) in 2004-2010 provided stock recovery. It seems probable that the best redfish catch level should be fixed at $F_{0.1}$ to F_{max} to provide its maximum possible yield and the stock to be sustainable; and that these references may be considered as candidates for fishing mortality values while regulating redfish fishing on the Flemish Cap Bank and estimating TAC.

Fishing optimization under the criterion of maintaining constant spawning biomass at a certain level proved that the criterion was practically reasonable. In the period of 1989-2014 such regulation could allow us to obtain the average annual yield higher than actual yield at any of the constant SSB values of 20,000 – 50,000 tons. In our opinion, it is preferable to effect fishing that would maintain spawning biomass (SSB) at a level higher than the average long-term value (40,000 tons).

Fishing optimization under the criterion of maintaining constant fishing mortality showed great dependence of the results on the stock recruitment size. However, maximum average annual yield varies insignificantly from 18,000 to 20,000 tons at both actual values and recruitment depending on spawning stock value by the Ricker's equation. Fishing mortality value of about 0.2 provides maximum yield. Fishing at F higher than 0.3 results in an abrupt decrease in the average annual yield, fishing and spawning biomasses.

The forecasts of dynamics for redfish stock and the yield for the following 30 years (2015-2045) proves that with maintaining constant spawning biomass at 40,000 tons or constant fishing mortality at 0.2 with average long-term recruitment values, fishing stock would amount to 150,000 tons and average annual yield may be 16,500 tons. This turns out to be considerably higher than the yield of 7,000 tons currently advised by SC NAFO.

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