SEVENTH FRAMEWORK PROGRAMME THEME 7 Environment

Collaborative project (Large-scale Integrating Project)

Project no: 246 933

Project Acronym: EURO-BASIN

Project title: European Basin-scale Analysis, Synthesis and Integration

# Deliverable 7.4 Projected future changes in maximum catch potential of key fish populations

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Due date of deliverable: Dec 2012
Actual submission date: Dec 2012
Organisation name of the lead contractor of this deliverable: UEA

Start date of project: 31.12.2010    Duration: 48 months
Project Coordinator: Michael St John, DTU Aqua

Project co-funded by the European Commission within the Seventh Framework Programme, Theme 6 Environment

| Dissemination Level | | |
|---|---|---|
| PU | Public | |
| PP | Restricted to other programme participants (including the Commission) | X |
| RE | Restricted to a group specified by the consortium (including the Commission) | |
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**Deliverable 7.4 Projected future changes in maximum catch potential of key fish populations**
is a contribution to

**Task 7.2 Predict the distribution and production of key fish stocks based on climate change projections**

Responsible: Jose Fernandes
Start month 1, end month 24

**Executive Summary:** Brief summary of deliverable.
This report summarizes all the outcomes from task 7.2. It corresponds to the deliverable D7.4 which consist on projections of distribution of maximum catch change for 50 species in the North Atlantic until 2050. The modeling has relied on predictions generated in packages 5 and 6.The results presented in this report use two models NSI-DBEM and SS-DBEM model. SS-DBEM is an extension of NSI-DBEM to incorporate trophic interactions and it is described in the deliverable D7.5. In deliverable D7.5 the SS-DBEM model is described and its projections are compared with the model without interactions NSI-DBEM and with time-series from ICES stock assessments.

This report presents some time-series extracted from the projected distribution of fish species. The raw data and the extracted time-series are available from the PML web site (see below). The climatic data used for the simulations are from Medusa model developed at NOC, since these are the only simulations produced inside EURO-BASIN that provide forecasts beyond 2004. The raw output of the model is provided (relative abundance and biomass). However, in order to facilitate its use by task 7.3 and other packages (WP5 can benefit from projections of prey biomass to test the models being developed), a procedure to convert into absolute values is provided (Appendix 1). Using this procedure time series of biomass and maximum catch have been produced for the years up to 2059 for 56 species in the North Atlantic. However, users are encouraged to revise and propose their own procedures to perform the conversion from relative to absolute values based on their expertise about specific species.

**Relevance to the project & potential policy impact:**
This report presents the results of scenarios based on climatic projections from the Medusa model. The parameters have mostly been fixed based on current data from assessments and different climatic models (GFDL, ERSEM and MEDUSA). While the work is innovative, additional work will still be required before the results might reasonably be used to inform policy. However, we have made a first step towards large-scale and long term models that consider climate change and species interactions. These models have the potential of providing realistic medium and long term scenarios of marine resource availability.

This project output is a first step towards long term predictions that can give an idea of future trends based on current knowledge and models. This work has the potential of becoming state-of-art since, to the best of our knowledge, it is the first work that produces projections based on integrating a wide range of models (species based, size spectrum and climatic models) for a high number of species that represents 80-90% of the catches in the North Atlantic.

The results of the scenarios have been compared with data for the years and species when this is possible, to help assess the reliability of predictions. However, the comparisons have to be interpreted with care. In particular, to be able to compare the models output with empirical time-series from ICES assessments, the assessed fishing mortality (F) has been incorporated. However, F is assessed for a limited number of species and for different time-periods. Therefore, certain assumptions must be made in cases when there is no assessed F. The approach has been to use the average F for species and years when assessments are available. When there is no assessment, species have been divided in two groups: bottom-dwelling (demersal) species and species in the water-column (pelagic), and the average F for assessed species of each group have been used.

**Report:**

Introduction

Four sets of projections have been produced. These combine projections with and without trophic interactions (competition or C) and projections with and without fishing mortality (F). These projections are labeled as follows.

- NoC_NoFM: This projection is without competition and without fishing mortality.
- NoC_FM: This projection is without competition, but incorporating fishing mortality.
- C_NoFM: This projection incorporates competition, but without fishing mortality.
- C_FM: This projection incorporates both, competition and fishing mortality.

All the derived time series related have been smoothed using 3 years moving average.

A procedure for converting relative biomass to absolute biomass is described in Appendix 1, along with a procedure to calculate changes in potential catch. The procedure needs an observed reference biomass or maximum catch. Therefore it can be applied only to the projection with competition and fishing mortality. The other projections can be compared with this one, but only in terms of inter-annual variability and trend, as here is no straight forward method of knowing a reference biomass of a fish species if there is no competition. Similarly, in the case of the projection without fishing mortality, there is no straight forward method to calculate a reference biomass without fishing mortality. This could be developed in future if it were possible to make an evaluation of the unexploited biomass.

Another issue to consider is that the projections are for full species distribution and not for stocks within species. This is because the data about species life history needed to produce such projections were available at species level and not at the level of specific stocks. For this reason, two sets of time series are provided: 1) A the time series of total biomass and catch potential of each species in all the ICES areas; and, 2) a time series of biomass and catch potential in each of the ICES areas.

In following sections a few species have been selected to provide a comparison of biomass and future potential change in maximum catch for projections with and without species competition. Total projected maximum catch change in all the ICES areas, and area by area, are then presented. Finally, the instructions for downloading the data and a description of the data files are provided.

Atlantic herring biomass and maximum catch projections

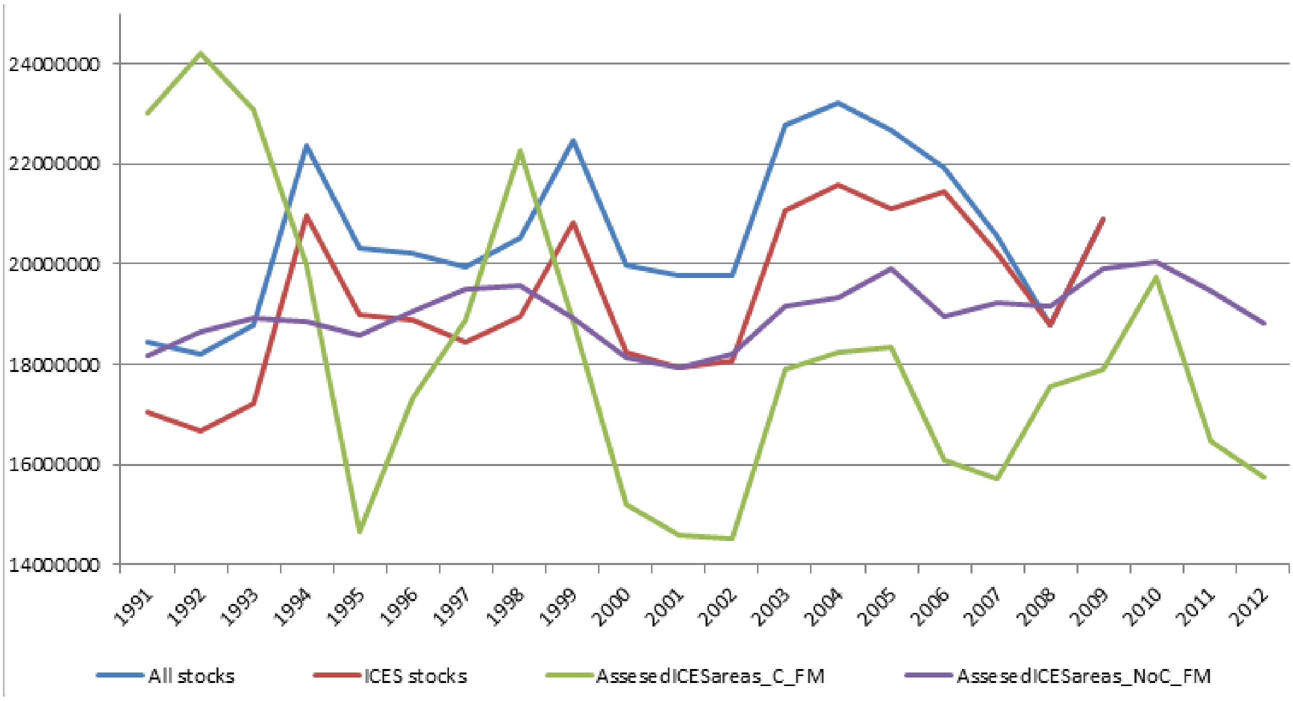


Fig. 1. Comparisons of predicted herring biomass with assessed biomass in ICES areas using Medusa forcing.

Estimates of the total stock biomass are not reliable before 1991 since there were no assessments for several of the stocks at that time. Simulated biomass shows a similar inter-annual variability and trend to the trend in the assessment data, but has a higher variance. .

The *all stocks* time-series include biomass of DFO stocks in FAO statistical area 27 (North Atlantic). ICES stocks include biomass of all the stocks assessed in ICES areas; extracted from RAM Legacy Stock Assessment Database (Ricard et al. 2011; http://ramlegacy.marinebiodiversity.ca/). The two time series labeled as *AssessedICESareas* time-series correspond with the two model projection of biomass considering only areas where there is ICES stock assessments. These also correspond to the two model projections with and without species interactions: *C* with competition and *NoC* without competition.

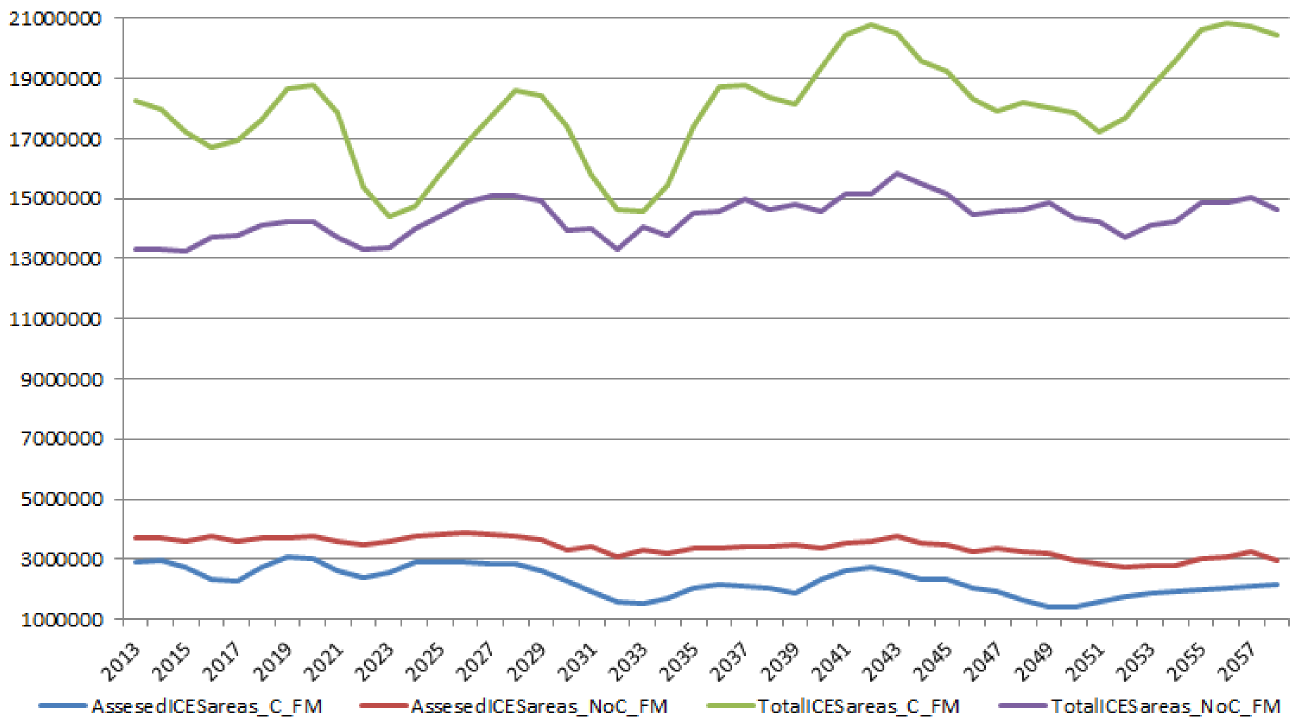


Fig. 2.Projection of maximum catch potential or herring using Medusa forcing. Projections with and without competition are shown.

Projected potential catch for herring shows similar behavior with and without species interactions. In general, the catch potential shows an increasing trend. However, the projected catch when interactions are not considered is lower than when they are considered in the areas with ICES assessments present (AssesedICESareas) but higher in the total set of ICES areas (TotalICESareas).

Atlantic mackerel biomass and maximum catch projections

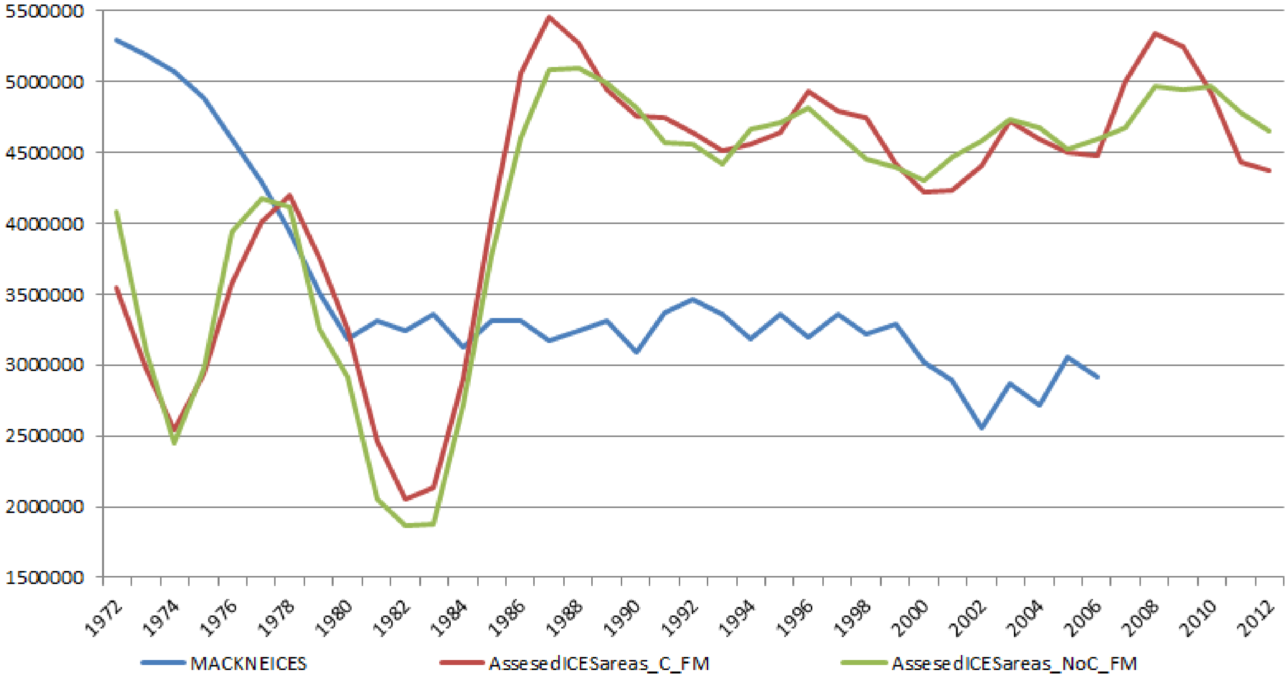


Fig. 3. Comparison of predicted Atlantic mackerel biomass with assessed biomass in ICES areas using Medusa forcing.

Using Medusa forcing the estimated biomass of Atlantic mackerel is usually greater than the estimates in ICES assessments (Fig 3). In addition, the difference in trends between assessment data and the predictions is considerable.

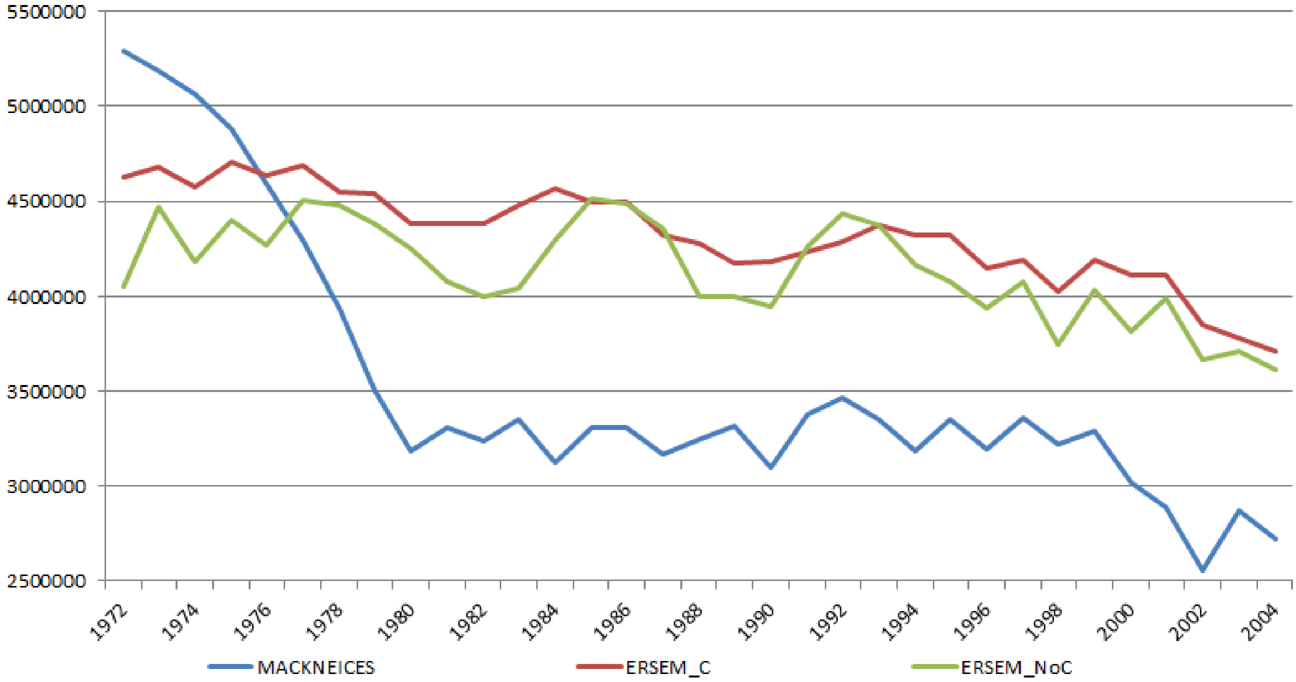


Fig. 4. Comparison of predicted Atlantic mackerel biomass with assessed biomass in ICES areas using ERSEM forcing.

However, using ERSEM forcing the decreasing trend observed in the ICES assessment can be observed also in the estimated biomass from DBEM models (Fig 4).

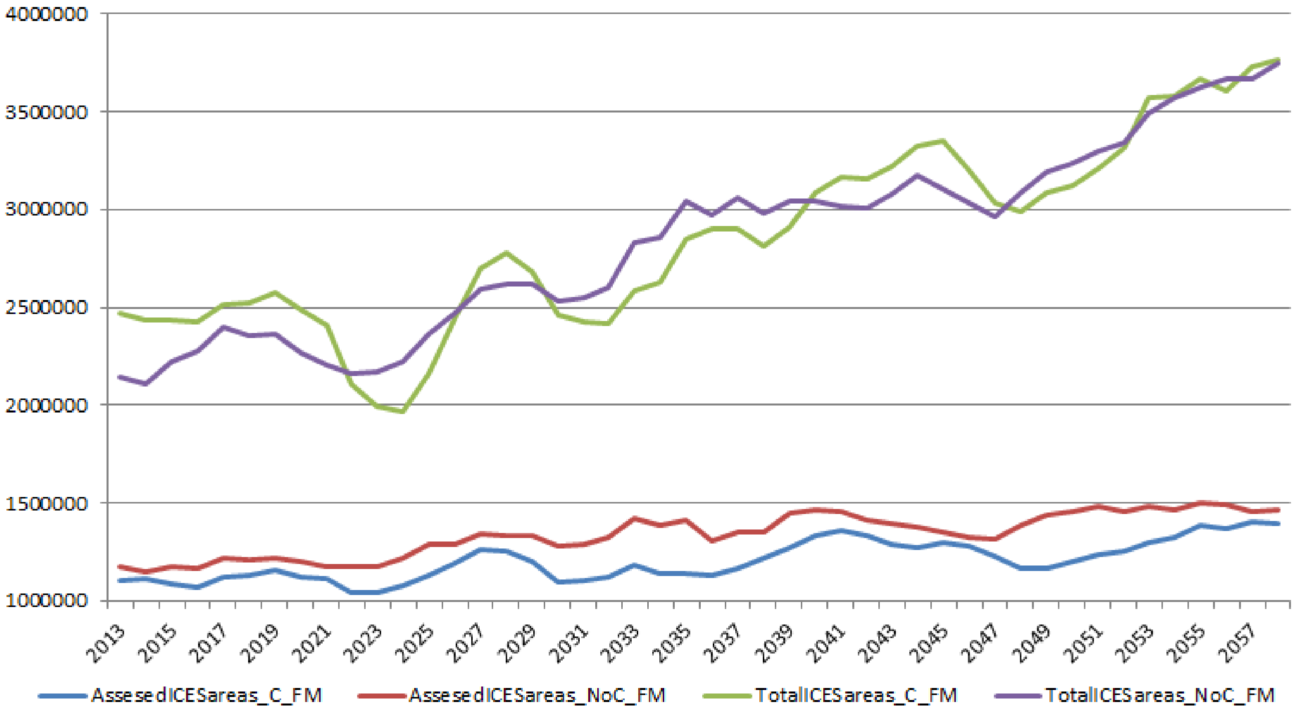


Fig. 5. Projection of maximum catch potential of Atlantic mackerel using Medusa forcing. Projections with and without competition are provided.

The catch potential of Atlantic mackerel is predicted to increase in areas with stock assessments (Fig 5). This increase seems to be enhanced when considering all the ICES areas. Models with and without species interactions have a similar behavior.

Albacore biomass and maximum catch projections

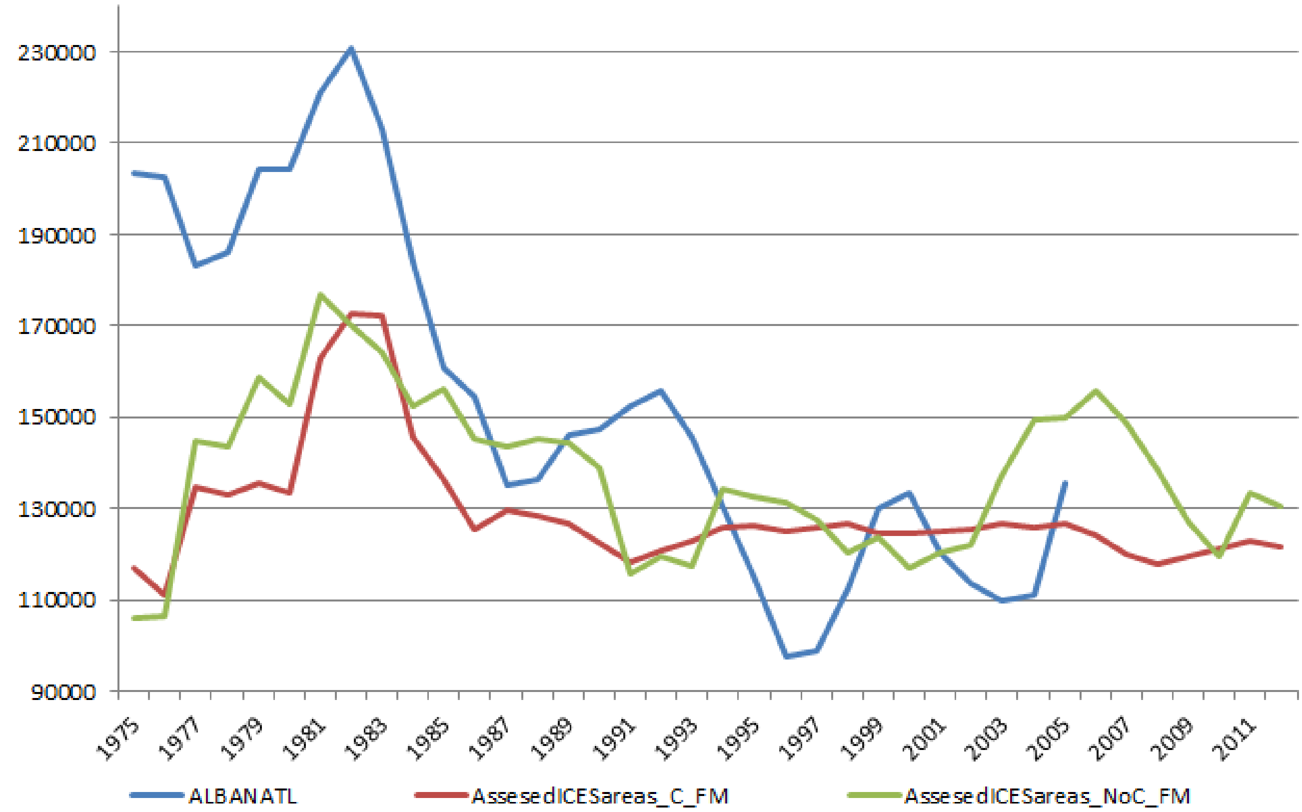


Fig. 6. Comparison of predicted albacore biomass with assessed biomass in ICES areas using Medusa forcing.

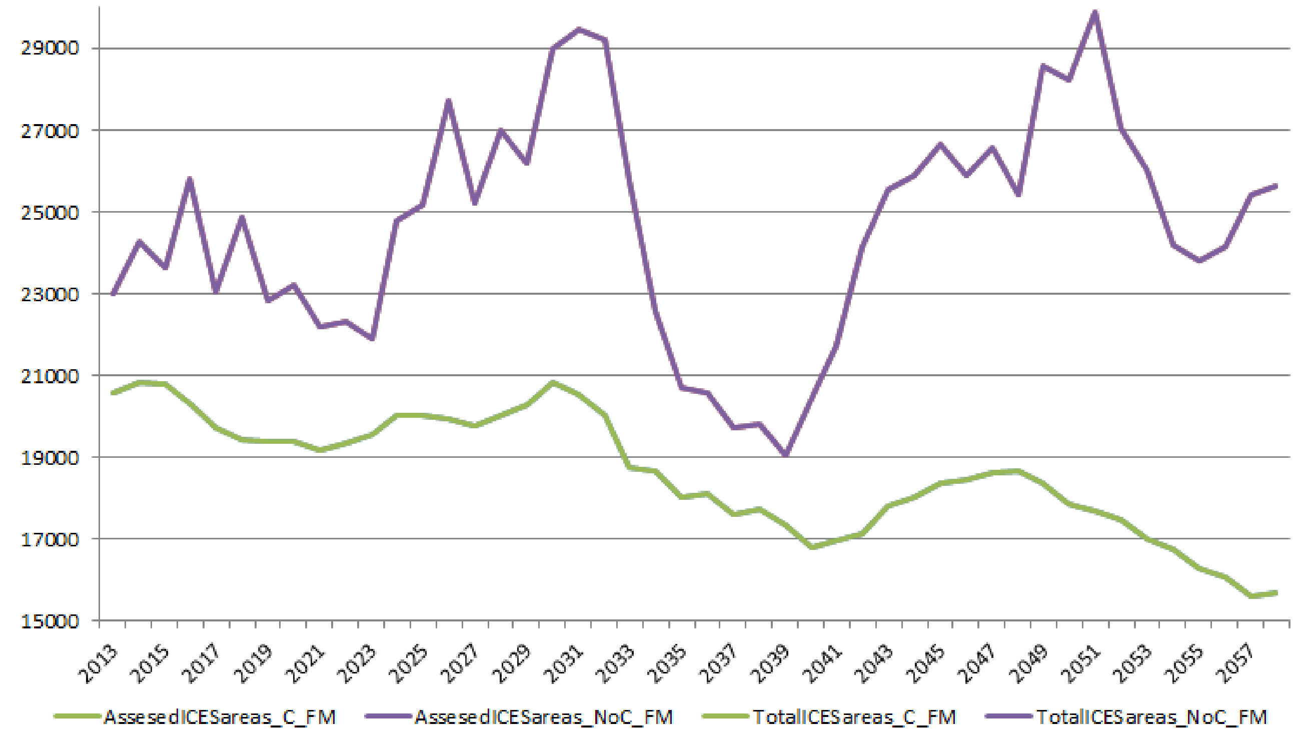


Fig. 7. Projection of maximum catch potential of albacore using Medusa forcing. Projections with and without competition are shown.

In the case of Albacore, the inclusion of species interactions affects the predicted trends. The simulation with competition predicts a decrease of potential catch (Fig. 7). The simulation without competition shows higher variability and a long term increase in catch, with a period of potential catch decrease around the period 2035-2040.

Atlantic horse mackerel biomass and maximum catch projections

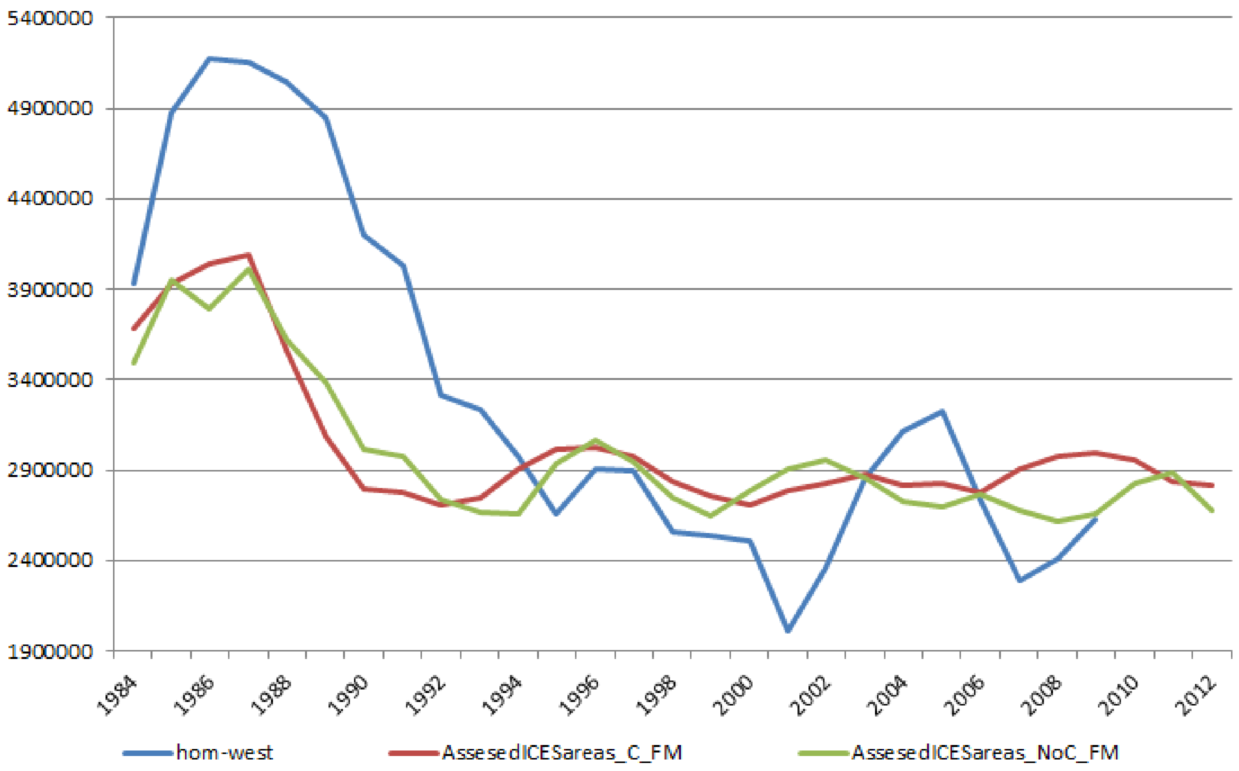


Fig. 8. Comparison of predicted Atlantic horse mackerel biomass with assessed biomass in ICES areas using Medusa forcing.

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Similar behavior between projections and assessments can be observed for Atlantic horse mackerel (Fig. 8).

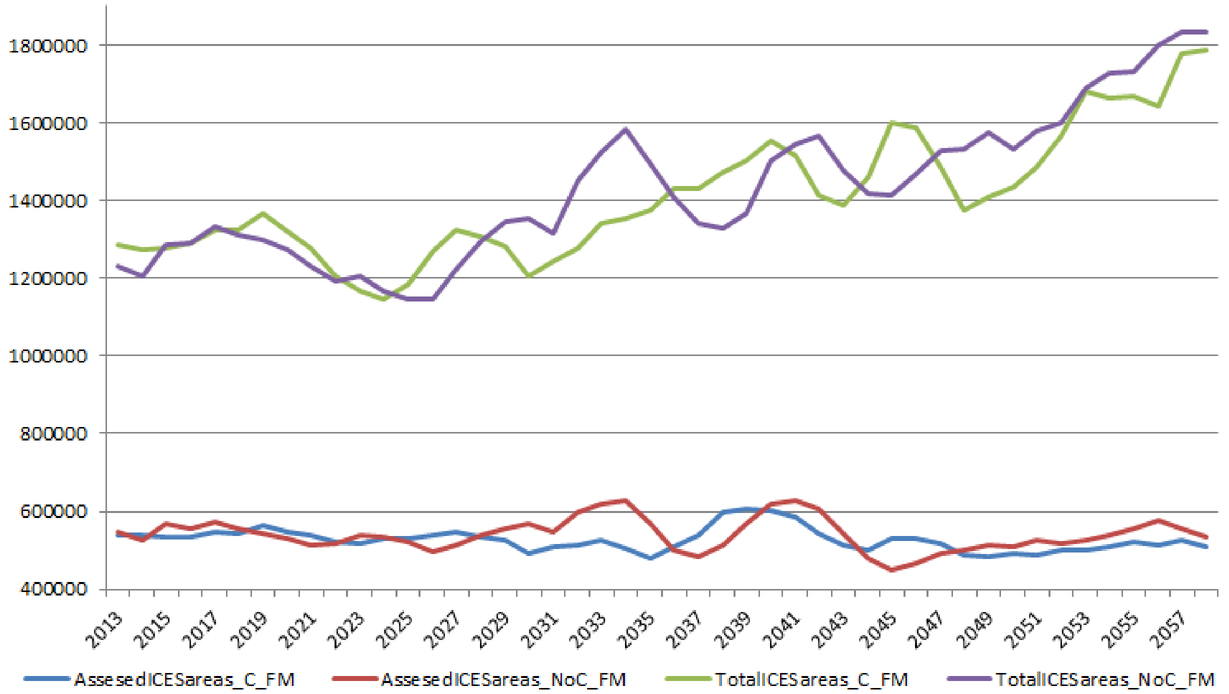


Fig. 9. Projection of maximum catch potential of Atlantic horse mackerel using Medusa forcing. Projections with and without competition are provided.

No trend can be observed in predicted maximum catch potential for Atlantic horse mackerel in assessed areas (Fig. 9). However, in all ICES areas, a significant long term increase is predicted by models with and without species interactions.

<u>Sardine biomass and maximum catch projections</u>

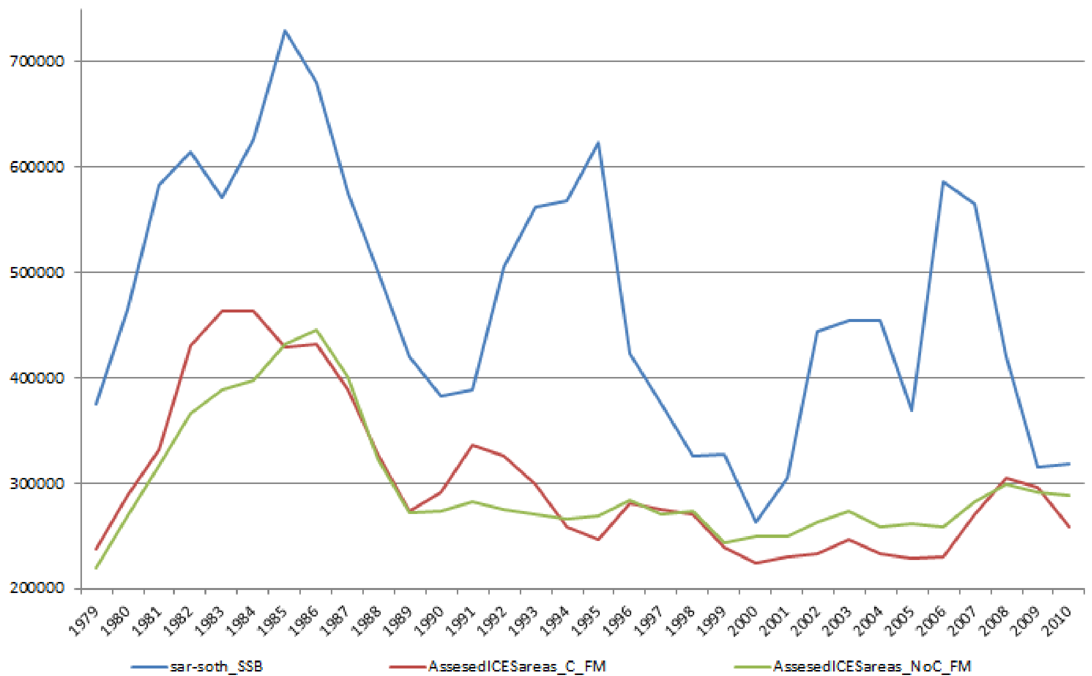


Fig. 10. Comparison of predicted sardine spawning stock biomass (SSB) with assessed stock spawning biomass in ICES areas using Medusa forcing.

There are no total biomass assessments for sardine, therefore the assessed SSB has been chosen as reference. The model reproduces some of the assessed variability (Fig. 10). However, the values are systematically lower. There is the need of getting good reference total biomass reference and improving the relative-absolute conversion procedure for this species.

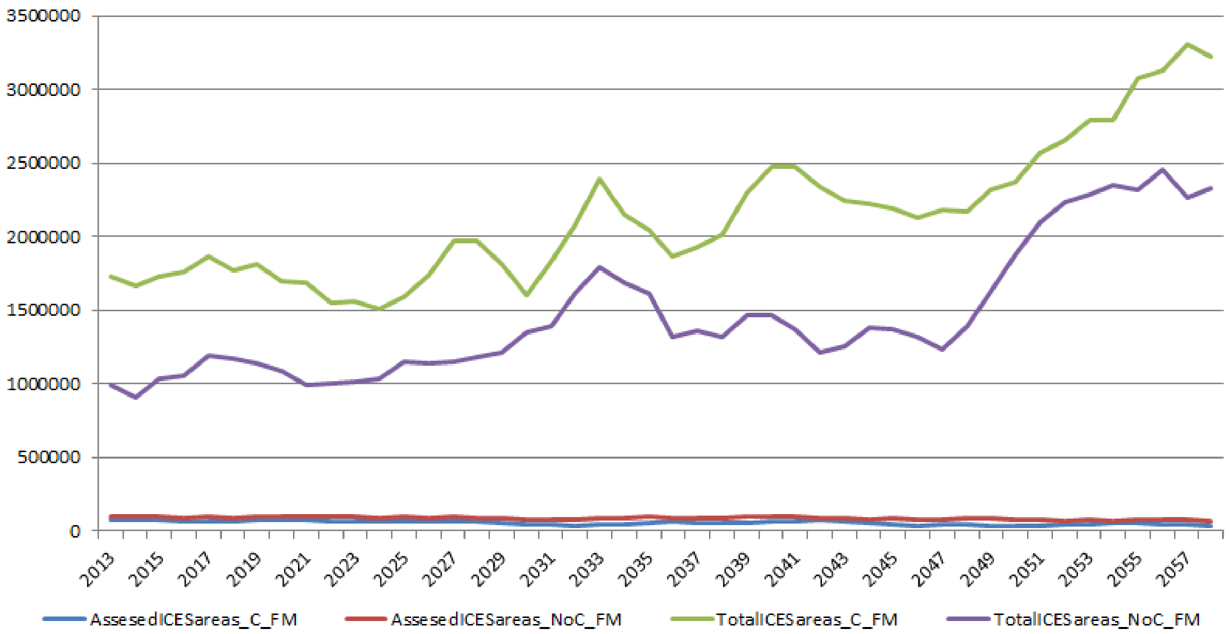


Fig. 11. Projection of maximum catch potential of sardine using Medusa forcing. Projections with and without competition are provided.

As with the Atlantic horse mackerel, sardine shows no trend in the assessed ICES areas (Fig. 11). However, it shows an increasing trend when considering all the ICES areas.

Blue whiting biomass and maximum catch projections

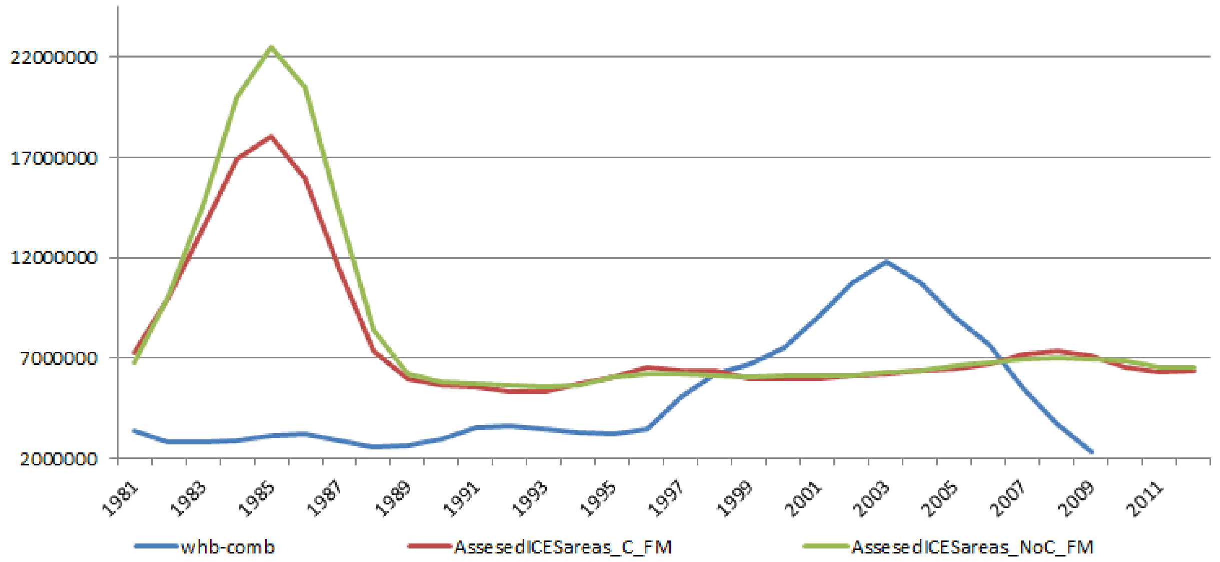


Fig. 12. Comparison of predicted blue whiting biomass using Medusa forcing in comparison with the ICES assessment.

The models does not reproduce the inter-annual variability or trend for blue whiting (Fig. 2). Further work is needed to understand the reasons for this discrepancy.

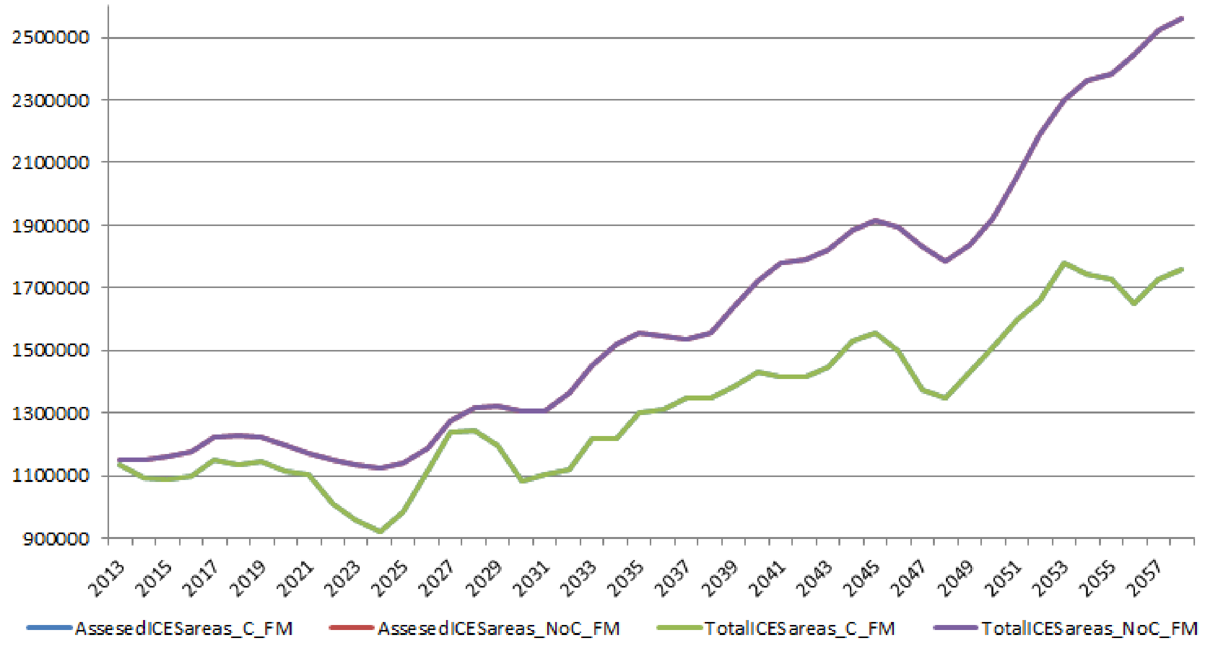


Fig. 13. Projection of maximum catch potential of blue whiting using Medusa forcing. Projections with and without competition are provided.

The maximum catch of this species is predicted to increase on the long term. However, it also predicts a medium term decrease. The model with competition predicts a higher decrease and a more moderate increase than the model without competition.

Maximum total catch projection

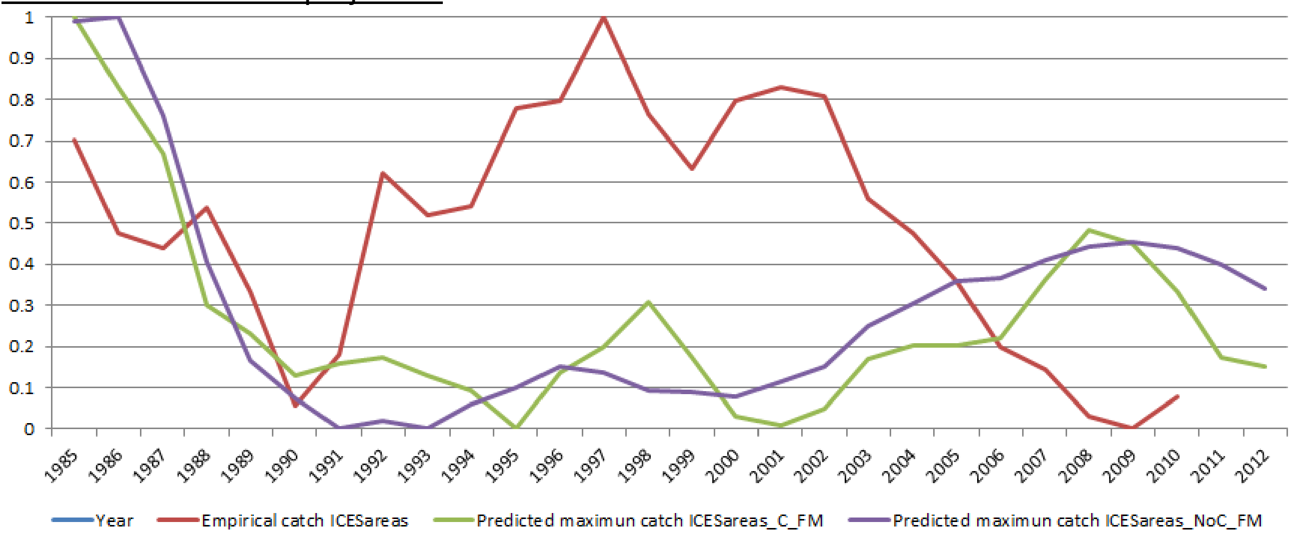


Fig. 14: Comparison between empirical catch and predicted maximum catch using the Medusa earth system forcing. Values normalized between 0 and 1 to facilitate the comparison.

The predicted maximum catch has been calculated using all 56 modeled species (Table I) in the ICES areas and it has been smoothed by calculating the 3 years moving average (Fig. 14). The empirical catch data is the result of aggregating all the catches reported in ICES areas as collected in the Eurostat/ICES database on catch statistics - ICES 2011, Copenhagen (http://www.ices.dk).

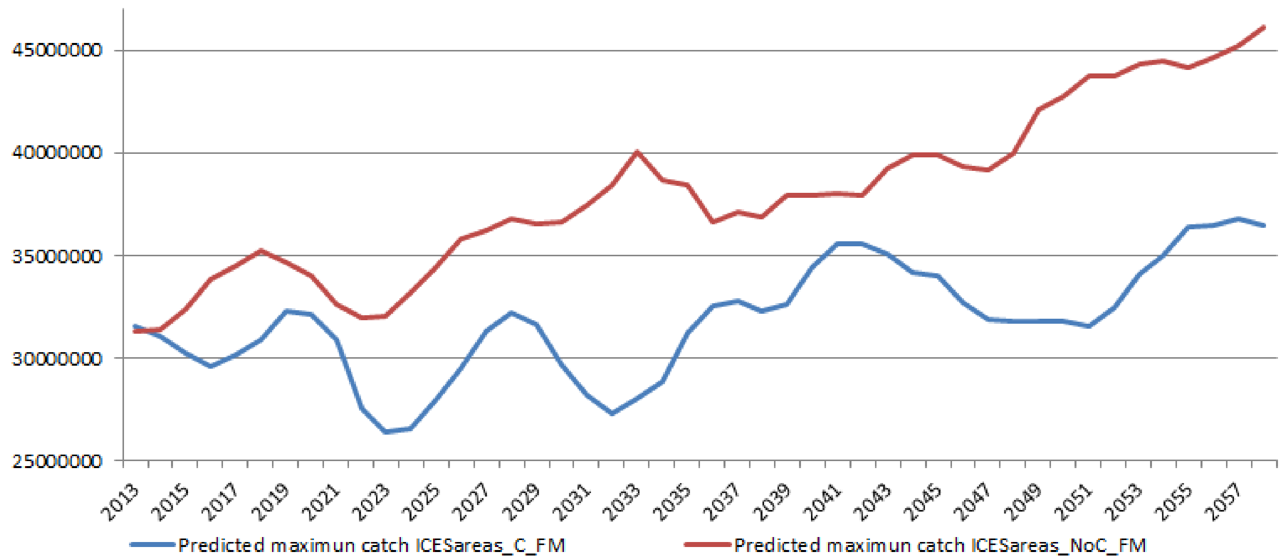


Fig. 15. The predicted maximum catch until 2059 is presented. The maximum catch projected to the future reported is based on the simulation with competition and without fishing mortality since it is the simulation where the total biomass that can be supported is limited by the estimated primary production.

Both models (with and without species interactions) predict high fluctuations in maximum catch in the medium term (Fig. 15). Actually, projections with competition show a decrease of catch next years, followed by a recovery afterwards; whereas projections without competition predicts directly and increase of potential catch next years. However, predictions without competition show an increasing trend that would start 1-2 decades earlier than predictions considering species interactions.

Maximum total catch projection by each ICES area

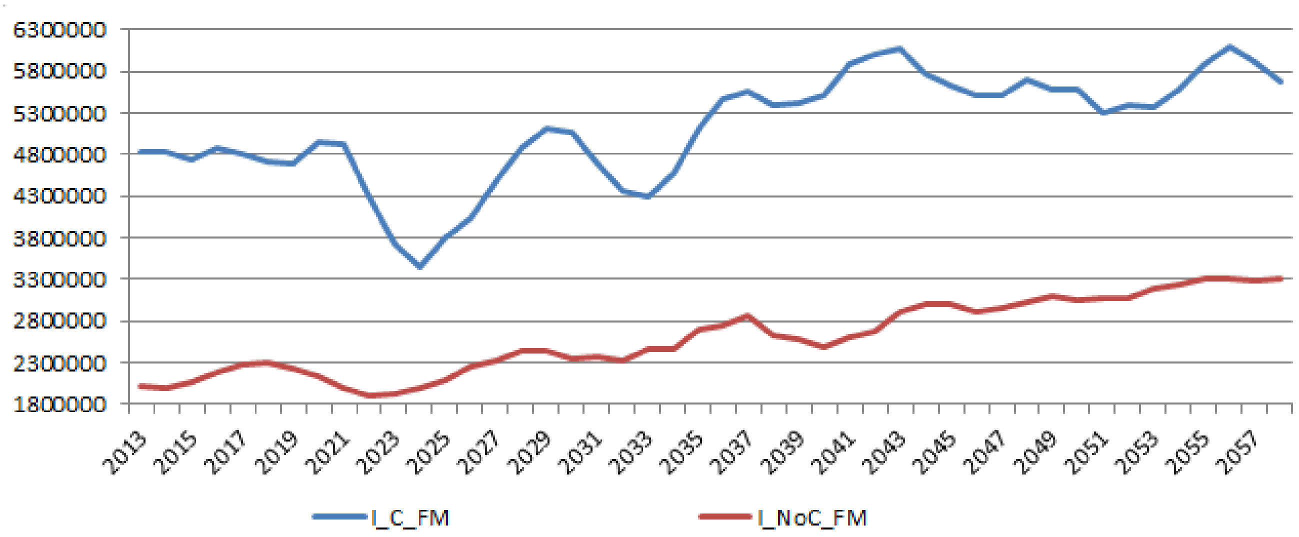


Fig. 16. Projected maximum catch change in ICES area I.

ICES area I is one of the areas where projections with competition show a higher maximum catch potential than projections without competition (Fig. 16). Both projections shows similar increasing trend on the long term. However, in the short- medium term, there is no apparent trend.

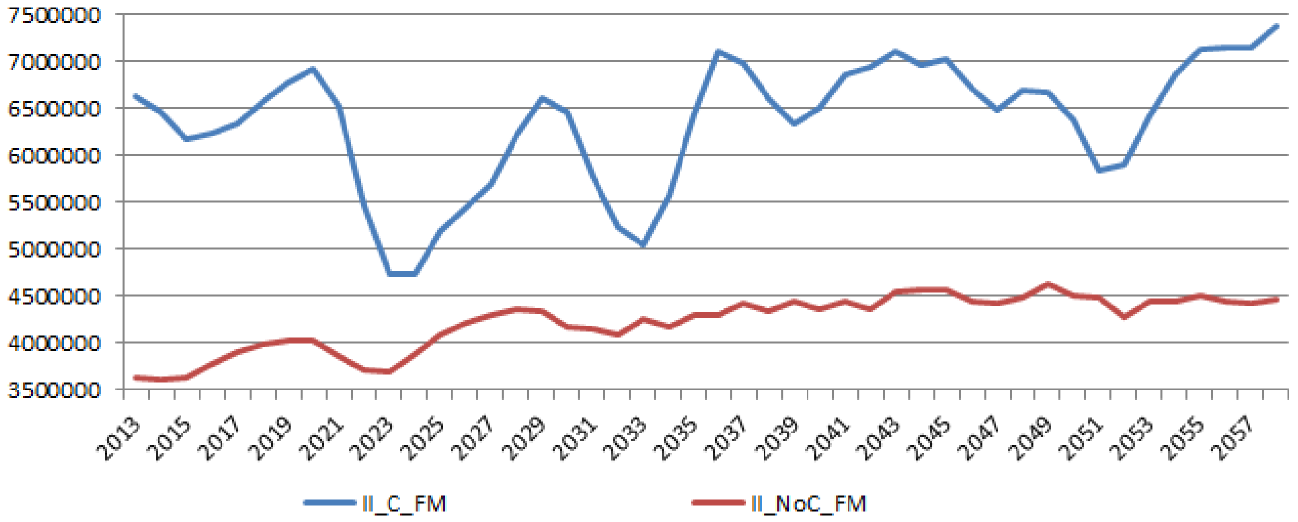


Fig. 17. Projected maximum catch change in ICES area II.

ICES area II also shows higher maximum catch potential when considering competition (Fig. 17). A slight increase in catch potential was predicted in the long term. However, high inter decadal variability can be observed with dramatic ups and downs, particularly in the projections with competition.

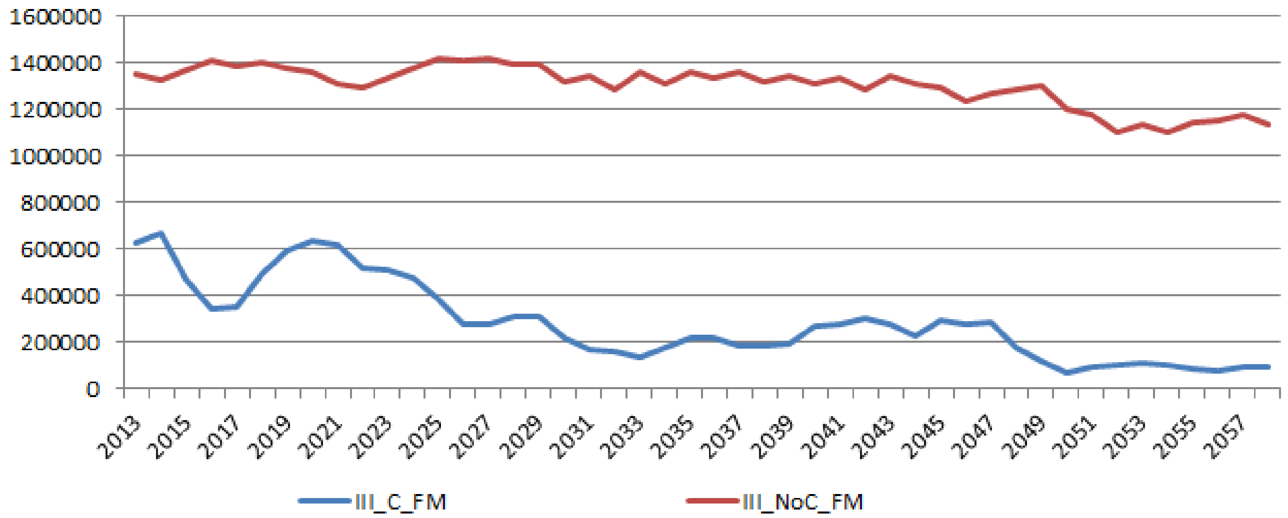


Fig. 18. Projected maximum catch change in ICES area III.

In ICES area III the predicted maximum catch is higher in the projections without species interactions (Fig. 18). Both projections show a decreasing trend in the long term. The projection with competition shows more dramatic ups and downs in the short and medium term.

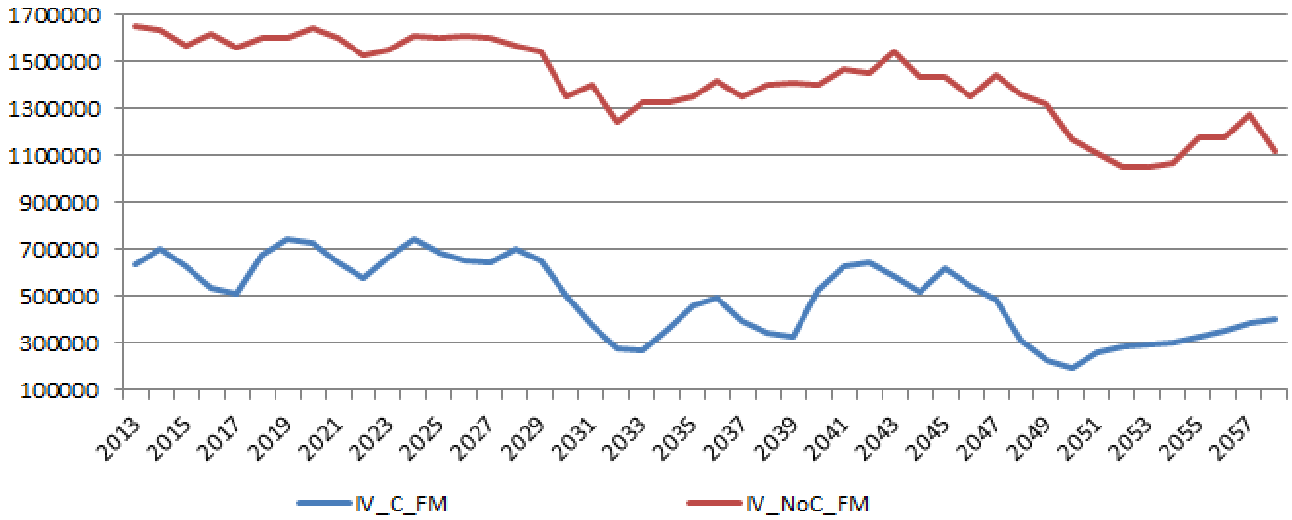


Fig. 19. Projected maximum catch change in ICES area IV.

ICES area IV shows similar behavior (Fig. 19) to the previous ICES area (III).

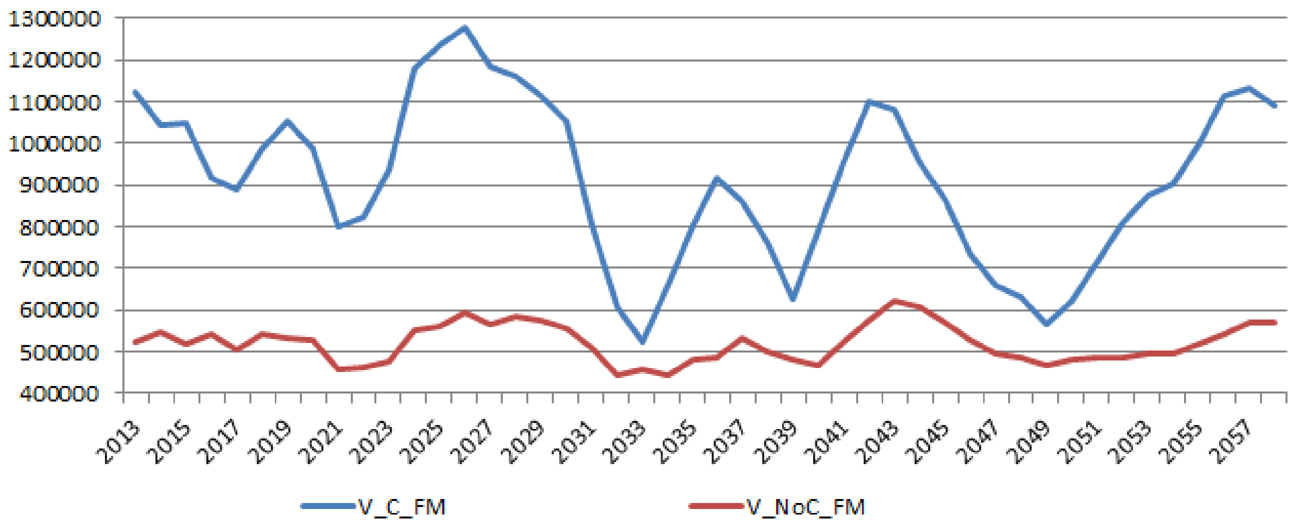


Fig. 20. Projected maximum catch change in ICES area V.

ICES area V is another of the areas where the projections with competition are higher than those without (Fig. 20). Both show similar trends, however, the variability is enhanced in the projections with competition.

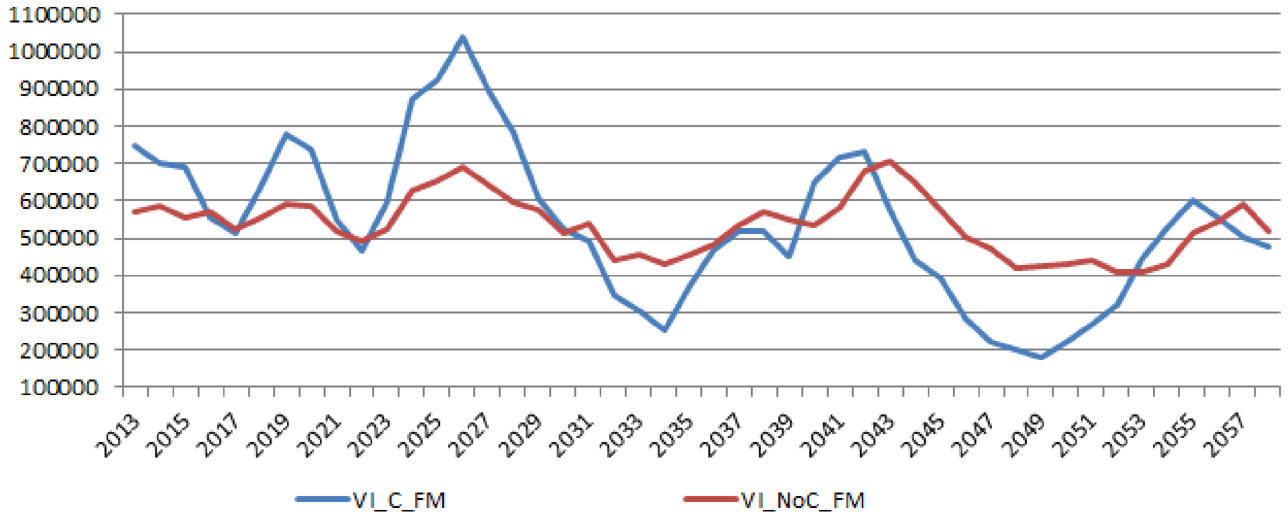


Fig. 21. Projected maximum catch change in ICES area VI.

ICES area VI shows no specific trend in either projection (Fig. 21). Once more the projections with competition show an enhanced variability in comparison with the projections without competition.

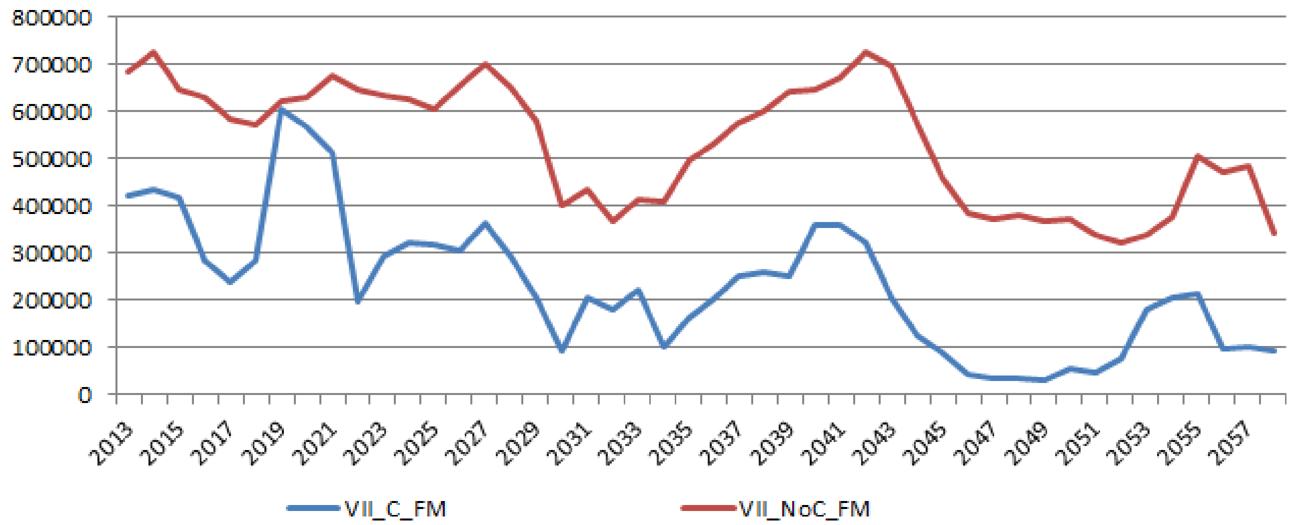


Fig. 22. Projected maximum catch change in ICES area VII.

In ICES area VII the projection without competition shows higher values (Fig. 22). However, both show similar decreasing trend and inter-annual variability.

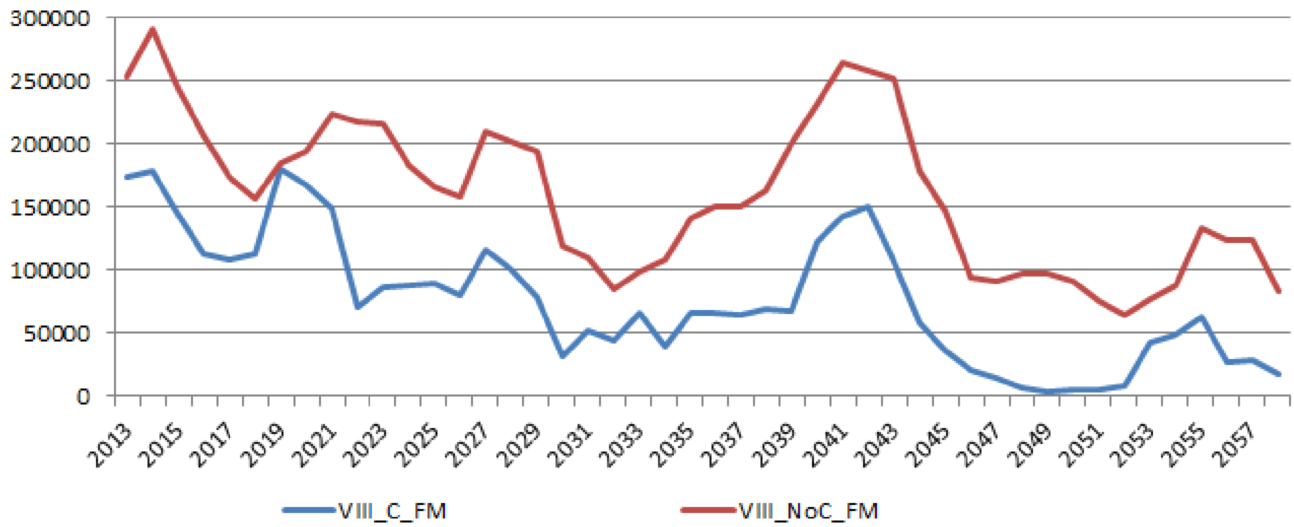


Fig. 23. Projected maximum catch change in ICES area VIII.

ICES area VIII shows similar behavior (Fig. 23) to the previous area (VII). The projection without competition shows higher values. However, both show similar decreasing trend and inter-annual variability.

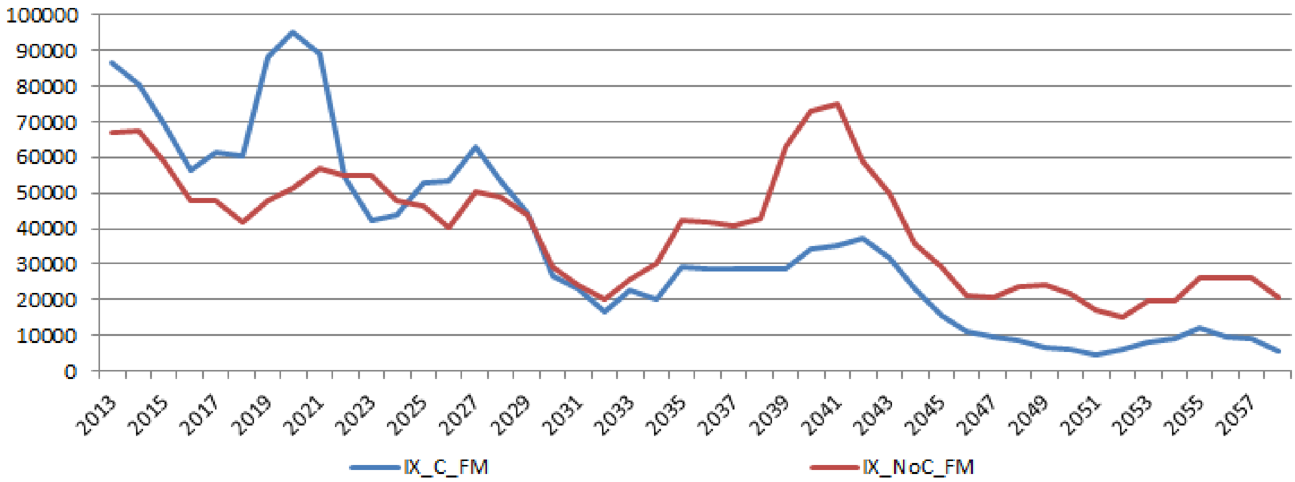


Fig. 24. Projected maximum catch change in ICES area IX.

ICES area IX shows similar behavior (Fig. 24) to the previous areas (VII and VIII). The projection without competition shows higher values. However, both show similar decreasing trend and inter-annual variability.

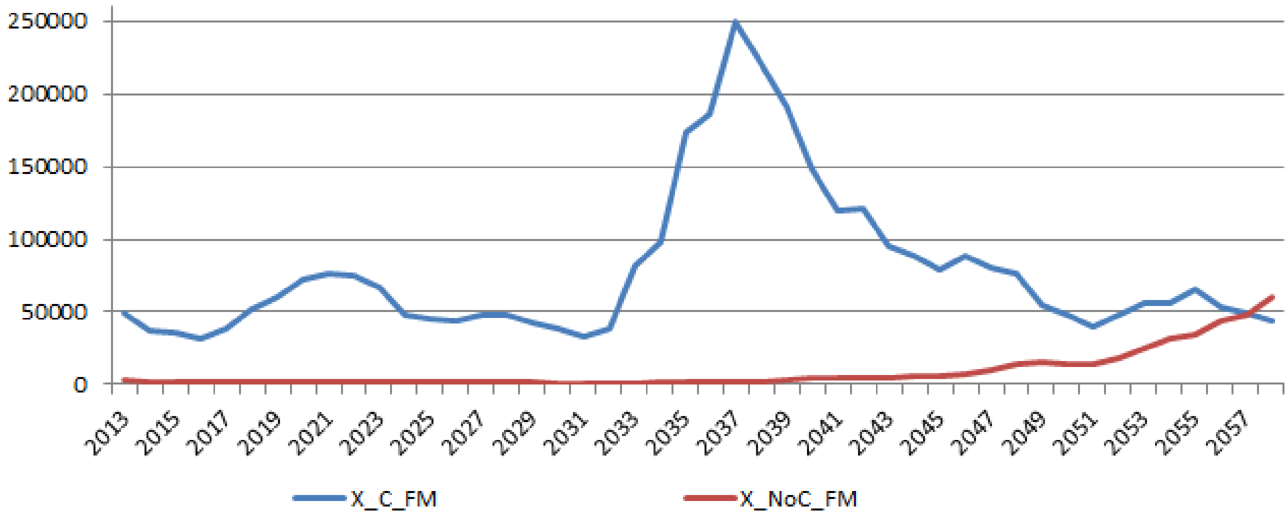


Fig. 25. Projected maximum catch change in ICES area X.

Projections in ICES area X show different behaviors with and without competition (Fig. 25). This is one of the few areas where maximum catch is predicted to be higher with competition. There are also differences in variability with a high peak in the projection with competition which is not observed with no competition. In the long term there are also signs of an increasing trend in the projection without competition which is not present when competition is included.

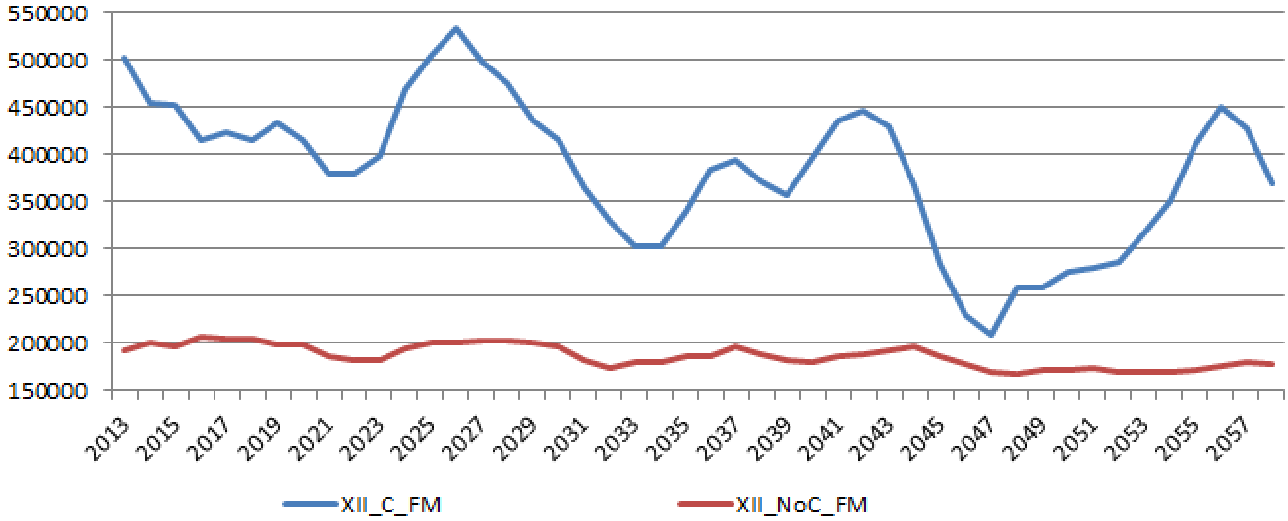


Fig. 26. Projected maximum catch change in ICES area XII.

Projections in ICES area XII also show higher values with competition and with higher variability. There is a slight decreasing trend.

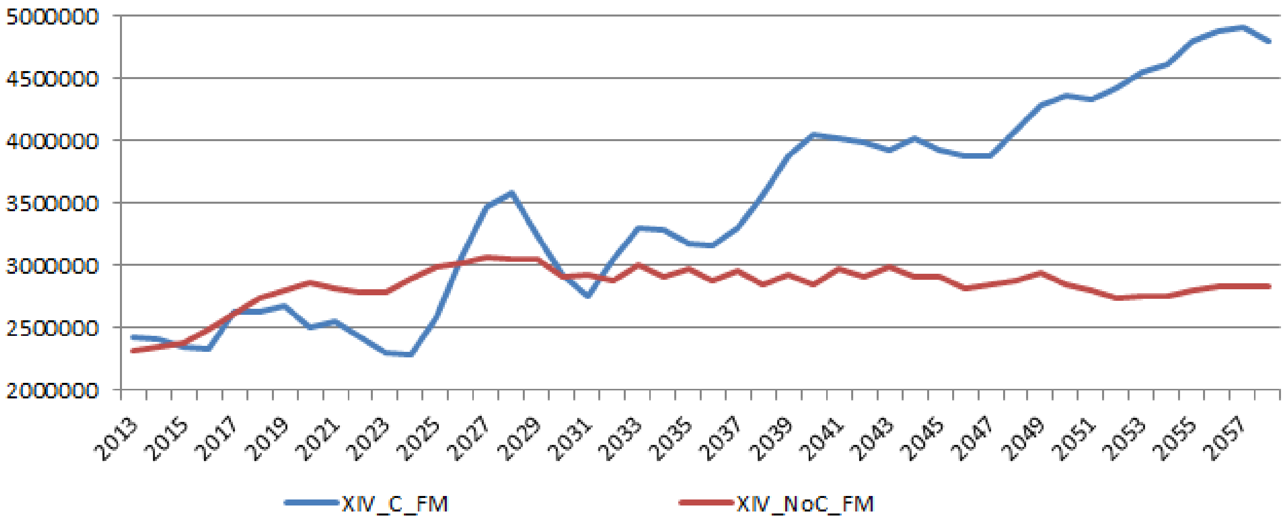


Fig. 27. Projected maximum catch change in ICES area XIV.

In ICES area XIV an increasing trend is observed in projections with competition. Projections without competition shows similar trend in the short term, but maximum catch stabilizes in the medium and long term.

**Access to Data and Models (where relevant):**

State location of datasets/models/simulations, and means of access

The relative abundance, biomass and potential catch projections are available in the following ftp server:
ftp.rsg.pml.ac.uk/SS-DBEM
user: basin
password: ersem

The main deliverable files are:

- MEDUSA_FM_C.rar: Relative biomass and abundance distribution with fishing mortality and competition (species interactions).
- MEDUSA_FM_NoC.rar: Relative biomass and abundance distribution with fishing mortality and without competition (species interactions).
- MEDUSA_NoFM_C.rar: Relative biomass and abundance distribution without fishing mortality, but with competition (species interactions).
- MEDUSA_NoFM_NoC.rar: Relative biomass and abundance distribution without fishing mortality and without competition (species interactions).

Each compressed file has file names of the form “601365Bio1983.txt” where the 6 first digits denote the fish species code (*searroundus* database format), “Bio” for biomass distribution or “Abd” for abundance distribution and four digits for the year.

Data aggregated, extracted and converted from relative to absolute values in order to build the time series used for above graphs are in the following files which contain biomass or catch potential for each species in each area and year:

- Biomass_ByICESareas_MEDUSA_FM_C.csv.
- Biomass_ByICESareas_MEDUSA_FM_NoC.csv.
- Biomass_ByICESareas_MEDUSA_NoFM_C.csv.
- Biomass_ByICESareas_MEDUSA_NoFM_NoC.csv.
- CathPotential_ByICESareas_MEDUSA_FM_C.csv.
- CathPotential_ByICESareas_MEDUSA_FM_NoC.csv.
- CathPotential_ByICESareas_MEDUSA_NoFM_C.csv.
- CathPotential_Bio_ByICESareas_MEDUSA_NoFM_NoC.csv.

Table 1. List of modelled fish species. Species with biomass assessment are marked in the last column. In the last column, the list of stocks that have been aggregated for the species from RAM database (STOCKID) are listed in capital letters. For some stocks not recorded in the RAM database, ICES Stock Summary Database was used (listed with no-capital letters).

| Common name | Scientific name | Type | Stocks |
|---|---|---|---|
| Albacore | *Thunnus alalunga* | Pelagic | ALBANATL. |
| Angler | *Lophius piscatorius* | Demersal | |
| Atlantic cod | *Gadus morhua* | Demersal | CODNEAR, CODBA2224, CODBA2532, CODVIa, CODIS, CODICE, CODNS and CODKAT. |
| Atlantic herring | *Clupea harengus* | Pelagic | HERRIsum, HERRNS, HERRVIa, ERRVIaVIIbc, HERR2224IIIa, HERR2532, HERR30, HERRRIGA, HERRNIRS, HERRNWATLC, HERR4VWX, HERR4RFA, HERR4RSP, HERR4TFA, HERR4TSP, HERR31, her-vian, her-noss and her-vasu |
| Atlantic horse mackerel | *Trachurus trachurus* | Pelagic | hom-west. |
| Atlantic mackerel | *Scomber scombrus* | Pelagic | MACKNEICES. |
| Atlantic salmon | *Salmon salar* | Demersal | |
| Bigeye tuna | *Thunnus obesus* | Pelagic | |
| Black seabream | *Spondyliosoma cantharus* | Demersal | |
| Black-bellied angler | *Lophius budegassa* | Demersal | |
| Blue ling | *Molva dypterygia* | Demersal | |
| Blue whiting | *Micromesistius poutassou* | Pelagic | whb-comb. |
| Brill | *Scophthalmus rhombus* | Demersal | |
| Capelin | *Mallotus villosus* | Pelagic | CAPEICE and CAPENOR. |
| Chub mackerel | *Scomber japonicus* | Pelagic | |
| Common cuttlefish | *Sepia officinalis* | Pelagic | |
| Common octopus | *Octopus vulgaris* | Demersal | |
| Common sole | *Solea solea* | Demersal | SOLENS, SOLEVIId, SOLEIS, SOLEIIIa, SOLEVIIe, SOLECS, and SOLEVIII. |
| Dab | *Limanda limanda* | Demersal | |
| Deepwater redfish | *Sebastes mentella* | Pelagic | |
| European anchovy | *Engraulis encrasicolus* | Pelagic | ANCHOBAYB. |

| | | | |
|---|---|---|---|
| European hake | *Merluccius merluccius* | Demersal | HAKESOTH and HAKENRTN. |
| European pilchard | *Sardina pilchardus* | Pelagic | sar-soth. |
| European plaice | *Pleuronectes platessus* | Demersal | PLAIC7d, PLAICIIIa, PLAICNS, PLAICIS, PLAICECHW and PLAICCELT. |
| European seabass | *Dicentrarchus labrax* | Demersal | |
| European sprat | *Sprattus sprattus* | Pelagic | SPRATNS. |
| Flounder | *Platichthys flesus* | Demersal | |
| Fourspotted megrim | *Lepidorhombus boscii* | Demersal | mgb-8c9a. |
| Greater argentine | *Argentina silus* | Demersal | |
| Greenland halibut | *Reinhardtius hippoglossoides* | Demersal | GHALNEAR, GHALBSAI and GHAL23KLMNO. |
| Haddock | *Melanogrammus aeglefinus* | Demersal | HAD4X5Y, HAD5Y, HAD5Zejm, HADICE, HADNEAR, HADFAPL, HADNS-IIIa, HADVIa, HADVIIb-k, HADROCK and HADGB. |
| John dory | *Zeus faber* | Demersal | |
| Lemon sole | *Microstomus kitt* | Demersal | |
| Ling | *Molva molva* | Demersal | |
| Lumpsucker | *Cyclopterus lumpus* | Demersal | |
| Megrim | *Lepidorhombus whiffiagonis* | Demersal | mgw-8c9a. |
| Northern bluefin tuna | *Thunnus thynnus* | Pelagic | ATBTUNAEATL and ATBTUNAWATL. |
| Norway lobster | *Nephrops norvegicus* | Demersal | |
| Norway pout | *Trisopterus esmarkii* | Demersal | nop-34. |
| Norway redfish | *Sebastes viviparus* | Demersal | |
| Ocean perch | *Sebastes marinus* | Demersal | |
| Pacific sandeel | *Ammodytes tobianus* | Demersal | |
| Pollack | *Pollachius pollachius* | Demersal | |
| Pouting / Bib | *Trisopterus luscus* | Demersal | |
| Roundnose grenadier | *Coryphaenoides rupestris* | Pelagic | |
| Saithe / Pollock | *Pollachius virens* | Demersal | POLL5YZ, POLLNEAR, POLLFAPL, POLL4X5YZ and POLLNS-VI-IIIa. |
| Skipjack tuna | *Katsuwonus pelamis* | Pelagic | |
| Smallspotted catshark | *Scyliorhinus canicula* | Demersal | |

| | | | |
|---|---|---|---|
| Swordfish | *Xiphias gladius* | Pelagic | |
| Thickback sole | *Microchirus variegatus* | Demersal | |
| Turbot | *Scophthalmus maximus* | Demersal | |
| Tusk/ Torsk / Cusk | *Brosme brosme* | Demersal | CUSK4X. |
| Whiting | *Merlangius merlangus* | Demersal | WHITNS-VIId-IIIa, WHITVIa and WHITVIIek. |
| Witch | *Glyptocephalus cynoglossus* | Demersal | |
| Wolf-fish | *Anarhichas lupus* | Demersal | |

**Appendix 1**

This appendix clarifies how DBEM model output (relative abundance) is being processed to prepare it for using in the bioeconomic model of package 7.3. The following steps are used to produce time-series of absolute biomass and maximum catch potential for each species:

1. For the species with assessments a reference biomass (RefBio) is used from the average of a time period (e.g. 1991-2003). This time period has been used because it is the time period when there are biomass assessments for a higher number of species. These assessments corresponds to specific ICES areas and not to the total distribution in all ICES areas for all species. For the species without assessments the initial reference biomass (RefBio) is calculated from maximum reported fisheries catch (MC) since 1950 and an estimate of the intrinsic growth rate (*r*) of the population (Schaefer 1954):

$$RefBio = B_{\infty} = MSY \cdot 4/r$$

where, MSY is the maximum sustainable yield, which can be approximated by the use of maximum catch (Froese *et al.* 2012). Maximum catch is calculated from the algorithm documented in Cheung *et al*. (2008) while estimated *r* values were obtained from FishBase (www.fishbase.org). Biomass estimated from survey data show significant correlation with those estimated from maximum catch (Fig. 1).

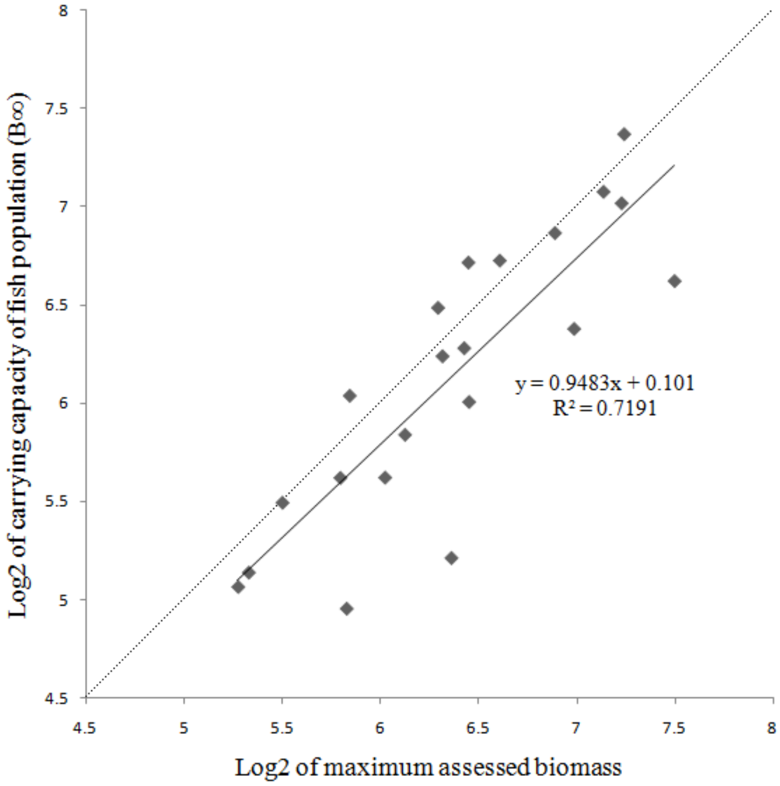


Fig. 1: Relationship between the maximum assessed biomass and the carrying capacity of fish population ($B_{\infty}$) for 22 species in the 27 FAO area (after removing extreme values, the lowest and highest $B_{\infty}$).

2. The sum of the output of DBEM for the reference year is calculated and used to define the conversion factor (CF) between the relative abundance and the reference

biomass. The sum is calculated for the ICES areas only, since the assessments corresponds only to these areas.

$$CF = RefBio/sum(relative\ abd)$$

3. The conversion factor can be them applied to each cell of the model in order to produce the absolute biomass distribution.

4. The cells can be aggregated in ICES areas to produce the absolute biomass in each area (AbsBio).

5. The maximum potential catch in each area can be calculated using the previous formula:

$$MSY = \text{AbsBio} \cdot r/4$$

**References**

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