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Deliverable D4.3

Parameterisation 2. Working model run for each case study which replicates the time series of the GES indicators

December 2016

Contents

Executive summary

This report is a deliverable of work package 4 (WP4 – Ecosystem models and assessment models) of the FP7 MareFrame research project. One of the aims of the MareFrame project is to identify management strategies which will achieve Good Environmental Status (GES) by applying a minimum of two ecosystem models on each of eight different case studies across Europe, namely: West of Scotland, the Baltic Sea, Iceland, the Strait of Sicily, the North Sea, South western waters, the Chatham rise, and the Black Sea (see MareFrame deliverable 4.1 (D4.1) for the description and parameterisation of the models employed in each case study). In this report we focus on the GES indicators which can be derived from the outputs generated by the first model employed in each case study (see D4.1 for a full description of what these outputs are for each model). The GES indicators calculated from the ecosystem models used in MareFrame cover 4 of the 11 GES descriptors defined by Marine Strategy Framework Directive (MSFD). Due to the type of the models employed and the format of the associated outputs, most of the indicators described here are based on two generic outputs: fish size and trophic levels. The Ecopath with Ecosim (EwE) model employed in the West of Scotland, Baltic and Black Seas case studies is a foodweb model. While this end-to-end model covers a wide range of trophic levels and, therefore, allows for relevant trophic indicators, it is not a size-based model and so any size-based indicator is approximated at best. By contrast, the GADGET model employed in the Iceland, South Western Waters and Black Sea is size-based, but can only include a limited number of species and is, therefore, more suited for size-based indicators than for trophic indicators. The Sicily case study is modelled with Atlantis for which only trophic indicators can be computed. The North Sea case study is modelled with the Stochastic Multi-Species (SMS) model, which allows for both biomass and size-based indicators to be calculated.

2. Introduction

Marine fisheries are a resource of political, economic and social importance in the European Union and in some cases have a significant contribution towards the Member States' economy. It is, therefore, essential to protect the European marine environment in order to maintain its health and ensure sustainable production from fish stocks in the future. The latest reform of the Common Fisheries Policy (CFP), which regulates the management of fish stocks in Europe took effect on January 1st 2014. The CFP entails a move towards the broad application of the Ecosystem Approach to Fisheries Management (EAFM). A major goal of EAFM in the context of the EU is to achieve Good Environmental Status (GES) in association with the Marine Strategy Framework Directive (MSFD). To this end the MareFrame EU research project (http://www.mareframe-fp7.org/) aims at applying EAFM to eight case studies (West of Scotland, the Baltic Sea, Iceland, the Strait of Sicily, the North Sea, South western waters, the Chatham rise of New Zealand, and the Black Sea) which cover a variety of ecosystems, fisheries-related issues, and data availability. The goal is to identify management strategies which achieve GES. It is essential, therefore, to be able to quantify, from the outputs of each ecosystem model employed in the various case studies, how close (or far) candidate management strategies get to GES.

This report follows MareFrame deliverable 4.1 (D4.1) which describes the parameterisation of the first ecosystem model employed in each case study, and D4.2 which describes a common procedure used to report outputs from the different ecosystem models employed in MareFrame in similar and comparable format. In this deliverable (D4.3) we focus on the GES indicators which can be derived from the outputs generated by the first model employed in each case study (see D4.1 for a full description of what these outputs are for each model). Those indicators play a crucial role in the MareFrame project as they will be used to assess whether the alternative management strategies simulated by the various ecosystem models employed here are likely to achieve GES in each case study. It is, therefore, important to ensure that, for each ecosystem model in each case study, the indicators calculated are related as closely as possible to the descriptor of GES defined by the MSFD. In this report, the indicators derived from the outputs of the first ecosystem model employed are listed for each case study. The calculation of each indicator is detailed, and the results of these calculations are displayed. The caveats and applicability of the indicators are discussed.

3. West coast of Scotland case study

3.1 Introduction

One of the objectives of MareFrame is to identify the management strategies which will achieve Good Environmental Status (GES) for all case studies considered. To do so it is crucial that the ecosystem models employed in MareFrame provide the indicators needed to assess whether GES is reached or not. At the very least it should be possible to derive such indicators directly from the outputs of the ecosystem models. In MareFrame a minimum of two ecosystem models will be applied to each case study to ensure that the simulated management strategies can lead to reliable and replicable results, regardless of the modelling tool employed. The six ecosystems models to be used in MareFrame are described in MareFrame Deliverable 4.2 (D4.2) along with a list of their outputs. Although these six models vary greatly in their type and functioning, they all return biomass and landings. As a result, a common reporting procedure has been proposed in D4.2 to allow for comparison of management strategies across models. This common reporting procedure includes fourteen indicators which can all be derived from biomass and landings and can be used to assess whether management strategies achieve GES or not, regardless of the ecosystem model employed to carry the simulations. This deliverable details the computation of these indicators for each MareFrame case study, depending on the model employed and the data available.

3.2 Good Environmental Status, descriptors and indicators

Achieving GES is one of the objectives set by the Marine Strategy Framework Directive. GES is defined by eleven descriptors, all of which refer to a particular aspect of ecosystem health:

- Descriptor 1: Biodiversity is maintained
- Descriptor 2: Non-indigenous species do not adversely alter the ecosystem
- Descriptor 3: The population of commercial fish species is healthy
- Descriptor 4: Elements of food webs ensure long-term abundance and reproduction
- Descriptor 5: Eutrophication is minimised
- Descriptor 6: The sea floor integrity ensures functioning of the ecosystem
- Descriptor 7: Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
- Descriptor 8: Concentrations of contaminants give no effects
- Descriptor 9: Contaminants in seafood are below safe levels
- Descriptor 10: Marine litter does not cause harm
- Descriptor 11: Introduction of energy (including underwater noise) does not adversely affect the ecosystem

To assess whether GES is achieved, indicators are needed for each one of these descriptors to evaluate if the condition of each descriptor is fulfilled. Each indicator consists of a value that can be measured against a defined threshold and/or over time to assess progress. In our case, the range of indicators that can be computed depends on the model employed. For example, none of the ecosystem models used in MareFrame include marine litter, pollutants or energy as components. As a result, it was decided that, due to model limitations, only descriptors 1, 3, 4 and 6 are relevant to MareFrame.

The list of indicators given in MareFrame D4.2 includes only indicators relating to descriptors 1, 3 and 4 that can be derived from all models employed, using biomass and landings. Descriptor 6, although deemed relevant, cannot be assessed explicitly from all models and no indicator was proposed in the list detailed in D4.2. This descriptor will be assessed whenever indicators can be derived from the model employed. The indicators listed in D4.2 are:

- Trends in biomass: do all species in the ecosystem reach a stable and sustainable status (% of species stabilised at the end of simulation)
- Abundance trends of functionally important species/groups
- Trends in landings: is economic sustainability achieved
- Fishing revenues: using mean price/kg
- Fishing mortality (species specific)
- Catch to biomass ratio
- Number of overfished stocks (assessed stock only)
- Proportion in weight of large species
- Number of species with significant landings (Gascuel *et al.*, 2014): landings higher than a minimum level (to be set for all models/ecosystem to be compared)
- Shannon's diversity index (Shannon, 1948): biodiversity index based on the proportion of species in the landings
- Mean Maximum Length (MML) (ICES, 2009): based on maximum asymptotic length L_∞ from Fishbase (www.fishbase.org) and the weight (biomass) of species
- Mean Trophic Level (MTL) (Pauly *et al.*, 1998): based on the mean trophic level from Fishbase (www.fishbase.org) and the weight (biomass) of species
- Marine Trophic Index (MTI) (Pauly and Watson, 2005): MTL of predatory fish i.e. species with a trophic level of 3.25 or higher
- Pelagic to demersal ratio: indicator of nutrient input and quality of benthic habitat (de Leiva Moreno *et al.*, 2000)

3.3 Computing GES indicators for the west coast of Scotland case study

The first ecosystem model to be employed in the west coast of Scotland case study is Ecopath with Ecosim (EwE). EwE for the west of Scotland has been published in peer-reviewed literature (Alexander *et al.*, 2014) and the parameterisation of the model has been described in D4.1. Although the model is currently being updated (the latest parameterisation covers the 1985-2008 period), the calculation of GES indicators from biomass and landings can already be developed and subsequently applied to updated versions of EwE. The biomass and landings time series given by the model are given in Figures 3.1 and 3.2 respectively. The calculations and results for all indicators is detailed below.

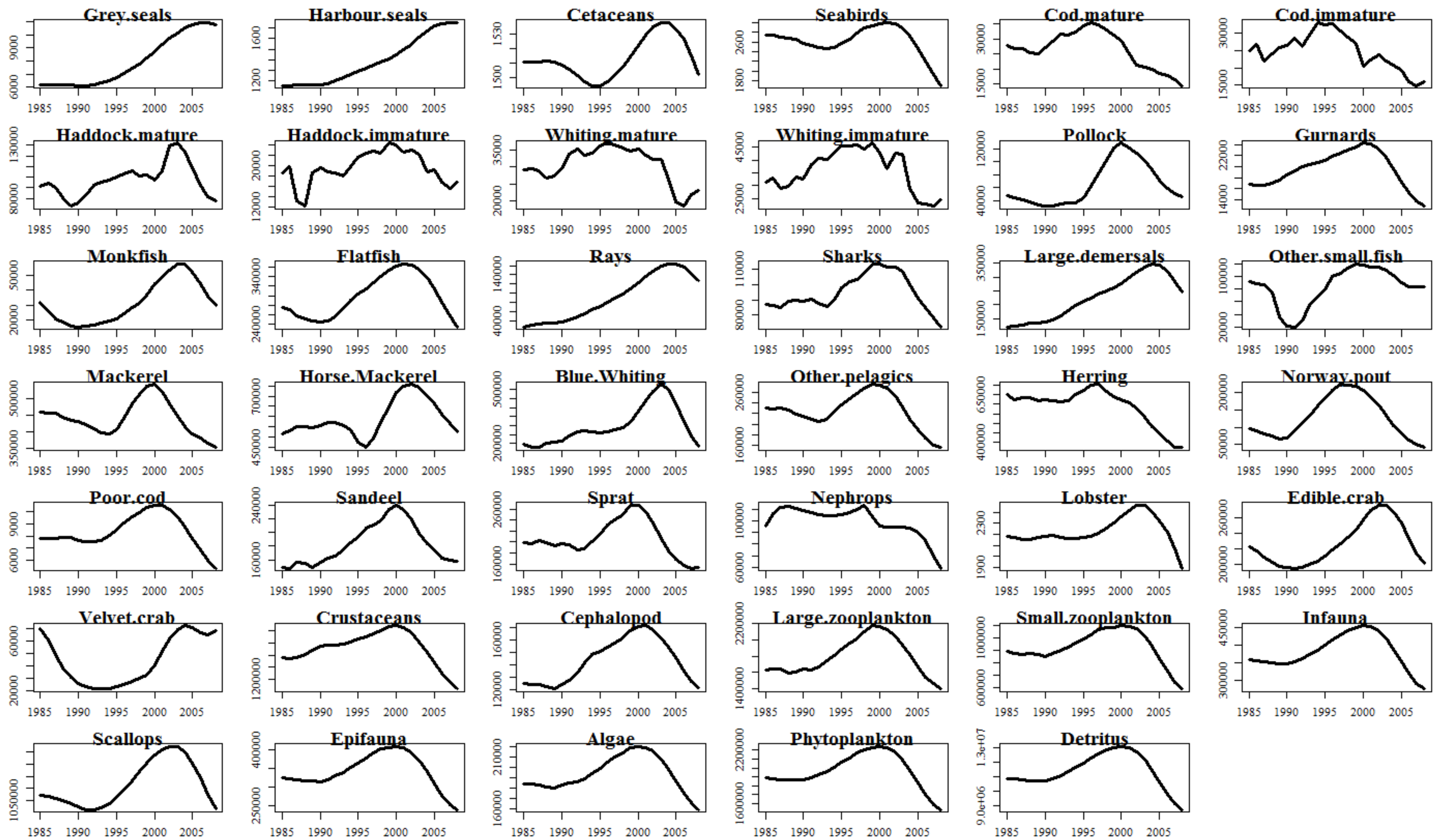

Figure 3.1. Biomass time series in tonnes for all functional groups

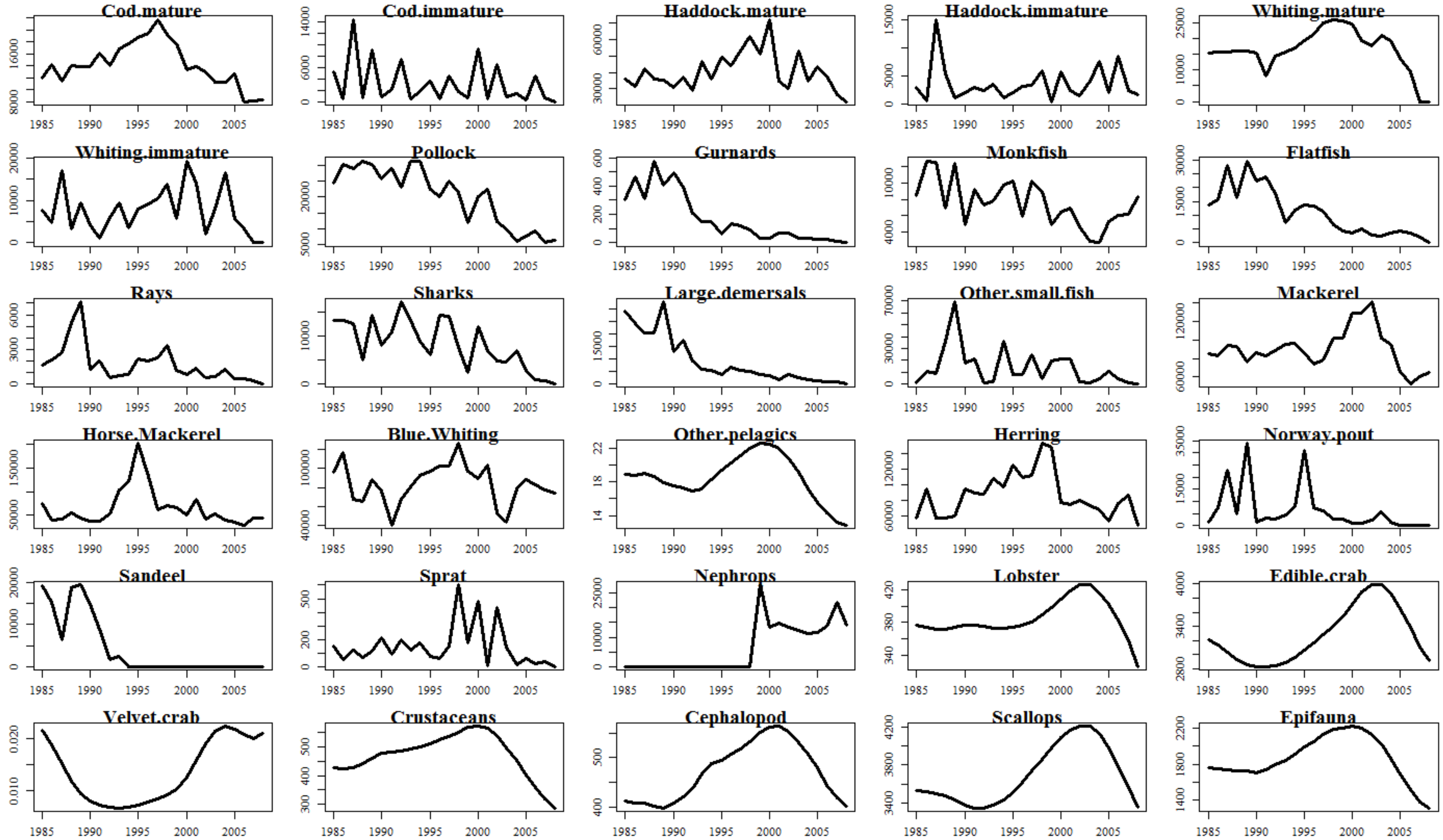

Figure 3.2. Landings time series in tonnes for functional groups targeted by fishing

The first three indicators of the list (i.e. biomass stability, abundance trends, landings trends) are qualitative indicators that represent the performance of the management at a given point in time. Therefore, values for these indicators were given for the last year of the simulation period as this would correspond to the last year of the management plan (in this case 2008 as no forward simulations were performed).

Fishing mortality and catch to biomass ratio are stock-specific indicators for all species targeted by fishing. As a result, time series for these two indicators were computed for all relevant functional groups.

The fishing revenue indicator requires a price per weight to be calculated. The price per tonne values were taken from the EwE model and averaged across fleets (see Alexander *et al.*, 2014 for more information). Prices were assumed to be constant. The values are given in Table 1.1.

Table 1.1. Prices in £/tonne for all fleets included in the model and corresponding average

Functional group	Demersal trawlers	Nephrops trawlers	Other trawlers	Pots and diving	Pelagic trawlers	Average
Cod.mature	1741.4	1717.5	1332.5			1597.1
Cod.immature	1741.4	1717.5	1332.5			1597.1
Haddock.mature	1145.5	890.6	1266.8			1101.0
Haddock.immature	1145.5	890.6	1266.8			1101.0
Whiting.mature	1019.4	943.8	1444.0			1135.8
Whiting.immature	1019.4	943.8	1444.0			1135.8
Pollock	1867.1	836.0	2549.8			1751.0
Gurnards	662.2	575.0				618.6
Monkfish	3427.1	3126.2	3340.2			3297.8
Flatfish	723.6	559.8	924.1			735.8
Rays	735.3	1374.5	1643.4			1251.0
Sharks	1383.6	2009.8	1345.5		1750.0	1622.2
Large.demersals	1471.1	659.1	1974.3			1368.2
Other.small.fish	413.7	405.0	405.0	405.0	396.3	405.0
Mackerel	798.2	807.5			826.3	810.7
Horse.Mackerel	145.6	200.0	307.2		468.7	280.4
Blue.Whiting	233.8	233.8	233.8		233.8	233.8
Other.pelagics	226.1	226.1	226.1	226.1	226.1	226.1
Herring	322.3	308.0	308.0		293.7	308.0
Norway.pout			96.3			96.3
Sandeel		49.9	238.1			144.0
Sprat					199.4	199.4
Nephrops	2367.2	2349.3	7064.6	8268.5		5012.4
Lobster	8537.9		9284.3	10317.5		9379.9
Edible.crab	1027.4		1126.0	1191.0		1114.8
Velvet.crab				2546.9		2546.9
Crustaceans	554.5		518.2	605.9		559.5
Cephalopod	2701.5	1640.3	2696.0			2346.0
Scallops	1880.4	1805.9	1850.2	2635.8		2043.1
Epifauna	46.2	46.2	579.8	533.3		301.4

The Mean Maximum Length (MML) indicator requires maximum length values for all functional groups. These values were obtained from Fishbase (www.fishbase.org) for all species composing the functional groups, and averaged across functional groups so as to get one value per functional groups.

Since body length data only apply to fish species, this indicator was restricted to the fish community only and excludes crustaceans and cephalopods. The average maximum length values are reported in Table 1.2.

Table 1.2. Maximum length values from Fishbase averaged across functional groups for fish species

Fish functional group	Average maximum length (cm)
Cod.mature	200
Cod.immature	63
Haddock.mature	112
Haddock.immature	35
Whiting.mature	70
Whiting.immature	29
Monkfish	150
Flatfish	71
Gurnards	57
Herring	45
Horse.Mackerel	70
Large.demersals	112
Mackerel	60
Norway.pout	35
Other.pelagics	37
Poor.cod	40
Pollock	130
Sandeel	33
Other.small.fish	30
Sharks	148
Sprat	16
Rays	135
Blue.Whiting	50

The Mean Trophic Level (MTL) and Mean Trophic Index (MTI) indicators require the trophic level of each functional group. The Ecopath component of EwE defines the trophic level of each functional group based on the groups included in the model and their diet compositions (i.e. their prey/predator interactions). As a result, trophic levels values were taken from EwE and reported in Table 1.3.

Trophic levels and prices per tonne values were obtained from the latest version of the EwE model. These values may be updated at a later stage of the project upon development of the model.

Stability of biomass

Biomass of a functional group was considered stable in the last year of the simulated period if the year-to-year variation in the last consecutive five years did not exceed 10% (biomassyear*90% < biomassyear+1 < biomassyear*110%). The results for functional groups are reported in Table 1.4 below.

Abundance trends

EwE is a foodweb model in which functional groups are expressed in weight. As a result, abundance trends for each group were identified by assessing trends in biomass. A linear model was fitted through the last three biomass values and the slop value was used to determine whether biomass was increasing or decreasing. The results for all functional groups are reported in Table 1.4 below.

Table 1.3. Trophic levels of the functional groups included in the model

Functional group	Trophic level
Cod.mature	3.92
Cod.immature	3.14
Haddock.mature	3.62
Haddock.immature	2.94
Whiting.mature	4.16
Whiting.immature	3.04
Monkfish	4.36
Flatfish	3.44
Gurnards	3.62
Herring	3.16
Horse.Mackerel	3.17
Large.demersals	4.29
Mackerel	3.34
Norway.pout	3.28
Other.pelagics	3.61
Poor.cod	3.53
Pollock	3.92
Sandeel	3.18
Other.small.fish	3.24
Sharks	4.04
Sprat	3.16
Rays	3.84
Blue.Whiting	3.65
Grey.seals	4.47
Harbour.seals	4.60
Nephrops	3.41
Lobster	3.40
Edible.crab	3.32
Velvet.crab	2.62
Crustaceans	2.69
Cephalopod	3.24
Scallops	2.00
Cetaceans	4.30
Seabirds	4.16
Large.zooplankton	2.16
Small.zooplankton	2.03
Infauna	2.04
Epifauna	2.39
Phytoplankton	1.00
Detritus	1.00
Algae	1.00

Landings trends

Methods used to assess abundance trends were employed to assess landings trends for functional groups targeted by fishing. The results for all functional groups are reported in Table 1.4 below.

Table 1.4. Results for the stability of biomass, abundance trends and landings trends indicators at the end of the simulation period (2008) for all functional groups

Functional group	Stable biomass	Abundance trends	Landings trends
Grey.seals	yes	down	
Harbour.seals	yes	up	
Cetaceans	yes	down	
Seabirds	no	down	
Cod.mature	no	down	up
Cod.immature	no	up	down
Haddock.mature	no	down	down
Haddock.immature	no	up	down
Whiting.mature	no	up	down
Whiting.immature	no	up	down
Pollock	no	down	down
Gurnards	no	down	down
Monkfish	no	down	up
Flatfish	yes	down	down
Rays	no	down	down
Sharks	yes	down	down
Large.demersals	no	down	down
Other.small.fish	no	up	down
Mackerel	yes	down	up
Horse.Mackerel	yes	down	up
Blue.Whiting	no	down	down
Other.pelagics	no	down	down
Herring	yes	down	down
Norway.pout	no	down	down
Poor.cod	no	down	
Sandeel	yes	down	up
Sprat	no	down	down
Nephrops	no	down	up
Lobster	yes	down	down
Edible.crab	yes	down	down
Velvet.crab	yes	up	up
Crustaceans	no	down	down
Cephalopod	yes	down	down
Large.zooplankton	yes	down	
Small.zooplankton	no	down	
Infauna	yes	down	
Scallops	yes	down	down
Epifauna	yes	down	down
Algae	yes	down	
Phytoplankton	yes	down	
Detritus	yes	down	

Fishing mortality

EwE does not return fishing mortalities. However, the model does return group-specific total mortalities (Z). Assuming low natural mortality, Z can be used as a proxy for fishing mortality for functional groups targeted by fishing. Z time series are given for all groups in Figure 3.3.

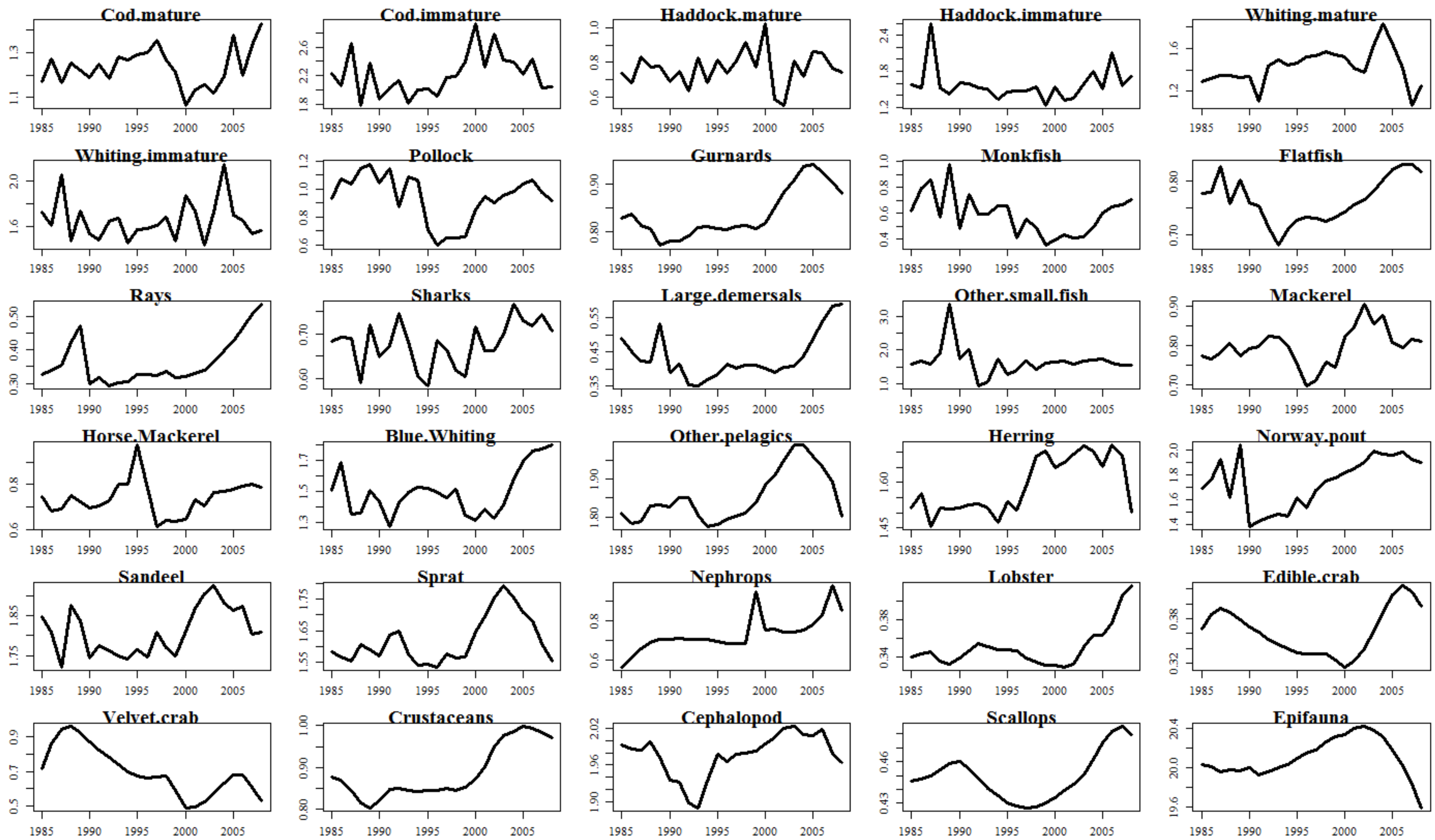

Figure 3.3. Total mortality time series estimated by the model for each functional group.

Catch to biomass ratio

The catch to biomass ratio (C/B) indicates the exploitation rate and can be employed as a proxy for fishing mortality. C/B was calculated for functional groups targeted by fishing by dividing the catches by the biomass. C/B time series are given in Figure 3.4.

Fishing revenue

Fishing revenue was calculated for the functional groups targeted by fishing by multiplying the landings (in tonnes) by the price (in £/tonne). The total revenue was then calculated for each year by summing revenues across groups. The fishing revenue time series is given in Figure 3.5.

Number of overfished stocks

Since most functional groups in EwE encompass several stocks, this indicator could not be calculated for the West of Scotland ecosystem.

Proportion in weight of large species

The following functional groups were considered to contain all large species of fish in the model: cod mature, haddock mature, whiting mature, Pollock, monkfish, flatfish, rays, sharks, large demersals. The proportion in weight of these groups in the total biomass was calculated for all years and the time series represented in Figure 3.5.

Number of species with significant landings

The number of groups with significant landings instead of species was calculated for this indicator. Significant landings were defined as equal to or greater than 5% of the biomass of the group. The number of groups with significant landings was calculated for each year and the results presented n Figure 3.5.

Shannon index

Shannon's diversity index (H) was calculated for each year with the following formula (Shannon, 1948):

$$H = \sum_{G} \left(P_G . log_2(P_g) \right)$$

where PG is the proportion in weight of group G in the yearly landings. The H time series is given in Figure 3.5.

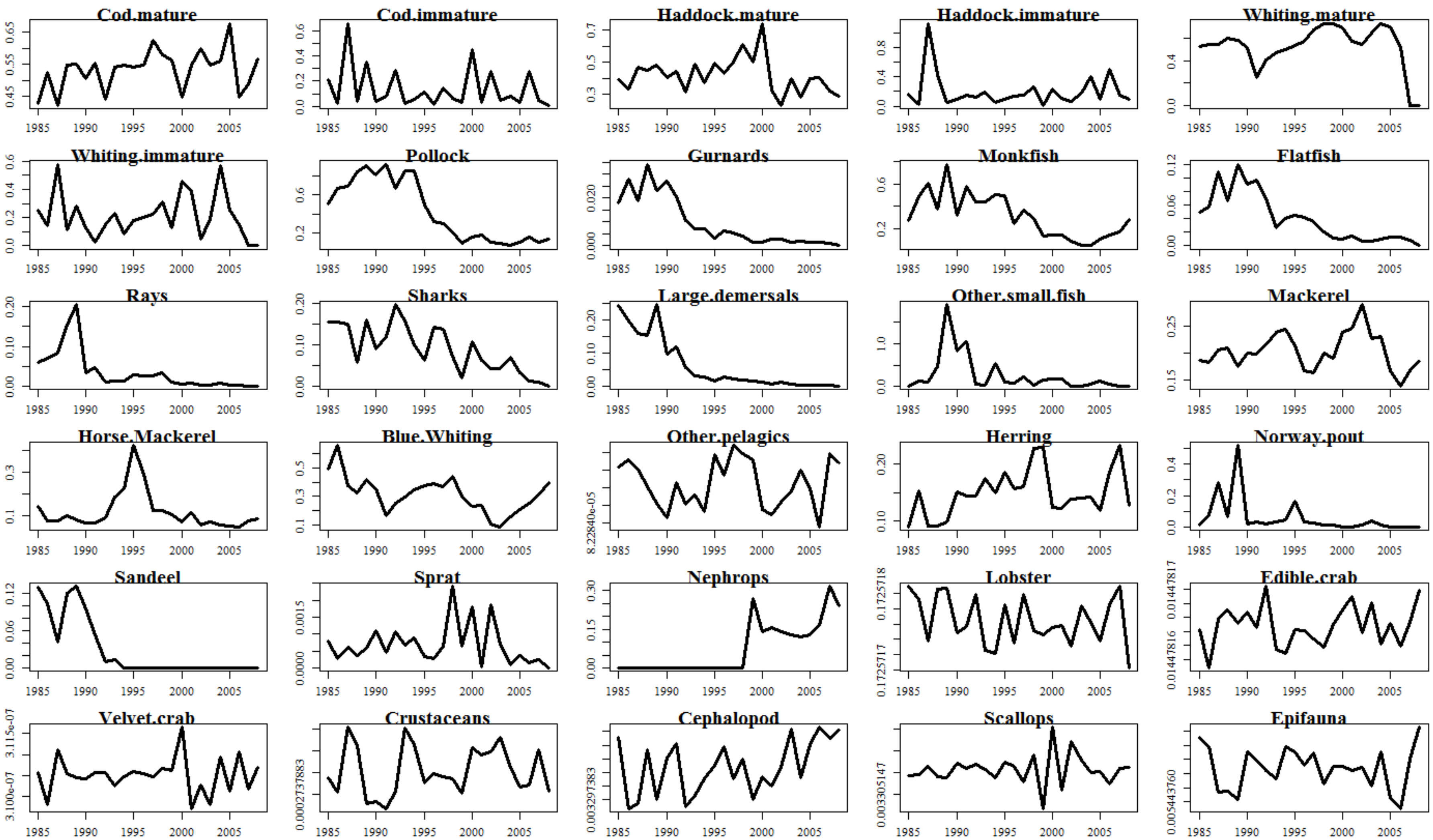

Figure 3.4. Catch to biomass ratio for the functional groups targeted by fishing

Mean maximum length

The mean maximum length (MML) was calculated for each year with the following formula (Gascuel et al., 2014):

$$MML = \sum (W_{G.}L_{\infty G}) / \sum W_G$$

where WG is the weight of the group G present in the biomass of the model and L∞G is the asymptotic length of the group G (see Table 2). As mentioned above, L∞G were obtained by averaging L∞ values across groups, and MML was computed for fish groups only. The MML time series is given in Figure 3.5.

Mean trophic level

The mean trophic level (MTL) was calculated for each year with the following formula (Gascuel et al., 2014):

$$MTL = \sum (TL_G . W_G) / \sum W_G$$

where TLG is the trophic level of the group G (see Table 3) and WG is the weight of the group G present in the biomass of the model. The MTL time series is given in Figure 3.5.

Marine trophic index

The marine trophic index (MTI) was calculated by repeating the MTL calculation detailed above using only groups with a trophic level above 3.25 (Gascuel et al., 2014). The MTI time series is given in Figure 3.5.

Pelagic to demersal ratio

The pelagic to demersal ratio (P/D) was calculated for each year by dividing the sum of biomass of pelagic groups by the sum of biomass of demersal groups. The pelagic groups are: mackerel, horse mackerel, blue whiting, other pelagics, herring and sprat. The demersal groups are: cod mature, cod immature, haddock mature, haddock immature, whiting mature, whiting immature, pollock, gurnards, monkfish, flatfish, rays, sharks, large demersals, other small fish, Norway pout, poor.cod and sandeel. The P/D time series is given in Figure 3.5.

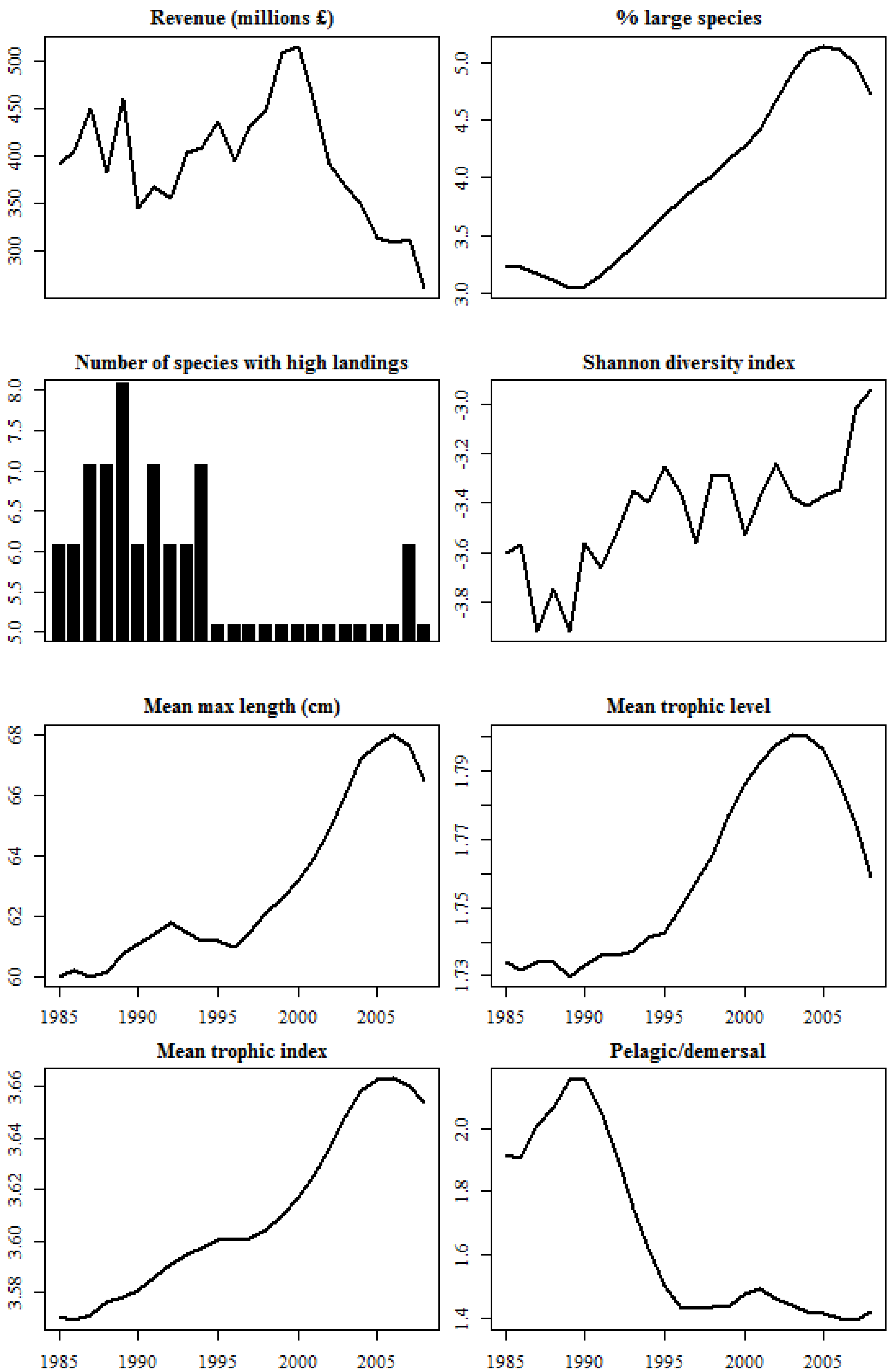

Figure 3.5. Ecosystem indicators time series calculated from the outputs of the Ecopath with Ecosim model for the west coast of Scotland ecosystem

3.4 References

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4. Baltic Sea case study

4.1 Introduction

A number of GES indicators have been investigated for Baltic Sea at surrounding countries. HELCOM has an EU mandate to coordinate Baltic member state countries in reference to MSFD. Core set of common indicators have been agreed and recommended to member states (HECLOM 2015).

Despite the lack of an ability to model of most of them using Ecopath and Ecosim for the Baltic Sea (Tomczak et al. 2015), a of number indicators are presented in the current report. Overlap between MSFD GES and Baltic EwE modelling results has been investigated by Larssen et al. (2013) and ICES/HECLOM Working Group on Integrated Assessment of the Baltic Sea (ICES 2013). The model used for the current report was based on a version used at Tomczak *et al.* (2013). The newest updated version for MAREFRAME EwE Baltic model is still under development and need to be tested further to provide results. Because of that model parameterisation and runs do not cover recent years - 2006 is the last year of the simulation. Referring historical values to GES (e.g **Fmsy**, fishing mortality consistent with achieving Maximum Sustainable Yield (MSY) or **Bmsy**, Spawning stock biomass (SSB) that results from fishing at FMSY for a long time) at the end of the simulation (and saying if the pressure/stock is or is not sustainable) is difficult since the Baltic ecosystem changed significantly over the following decade.

4.2 Model description

Ecopath with Ecosim [38] was created for building food-web models (www.ecopath.org). The dynamic extension of Ecopath that allows temporal analysis and fitting the model to time series is undertaken by Ecosim, using the master equation (1)

$$dB_i / dt = g_i \sum_j Q_{ji} - \sum Q_{ji} + I_i - (M0_i + F + e_i) \bullet B_i \qquad (1)$$

where dBi/dt represents the growth rate during the time interval dt of group (i) in terms of its biomass (Bi), gi is the net growth efficiency (production/consumption ratio), Qji is the consumption rates, M0i the non-predation (‘other’) natural mortality rate, Fi is fishing mortality rate, ei is emigration rate, Ii is immigration rate (and ei*Bi-Ii is the net migration rate).

The current Baltic Ecopath with Ecosim model, based on Tomczak et al. (2013), covers the area of the Central Baltic Sea (ICES subdivisions 25-29, excluding Gulf of Riga) and contains 21 functional groups (Fig. 4.1), including three fishing fleets on the main commercial fish species: cod, sprat and herring. Further details are provided in Tomczak et al. (2013).

The forcing data represent both environmental and human impacts on the Baltic Sea food-web. Temporal anomalies of sea surface temperature in August and the spring temperature from 0-50 m depth (SST_aug; TempWC_spring), primary production (PP_BALTSEM), hypoxic area, Cod Reproductive Volume (CodRV [41]), herring recruitment (HER_rec), as well as fishing mortality (ICES 2006) on small and adult cod (FSmallCod, FAdCod), sprat (FJuvSprat, FAdSprat) and herring (FJuvHerr , FAdHerr) was used to drive the model.

Figure 4.1 presents the Ecopath model structure which contains 21 functional groups representing all trophic levels and parameterised for 1974. The year1974 plays a role of initial conditions for the simulations at time dynamic model simulations for Ecosim till 2005. Model is forced by number of external drivers - environmental and anthropogenic (Fig. 4.2 - TLP), for details see Tomczak et al., (2012) and Tomczak et al (2013).

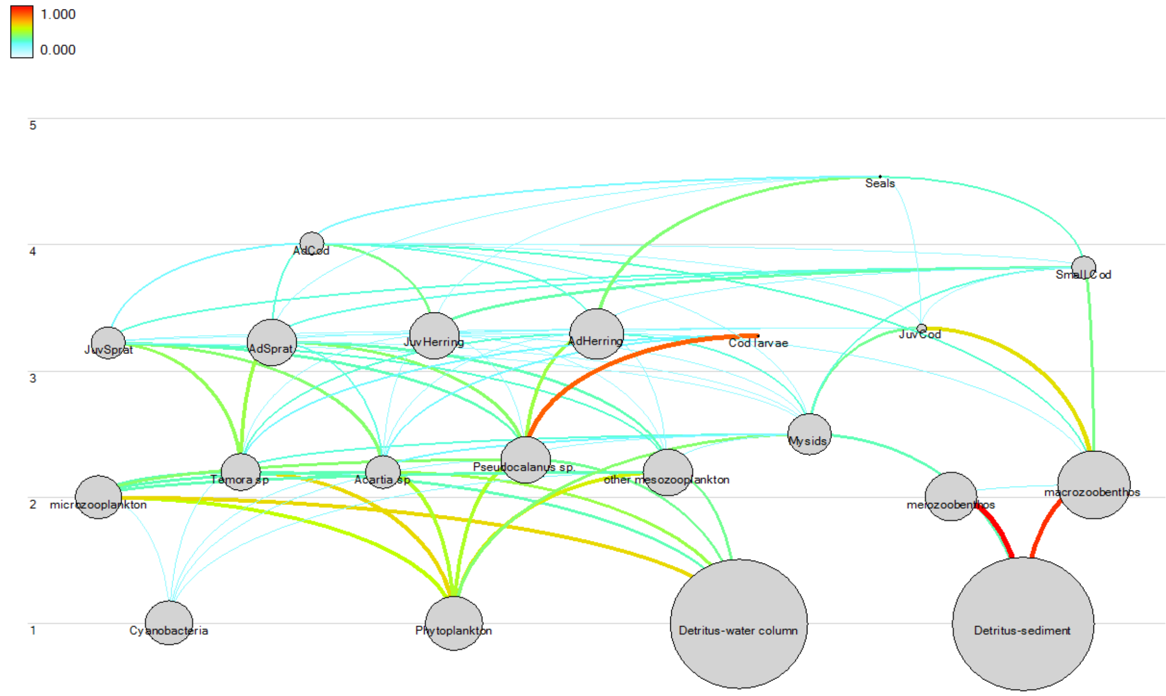

Figure 4.1. Flow diagram of Central Baltic Sea Ecopath food-web model (Tomczak et al., 2013)

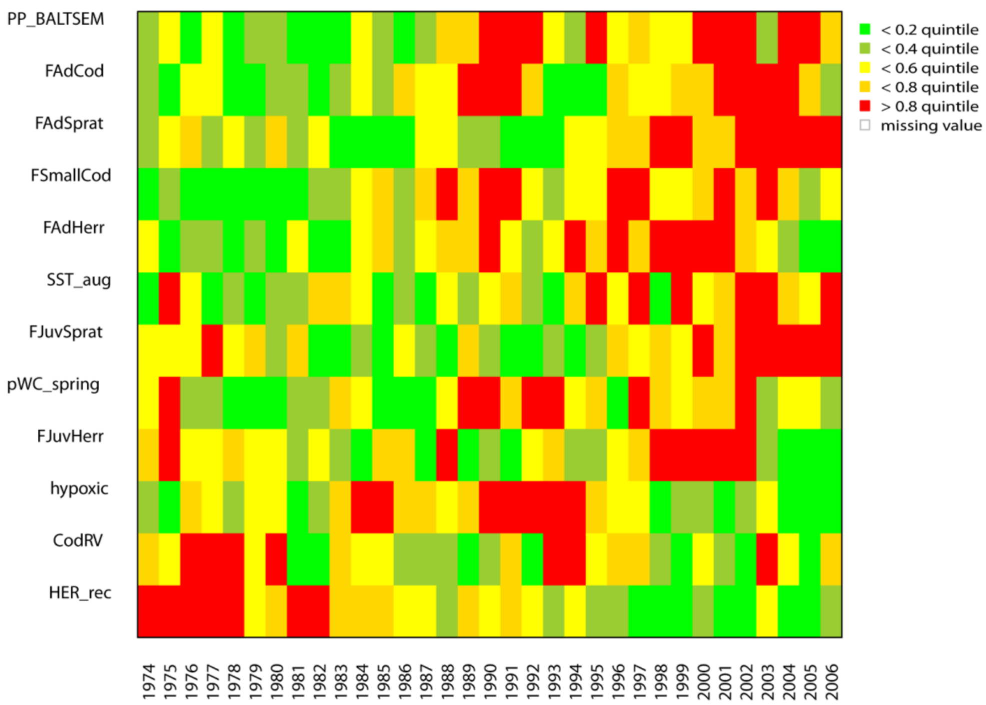

Figure 4.2. Dynamics of model drivers

4.3 Model Fit

Despite the fact that residuals for some functional groups still show patterns, the model represents observed data relatively well and it has been used in number of publications (Tomczak et al., 2012; Tomczak et al., 2013; Niiranen et., 2012; Niiranen et., 2013; Gårdmark et al., 2013; Lassalle., 2012). Uncertainty have not been done using MCMC in case of this version of the model, so it is not possible to give confidence intervals, however structural uncertainty and sensitivity analysis was investigated by Nirannen et al. (2012).

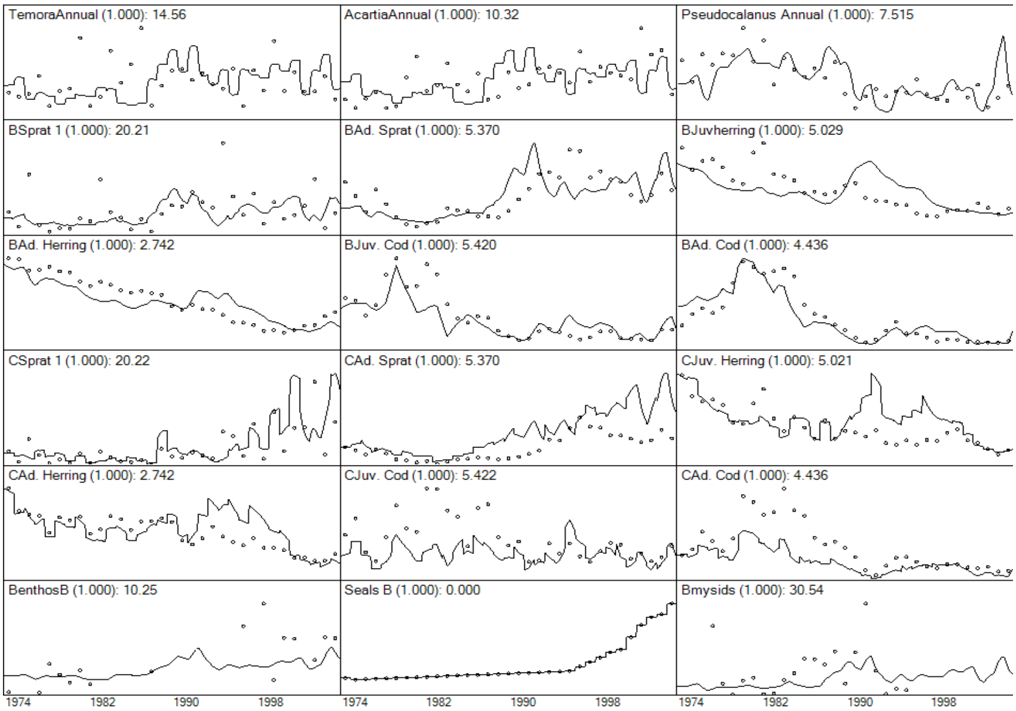

Figure 4.3. Model fit to the observed time series. In left corner additional information - Name of functional groups and type of data (biomass - B or catch - C); weight of time series for fitting - in brackets; contribution of given functional group in the sum of squares.

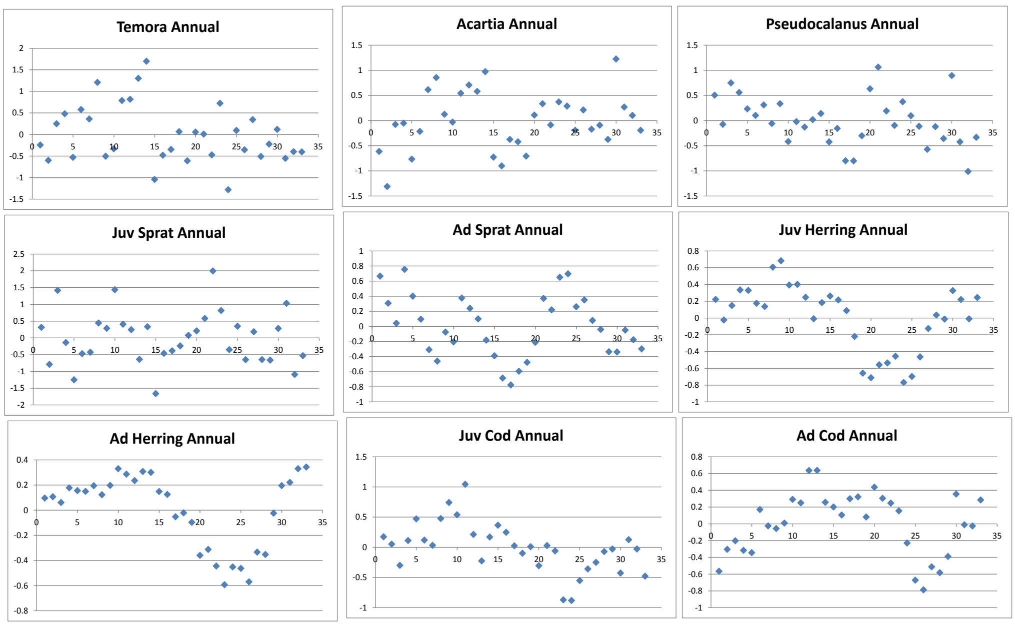

Figure 4.4. Plots of residuals for used biomass time series of chosen groups.

4.4 MSDF Descriptor 3. Healthy status for exploited fish species. MSDF Descriptor 3.1 Pressure Descriptor.

Fishing mortality rate is normally regarded as the appropriate measure of fisheries pressure on a stock. ICES (2015) provides Fmsy reference points for Baltic fish stocks (Table 2.1).

Table 2.1. F_{MSY} ranges for Baltic Sea [F_{lower}, F_{upper}] derived to deliver no more than 5% reduction in long-term yield compared with F_{MSY}. Two approaches have been used to derive the values of F_{upper}. One conforms to the ICES MSY advice rule (AR), and requires reducing F_{MSY} and F_{upper} linearly towards zero when SSB is below MSY $B_{trigger}$ (framed). The second (grey) uses a constant F without an advice rule. Although the first provides a wider range, it requires the ICES MSY advice rule to be used (ICES 2015).

Stock	MSY Flower	FMSY	MSY Fupper with AR	MSY Btrigger (thousand t)	MSY Fupper with no AR
Cod in Subdivisions 22–24	0.15	0.26	0.45	38.4*	0.45
Herring in Subdivisions 25–29 and 32 (excluding Gulf of Riga herring)	0.16	0.22	0.28	600	0.22
Sprat in Subdivisions 22–32 (Baltic Sea) a)	0.19	0.26	0.27	570	0.21

a) Year range of stock-recruitment curve: 1992–2013.
* Version 2: Value corrected.
** Version 3: Value updated (ICES, 2015d).

F and B reference point ranges provided by ICES do not include multispecies interactions. Since Baltic EwE is driven by fishing mortality as a driver and estimates only “yield per biomass ratio” (Y/B) values of fishing caused mortality, the values are not directly comparable and will need further work on translation the Y/B to F. In general Y/B should be a good proxy of F and used as GES indicator, in Baltic case due to high variation of mean individual weight of cod and herring is not giving comparable values.

4.5 MSDF Descriptor 3.2 State Descriptor.

ICES (2015) also provides estimates of Bmsy (Table 2.1), although this may need rethinking due to problems with age structure assessments (ICES 2014) and the multispecies context. Their current values are given in Table 2.1.

4.6 Model output according to Mareframe Deliverable 4.2

The most recent guidance on the MSFD descriptors that are of most relevance to fisheries management (descriptors 3, 4) was provided by three Workshops organised by ICES in February 2015 (ICES 2015a,b,c) and together with D4.2 is a basis for current reporting.

4.6.1 Trends in biomass: do all species in the ecosystem reach a stable and sustainable status (% of species stabilised at the end of simulation).

Referring to the biomass of the Eastern Baltic cod stock to the biomass estimated by food-web model to Bmsy given by ICES as a basis for management it is clearly visible that stock in 2005-2006 is at or just slightly above Bmsy. Baltic sprat stock is sustainable at the end of the simulation (above Bmsy).

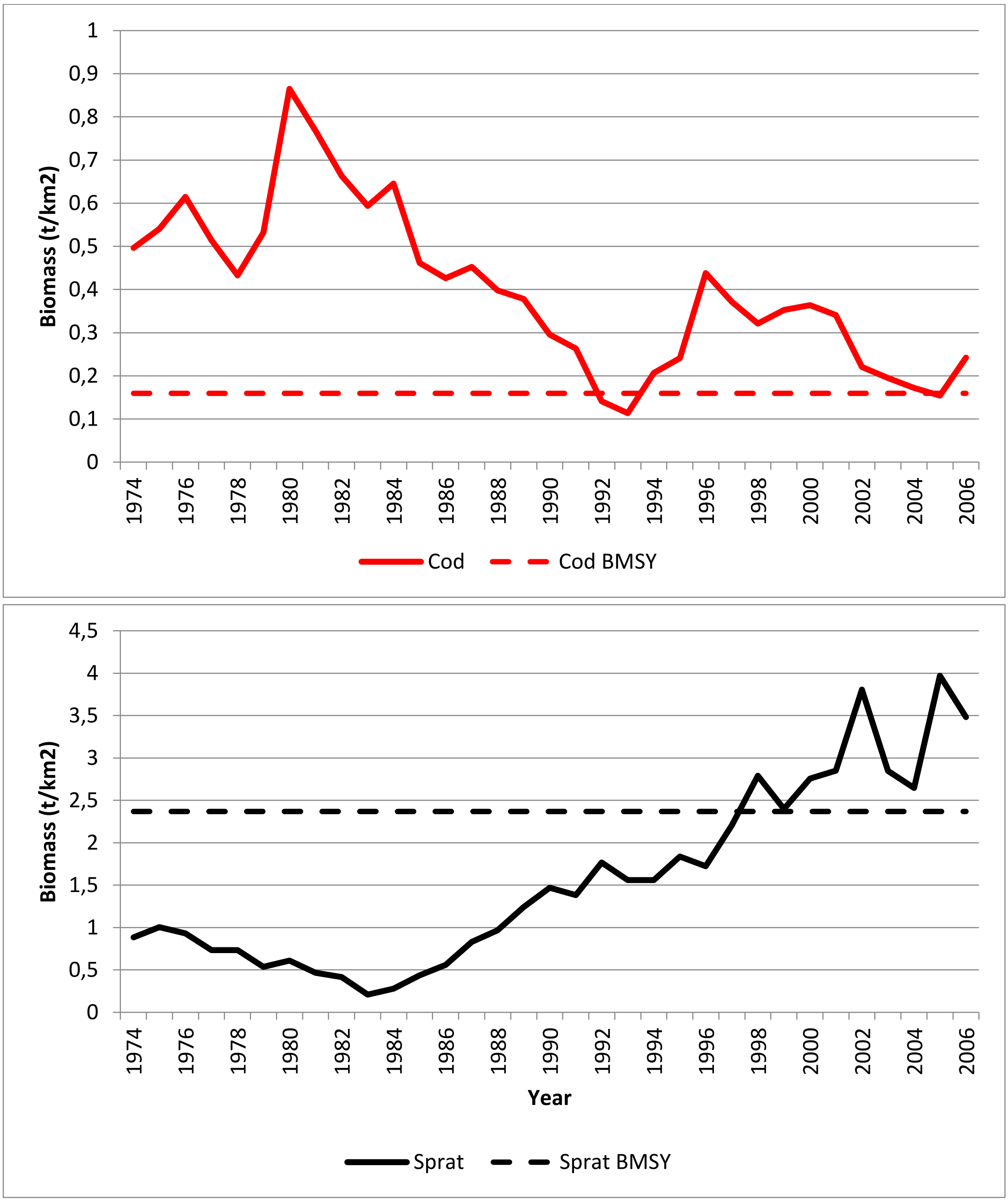

Figure 4.5. Biomass dynamics of Eastern Baltic Cod and Baltic Sprat stocks (1974-2006) in reference to Bmsy (ICES 2015). Herring is not shown since model calculates different absolute biomass values than ICES assessments (even if trend is right) and could lead to wrong conclusions.

4.6.2 Abundance trends of functionally important species/groups

The traffic light plot of modelled biomass (Fig. 4.6) shows a clear dichotomy in the food-web –before and after a regime shift (Möllmann et al., 2008), between cod vs. sprat and zooplankton vs. plankton.

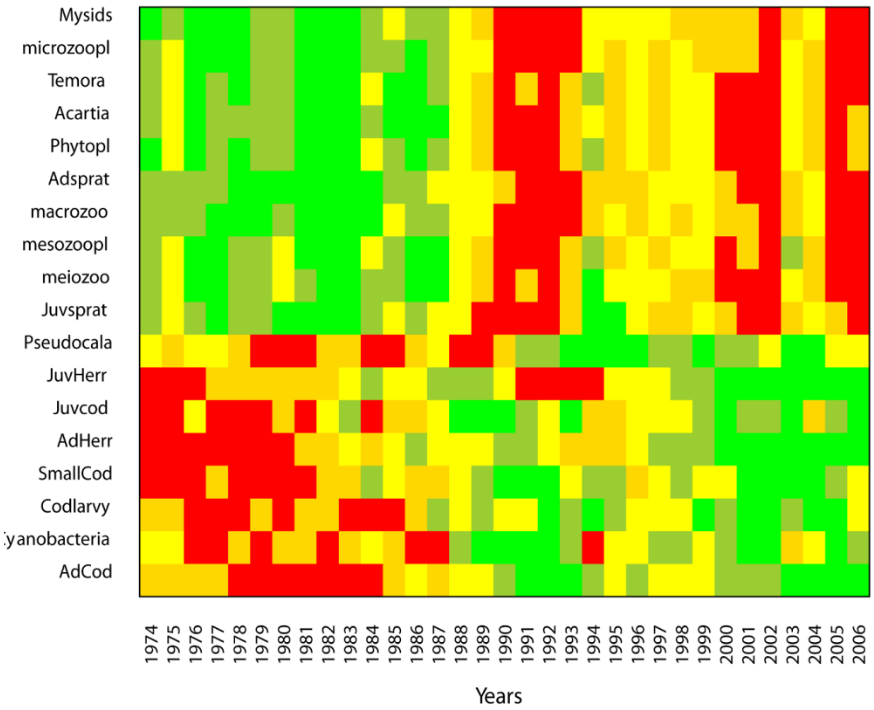

Figure 4.6. Changes in model biomass of all modelled species (functional groups) in the model.

4.6.3 Fishing mortality (species specific) as catch to biomass ratio

Yield/biomass (Y/B) ratios are estimated for calibration period (1974-2006). Trends and fluctuations estimated by the model are close to the dynamics of F presented by ICES (2007). There is a clear drop of Y/B for cod in the 1990's and increasing of Y/B for sprat until the end of simulation ware calculated. Herring Y/B been relatively constant from 1970's-1990, during 1990's it increased, then during the 2000's it decreases to the lowest modelled level.

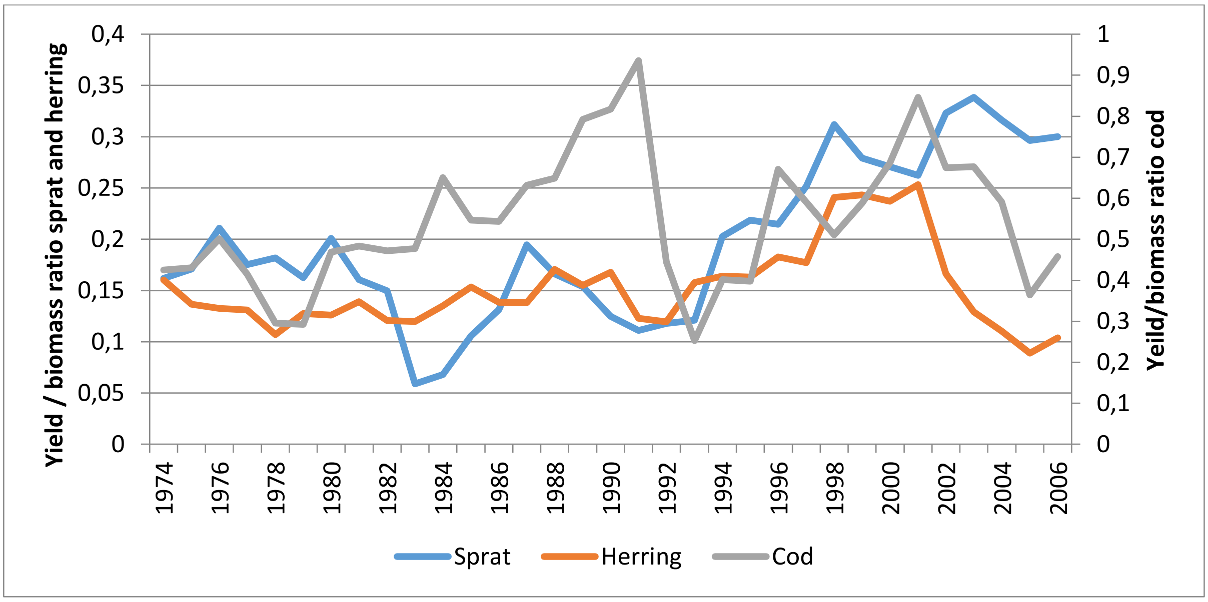

Figure 4.7. Yield per Biomass estimated from Baltic food-web model (Tomczak et al., 2013).

4.6.4 Number of overfished stocks (assessed stock only)

See Table 2.1.

4.6.5 Number of species with significant landings

According to definition (Gascuel et al., 2014) all three models stock at the Baltic Sea had and have significant landings, if we take in to consideration only modelled period).

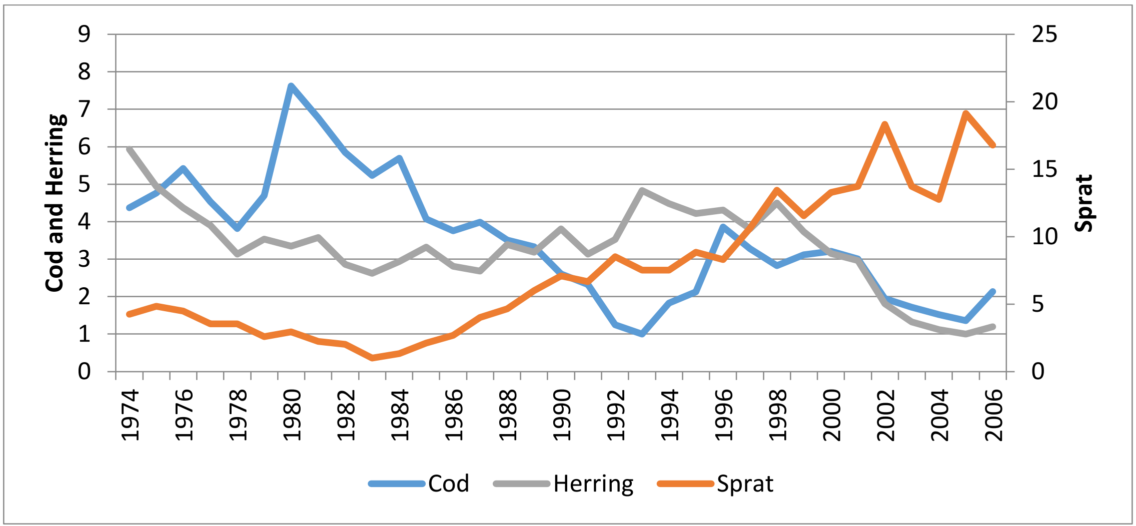

Figure 4.8. Modelled landings. Relative values in reference to minimum observed level.

4.6.6 Mean Trophic Level (MTL)

The MTL (Pauly et al., 1998) is based on the mean trophic level from Fishbase (www.fishbase.org) and the weight (biomass) of species. Mean TL of community (mTLco) for Baltic Sea is fluctuating between 2.45 and 2.3 (Fig. 4.9) showing the changes in biomass proportion but also in diet compositions of included functional groups. Generally, we can observe decreasing trend in mTLco for the Baltic Sea food-web.

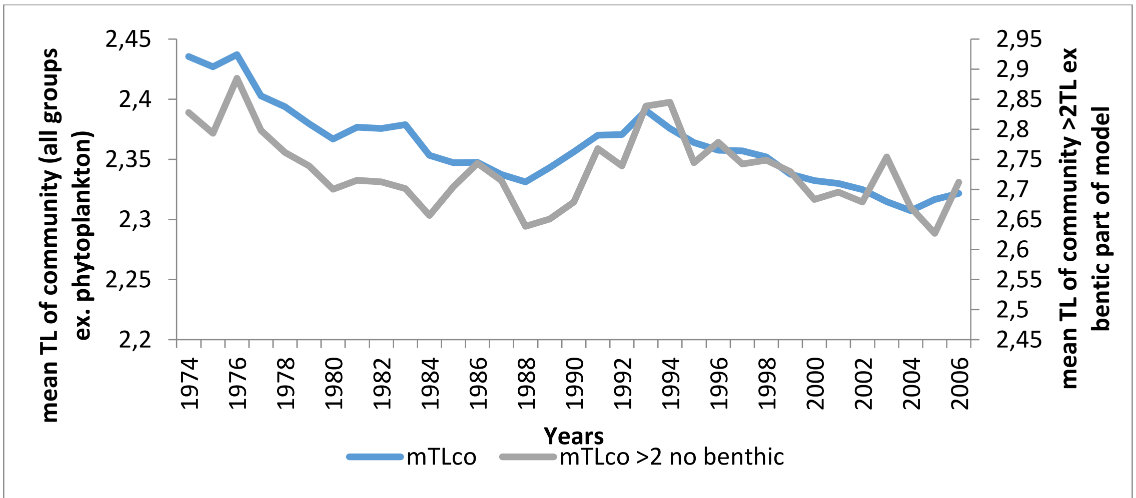

Figure 4.9. Changes in mean TL of community over time.

4.6.7 Marine Trophic Index (MTI)

The Mean Trophic Level of predatory fish is indicative of the number of species with a trophic level of 3.25 or higher. In the Baltic Sea the main predatory fish in terms of biomass is cod which occupied a TL between 4.1-3.5. Changes in TL are associated with changes in diet composition of cod and type of feeding in specific periods. In the 1980's we observed the so-called "cod peak" where the diet of cod contained a large proportion of benthic organisms (decrease in TL). After the regime-shift sprat become more available and become main food item leading to a TL increase (for details see Tomczak et al., 2012).

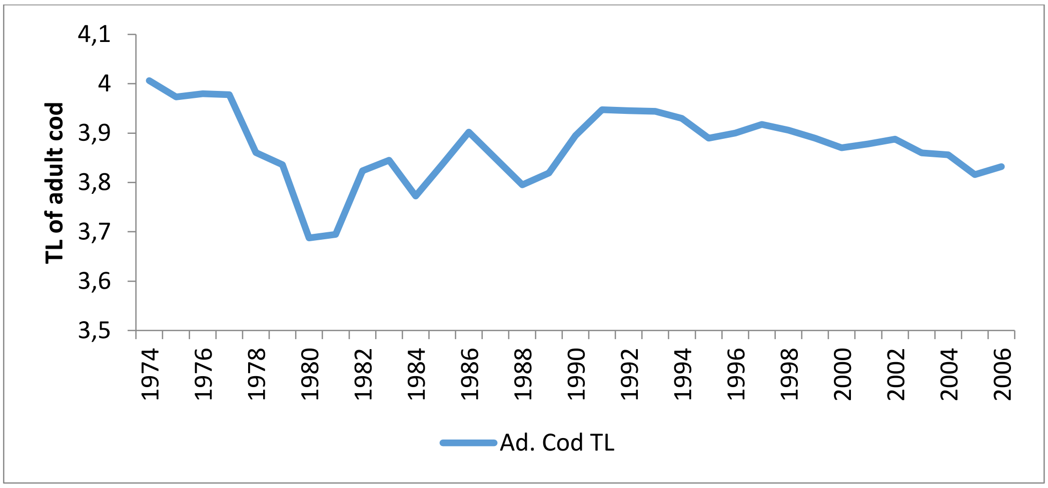

Figure 4.10. Trophic level of adult cod defends as a MTI

4.6.8 Pelagic to demersal ratio

This is an indicator of nutrient input and quality of benthic habitat (de Leiva Moreno et al., 2000). The Pelagic/Demersal ratio fluctuates for the entire simulation period between ca. 1 and 0.5, however show constant degreasing trend coursed by increase of biomass in pelagic and decrease in benthic functional groups. Ratio between clupeids and cod clearly indicate regime-shift from cod-to-sprat dominated system. The extremely high values of ratio at mid-1990s indicate time of cod stock collapse.

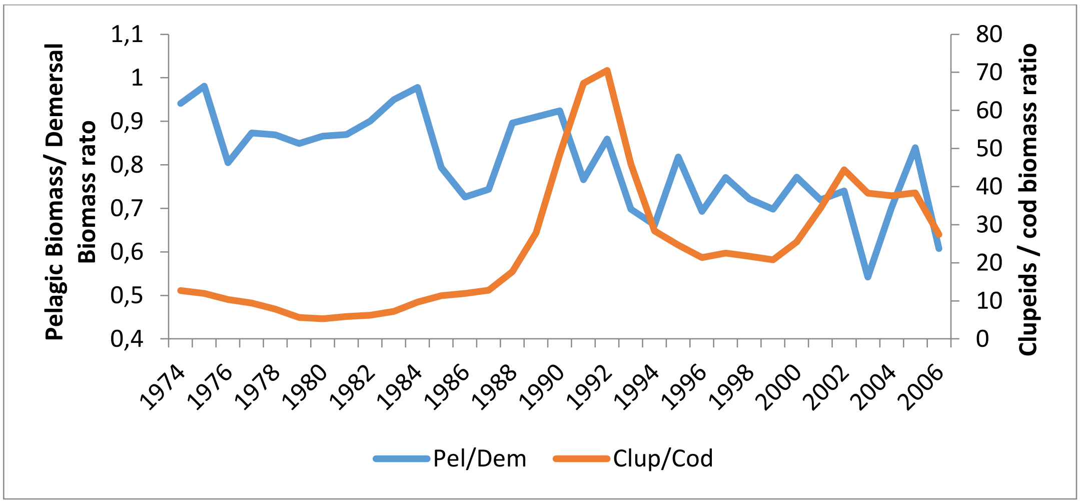

Figure 4.11. Pelagic/Demersal ratio including all functional groups excluding phytoplankton (blue) and Clupeids (Sprat and Herring biomass) per Cod biomass ratio (red).

4.7 References

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5. Icelandic waters case study

5.1 Computing GES indicators for the Icelandic waters case study

The first ecosystem model to be employed in the Icelandic waters case study was built using the Gadget modeling framework. The model is an age-length based forward simulation model where species interactions are defined via consumption and three key fleet components, bottom trawl (bmt), gillnet (gil) and longliners (lln) which are the key components of the demersal fishery in Icelandic waters. In the model the selection of the fleet is based on length. The processes of the model are estimated through comparisons with data via a weighted likelihood function. Similar models, albeit single species, have been developed and used to provide tactical advice in a management setting in Iceland and elsewhere. The model was built using Rgadget, a specialised R package for Gadget, and the Mareframe database developed in WP3. The model setup routines and the analysis illustrated here can be found on github.com/bthe/gadget-models. The following GES indicators were calculated based on the output from Gadget:

- Trends in biomass
- Abundance trends
- Recruitment
- Trends in landings
- Fishing reveneu
- Fishing mortality
- Catch to biomass ratio
- Shannon index
- Large fish indicator
- Mean maximum length
- Number of stocks overfished
- Fleet harvest rates

Indicators derived from the trophic level were not considered as they were not considered meaningful for this model.

5.2 Stock assessment indicators

In typical stock assessments the status of the stock is illustrated with the Spawning stock biomass, number of recruits, fishing mortality and catches. To assess the stock status relative MSY reference points a stochastic forward simulation was conducted where the ecosystem was simulated forward 100 years for various harvest rates. As none of the stocks are considered to have exhibited impaired recruitment the biomass reference point, B_{lim}, was set to be the lowest historical spawning stock biomass observed. The results of these forward simulations are illustrated in figures 5.1 and 3.2 where the steady state yield and SSB as function of relative harvest rates are shown.

In general, the stocks appear to be harvested close to or at F_{msy} with the notable exception of haddock which harvested at a lower rate than possible and have come down considerably in recent years (Fig. 5.6). The reason for the low harvest rate in haddock is the observed sporadicity in recruitment, which is not fully accounted for in the forward simulations, and the harvest control rule employed for haddock takes this into account. Overall the stocks are estimated to be recovering after a period of overexploitation, notably the cod stock is estimated to have reached pre 1980 levels. Saithe on the other hand appears to have decreased and is estimated close to B_{lim}, although the saithe stock never saw similar exploitation rates as the cod.

Fleets appear to target different species and size ranges. Longline and bottom trawl target similar size ranges whereas gillnets generally target larger fish. Saithe is almost exclusively caught by trawlers, tusk only on longline while other species are caught by all gears. The fleet operations have also changed dramatically in recent years, as illustrated in figure 5.8, as there has been a shift from gillnets and bottom trawls to longliners.

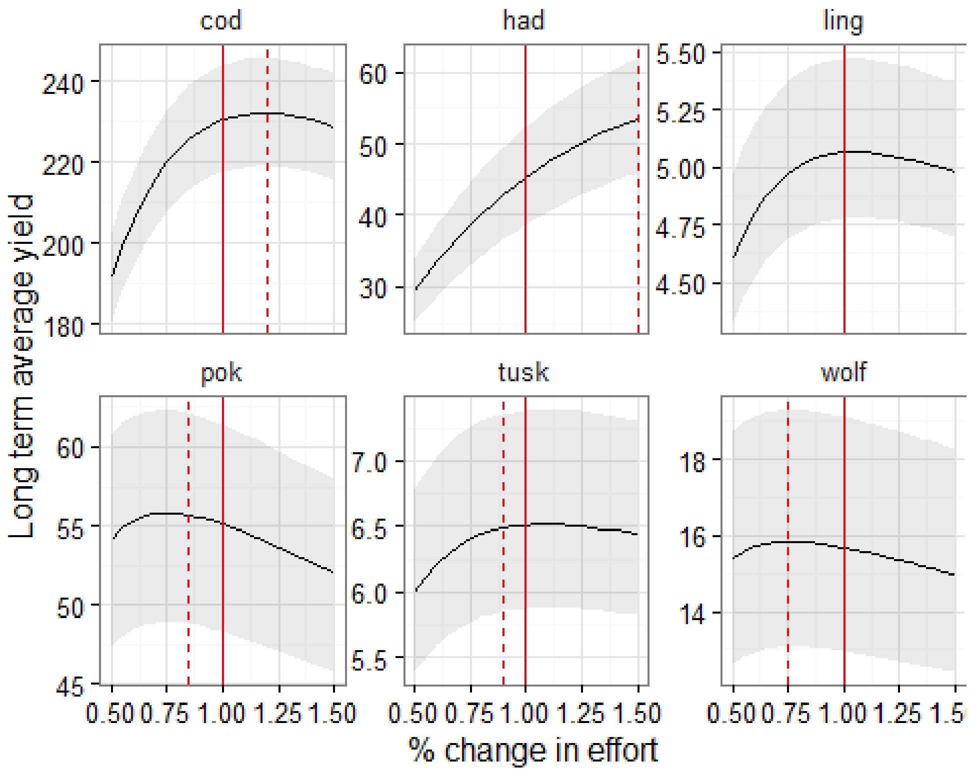

Figure 5.1. Long term average single species yield as function of relative harvest rate. Solid black line indicates the estimated average while the shaded region the 95% confidence intervals. Vertical red lines indicate status quo (solid lines) and optimal (dashed lines) harvest rates.

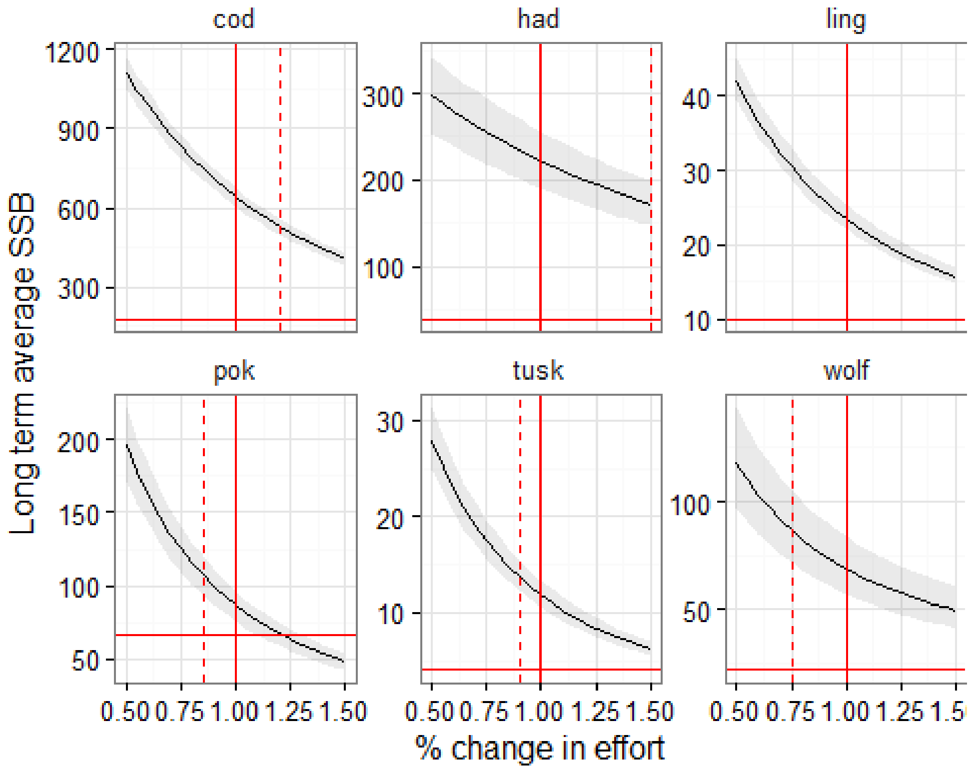

Figure 5.2. Long term average SSB as function of relative harvest rate. Solid black line indicates the estimated average while the shaded region the 95% confidence intervals. Vertical red lines indicate status quo (solid lines) and optimal (dashed lines) harvest rates, and horizontal line the ▯▯▯▯.

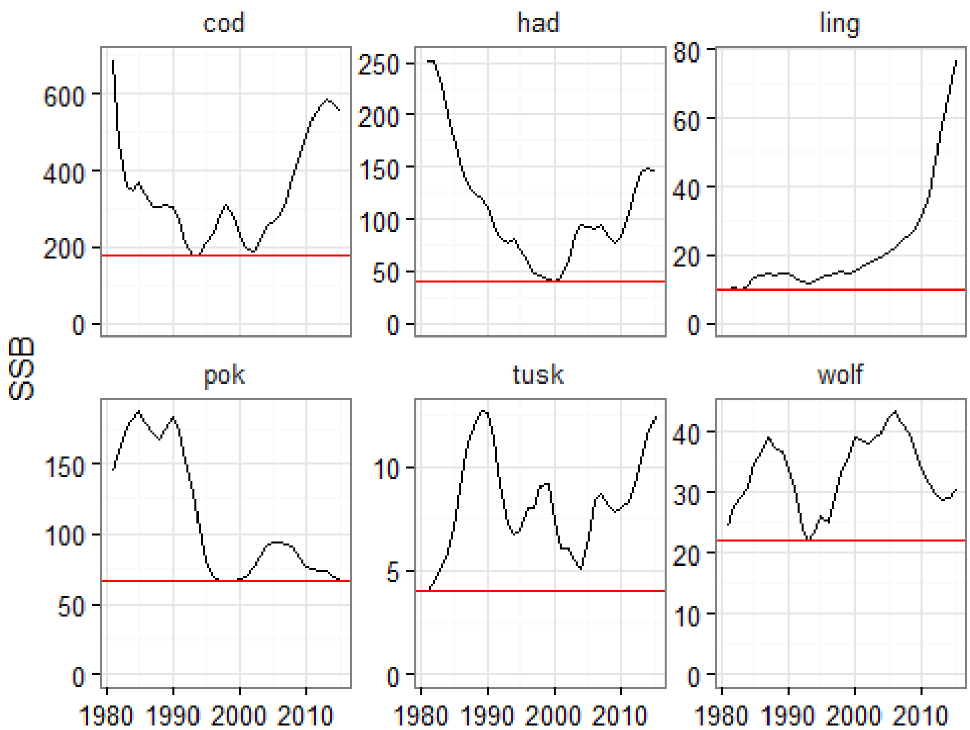

Figure 5.3. Spawning stock biomass by species. Horizontal red line indicates ▯▯▯▯

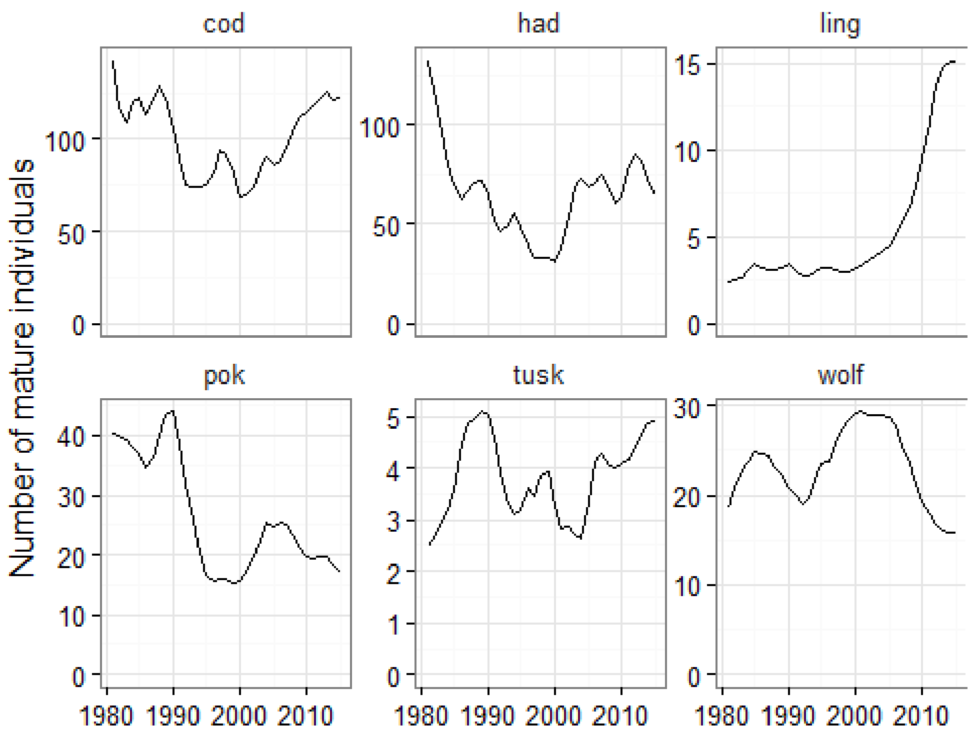

Figure 5.4.: Number of mature individuals by species

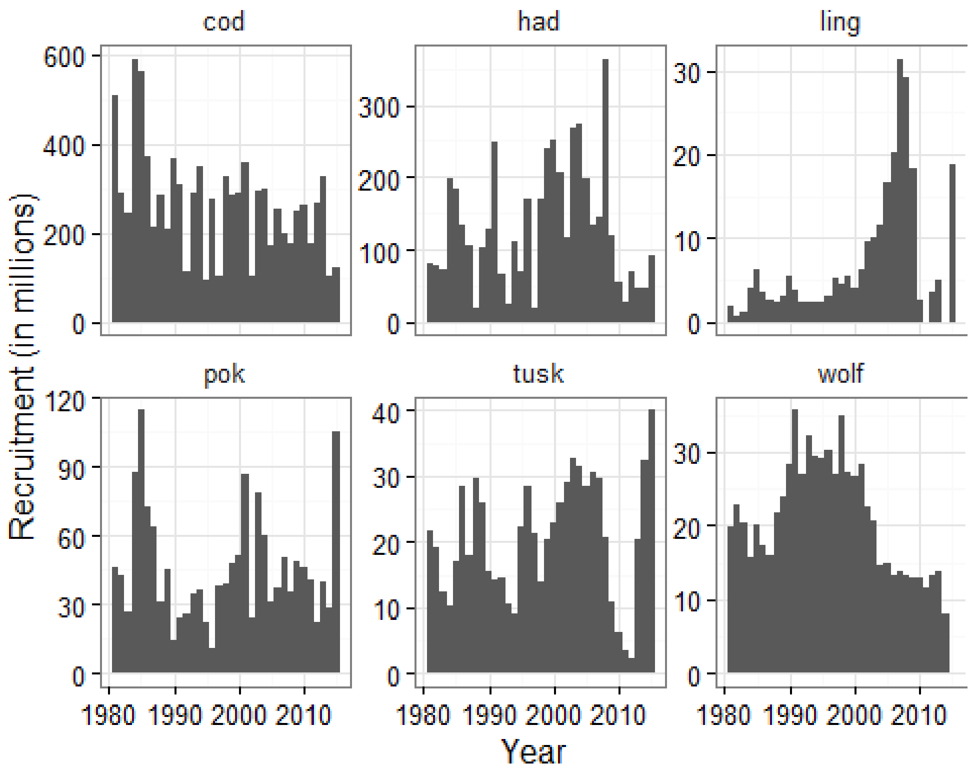

Figure 5.5. Estimated recruitment at age 1 by species

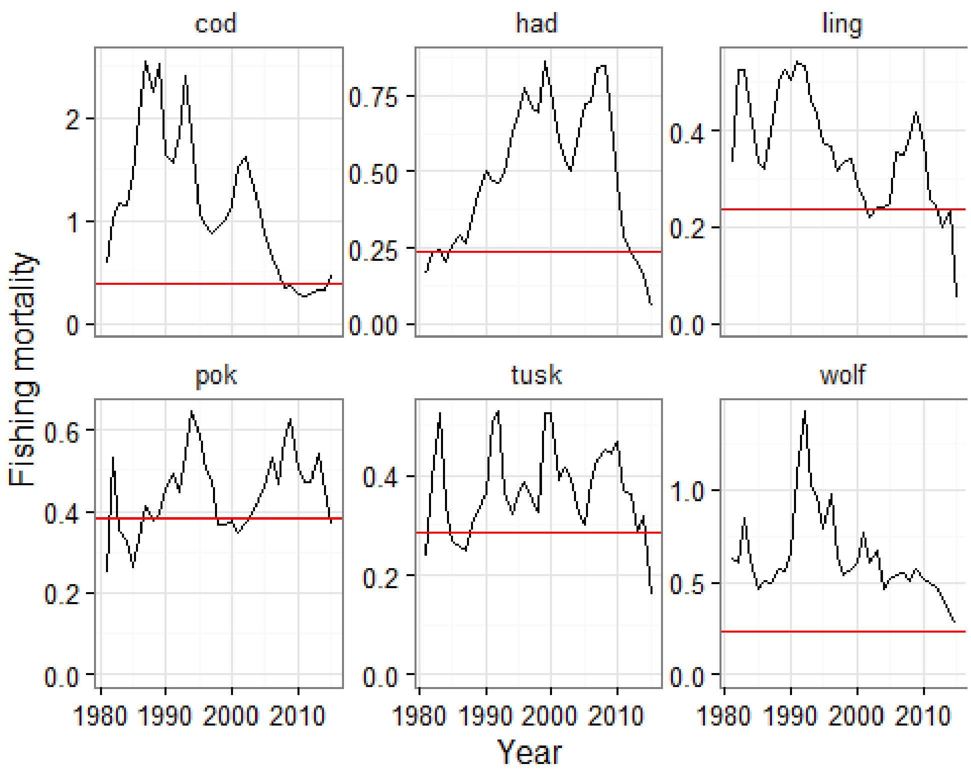

Figure 5.6. Estimated fishing mortality by species. Horizontal red line denotes ⍰⍰⍰⍰.

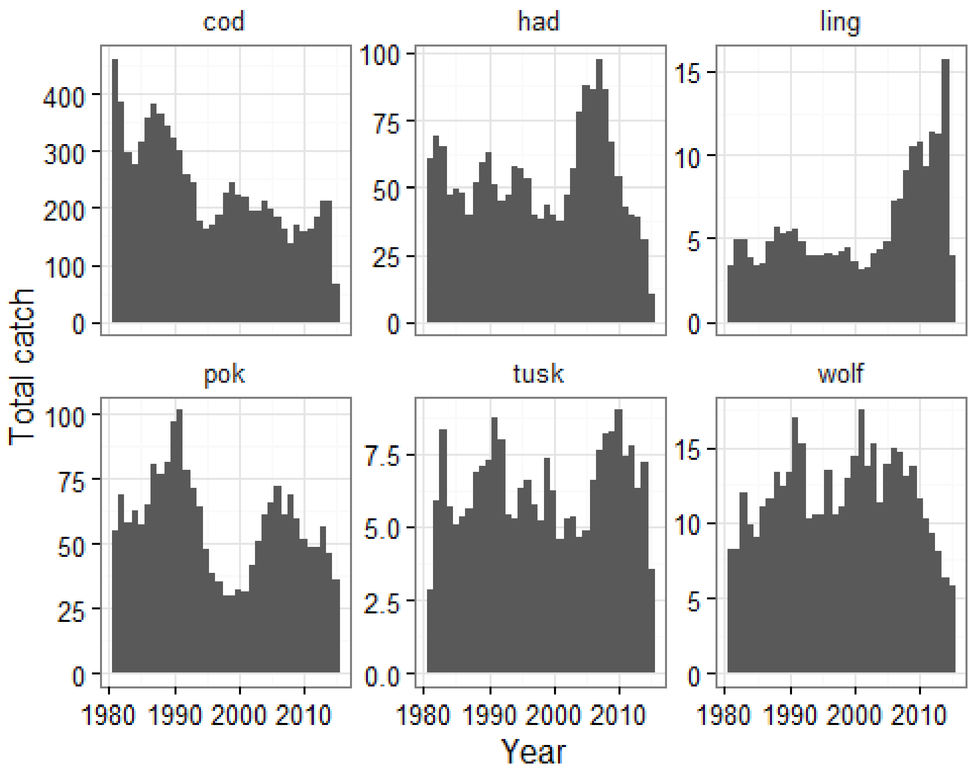

Figure 5.7. Landed catch by species.

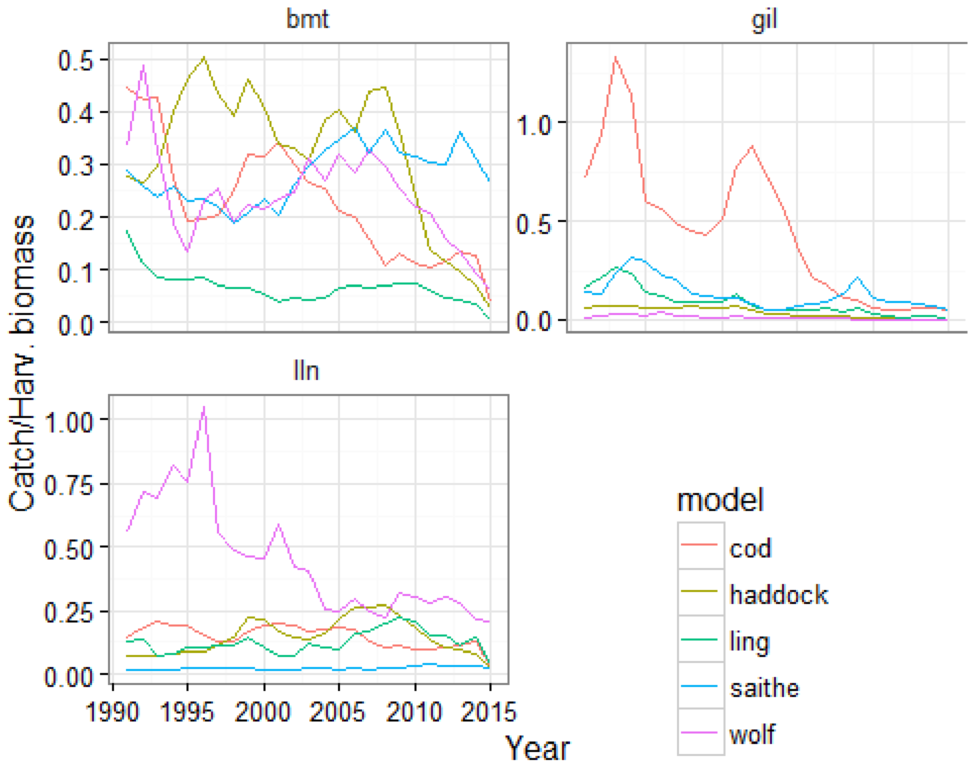

Figure 5.8. Harvest rate by fleet and species.

Overall ecosystem indicators

Figure 5.9 illustrates how the large fish indicator, Shannon index and maximum mean length (MML) has developed through the years. MML was estimated based on the maximum observed length recorded in MRI's database.

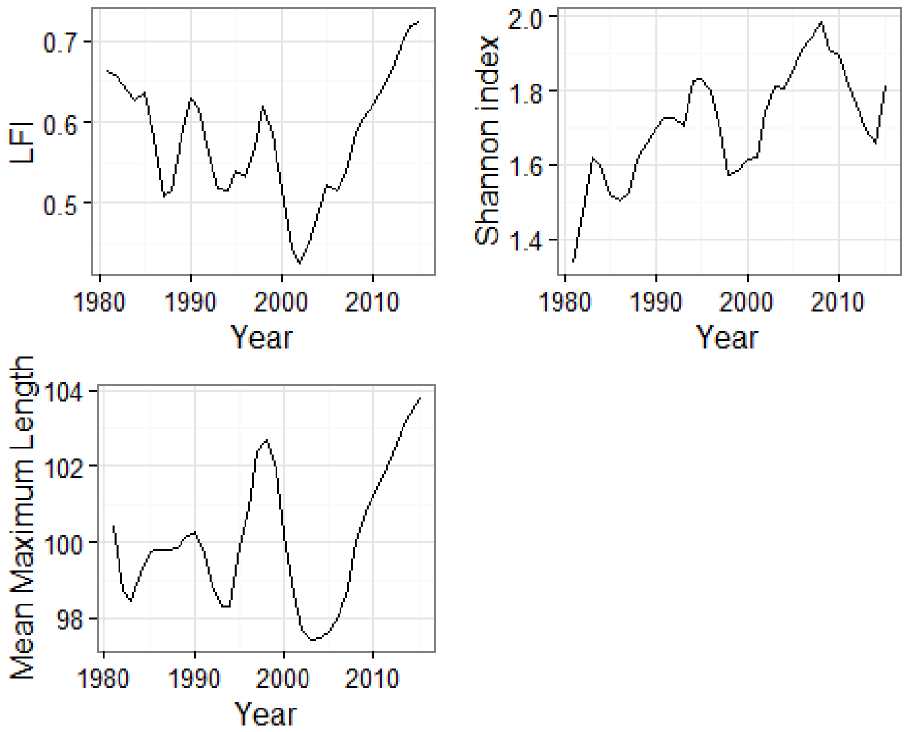

Figure 5.9.: Large fish indicator, Shannon index and Maximum mean length

5.3 Total revenue

Figure 5.10 illustrates the total revenue by species. The total revenue was estimated based on total landing and the average price from the directorate of fisheries in the years 2014 and 2015 and do not reflect changes in processing and market preference.

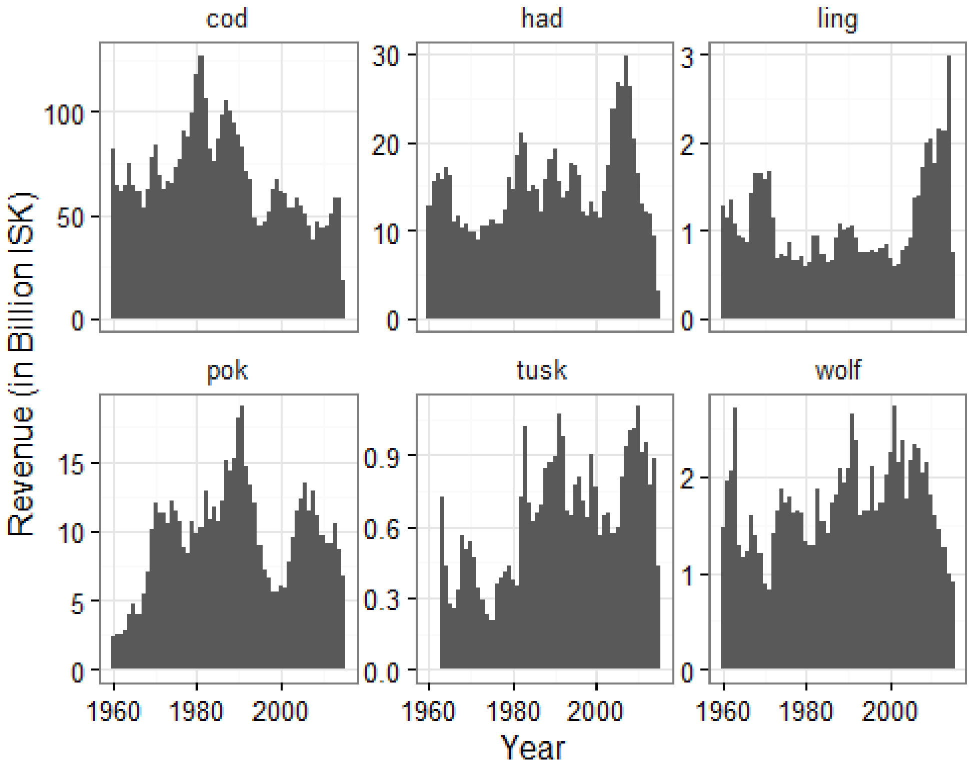

Figure 5.10. Total revenue by species

6. Strait of Sicily case study

6.1. Good Environmental Status, descriptors and indicators

The indicators listed in MareFrame Deliverable 4.2 that will be estimated in the Strait of Sicily case study are:

- Trends in biomass: do all species in the ecosystem reach a stable and sustainable status (% of species stabilised at the end of simulation)
- Abundance trends of functionally important species/groups
- Trends in landings
- Mean Trophic Level (MTL)
- Catch to biomass ratio
- Pelagic to demersal ratio: indicator of nutrient input and quality of benthic habitat (de Leiva Moreno *et al.*, 2000)
- Fishing revenues: using mean price/tonnes

6.2 Computing GES indicators for the Strait of Sicily case study

The first ecosystem model to be employed in the Mediterranean case study is Atlantis. Atlantis parameterisation has been described in MareFrame Deliverable 4.1. Although the model is currently being updated, the calculation of GES indicators from biomass and landings can already be developed and subsequently applied to updated versions of Atlantis. A full list of functional groups names and codes is given in the appendix (Table 6.3). The biomass and landings time series given by the model are given in figures 6.1 (a-c) and 6.2 respectively. The calculations and results for all indicators is detailed below.

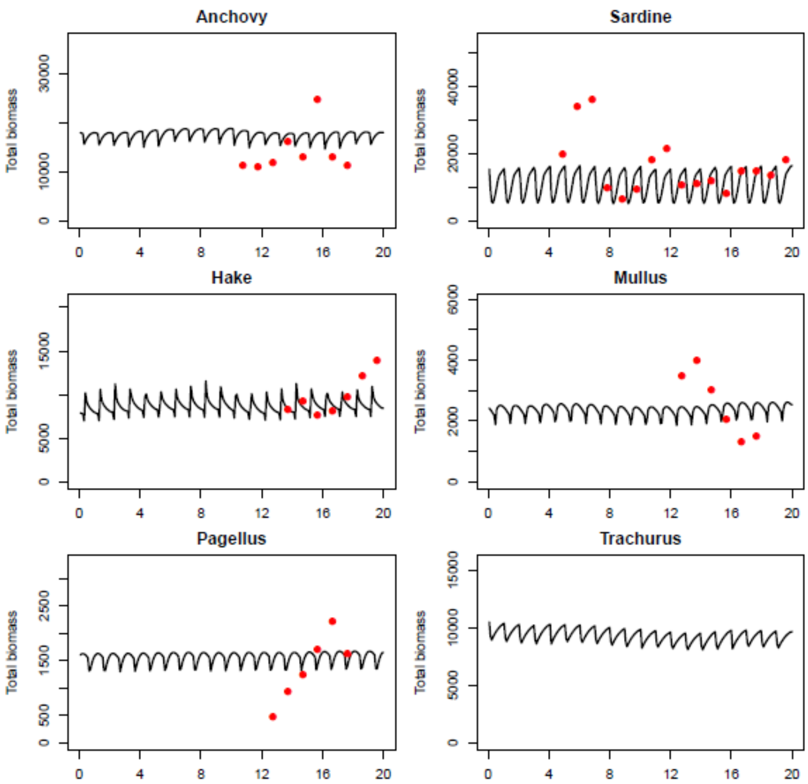

Figure 6.1a. Biomass time series in tonnes for all functional groups

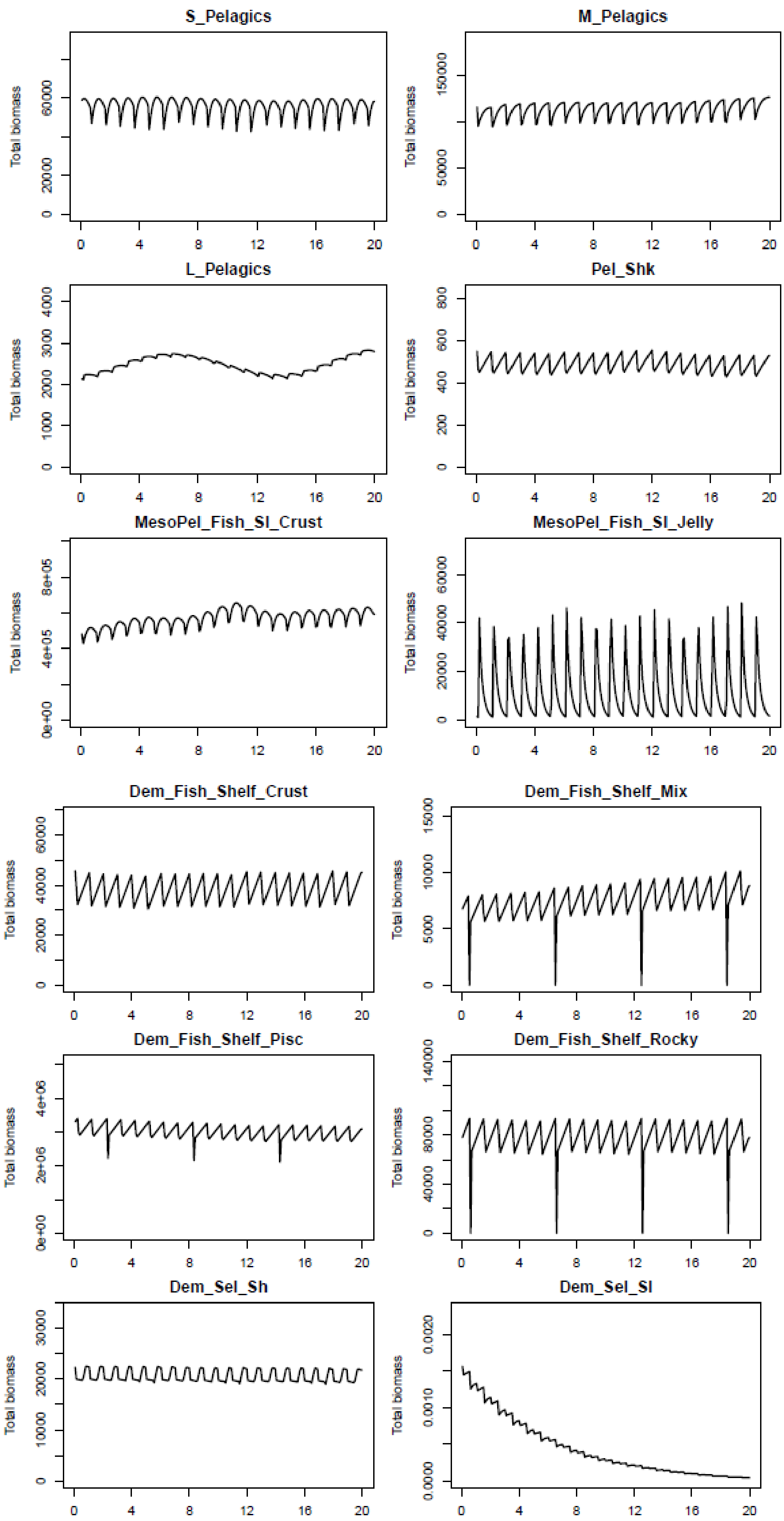

Figure 6.1b. Biomass time series in tonnes for all functional groups

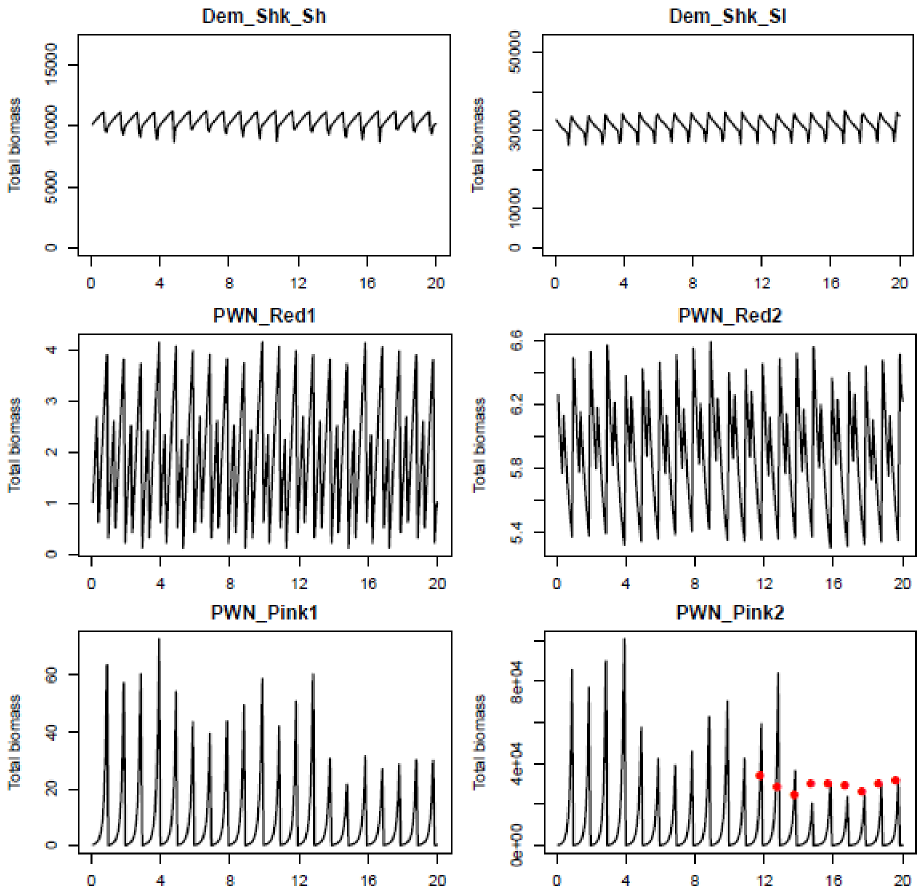

Figure 6.1c. Biomass time series in tonnes for all functional groups

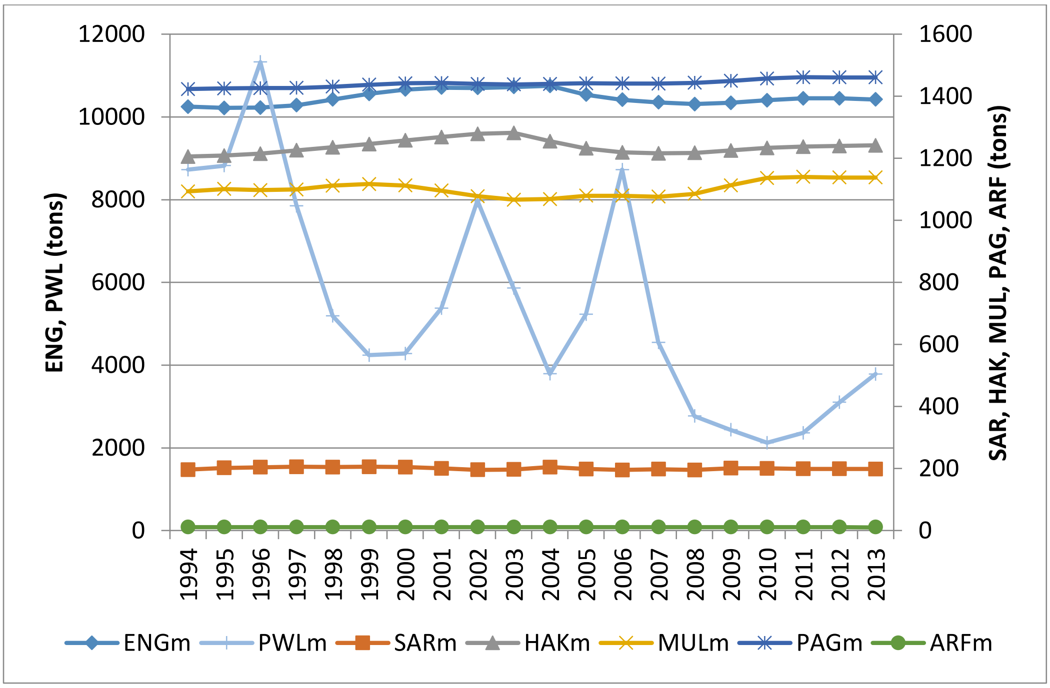

Figure 6.2. Landings time series in tonnes for functional groups targeted by fishing

The first three indicators of the list (i.e. biomass stability, abundance trends, landings trends) are qualitative indicators that represent the performance of the management at a given point in time. Figure 6.1 shows the total biomass time series reproduced by the model. Red dots represent assessment biomass data for the target species. Catch to biomass ratio are stock-specific indicators for all species targeted by fishing (Fig. 6.3)

6.2.1 Stability of biomass

The biomass of a functional group was considered stable in the last year of the simulated period if the year-to-year variation in the last consecutive five years did not exceed 10% (biomassyear*90% < biomassyear+1 < biomassyear*110%). The results for all functional groups are reported in Table 6.1.

6.2.2 Abundance trends

Abundance trends for each group were identified by assessing trends in biomass. To do so a linear model was fitted through the last three biomass values and the value of the slop was used to determine whether biomass was increasing or decreasing. The results for all functional groups are reported in Table 6.1.

6.2.3 Landings trends

Methods used to assess abundance trends were employed also to assess landings trends for functional groups targeted by fishing. The results for all functional groups are reported in Table 6.1.

Table 6.1. Results for the stability of biomass, abundance trends and landings trends indicators for the last 5 years of simulation for all functional groups.

FG	Stable biomass	Abundance trend	Landing trends
ENG	Yes	down	up
SAR	Yes	up	down
TRA	Yes	down	down
SPL	Yes	down	down
MPL	Yes	up	up
LPL	Yes	up	up
PSH	Yes	down	
MSC	Yes	up	up
MSG	Yes	up	up
MSP	Yes	up	up
SB	Yes	up	
MM	Yes	up	
TUR	No	0	
HAK	Yes	up	up
MUL	Yes	up	up
PAG	Yes	up	up
EPI	Yes	up	up
DFS	Yes	up	up
DFH	Yes	up	up
DSM	Yes	up	up
DSP	Yes	down	down
DSR	Yes	down	up
RSH	Yes	down	up
RSS	Yes	down	down
SSH	Yes	down	down
SSS	Yes	up	up

CPH	Yes	down	up
CPS	Yes	down	up
CBH	Yes	up	up
CBS	Yes	down	down
ARF	Yes	down	down
PWL	Yes	down	down
DNH	Yes	up	
DRH	Yes	down	
DNS	Yes	down	
DRS	Yes	down	
BC	Yes	down	
BO	Yes	down	
MBH	Yes	down	
MBS	Yes	up	
EUP	Yes	up	
SUH	Yes	up	
SUS	Yes	up	
PB	Yes	up	
BB	Yes	up	
ZG	Yes	down	
PS	Yes	down	
PL	Yes	down	
DF	Yes	up	
ZS	Yes	up	
ZM	Yes	down	
ZL	Yes	up	
MA	Yes	down	
MB	Yes	down	
SG	Yes	down	

6.2.4 Catch to biomass ratio

The catch to biomass ratio (C:B) indicates the exploitation rate and can be employed as a proxy for fishing mortality. C:B was calculated for functional groups targeted by fishing by dividing the catches by the biomass. C:B time series are given in Figure 6.3.

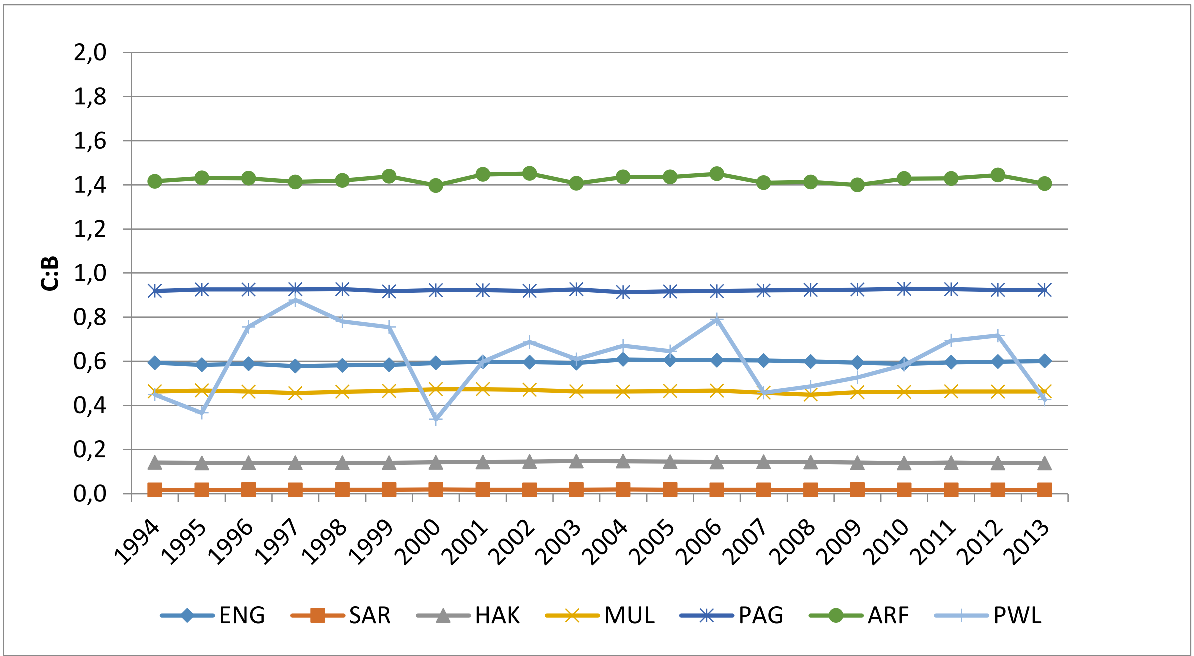

Figure 6.3. Catch to biomass ratio (C:B) for target functional groups

6.2.5 Mean trophic level

Trophic level (Table 6.2) is a measure of a node's 'distance' from the primary producers in the community and hence indicates how many steps matter, and hence energy, has been through to reach that node. It was calculated for each functional group using the definitions of Williams and Martinez (2004). The value returned is the sum of 1 plus the mean trophic level of the node's resources, using the matrix inversion method of Levine (1980) that is very fast and accounts for flow through loops.

Table 6.2. Trophic levels of the functional groups included in the model

Functional Group	MTL
PSH	5.28
MSP	5.13
SB	5.12
LPL	5.03
MM	5.02
SSH	4.92
SSS	4.91
RSS	4.80
DSP	4.77
RSH	4.71
TRA	4.69
DFS	4.64
TUR	4.56
HAK	4.56
MPL	4.43
SPL	4.32
MSC	4.30
CPH	4.29
CPS	4.29
DSR	4.28
PAG	4.27
DRH	4.15
DRS	4.15
MSG	4.13
DFH	4.13
EPI	4.04
DNH	3.91
DSM	3.81
CBH	3.44
DNS	3.40
SAR	3.33
ENG	3.32
CBS	3.25
ZL	3.24
MUL	3.19
ZG	3.00
ARF	2.84
MBH	2.59
MBS	2.59
ZM	2.55
SUH	2.47

SUS	2.47
PWL	2.40
BC	2.20
EUP	2.20
ZS	2.20
BO	2
DF	2
BB	1
DC	1
Dcsed	1
DL	1
Dlsed	1
DR	1
Drsed	1
MA	1
MB	1
PB	1
PL	1
PS	1
SG	1

6.2.6 Pelagic to demersal ratio

The pelagic to demersal ratio (P/D) was calculated for each year by dividing the sum of biomass of pelagic groups by the sum of biomass of demersal groups. The pelagic groups considered are: ENG, SAR, TRA, SPL, MPL, LPL, PSH, MSC, MSG, MSP, MM, TUR, CPH, CPS.

The demersal groups are: HAK, MUL, PAG, EPI, DFS, DFH, DSM, DSP, DSR, RSH, RSS, SSH, SSS, CBH, CBS, ARF, PWL. The P/D time series is given in Figure 6.4.

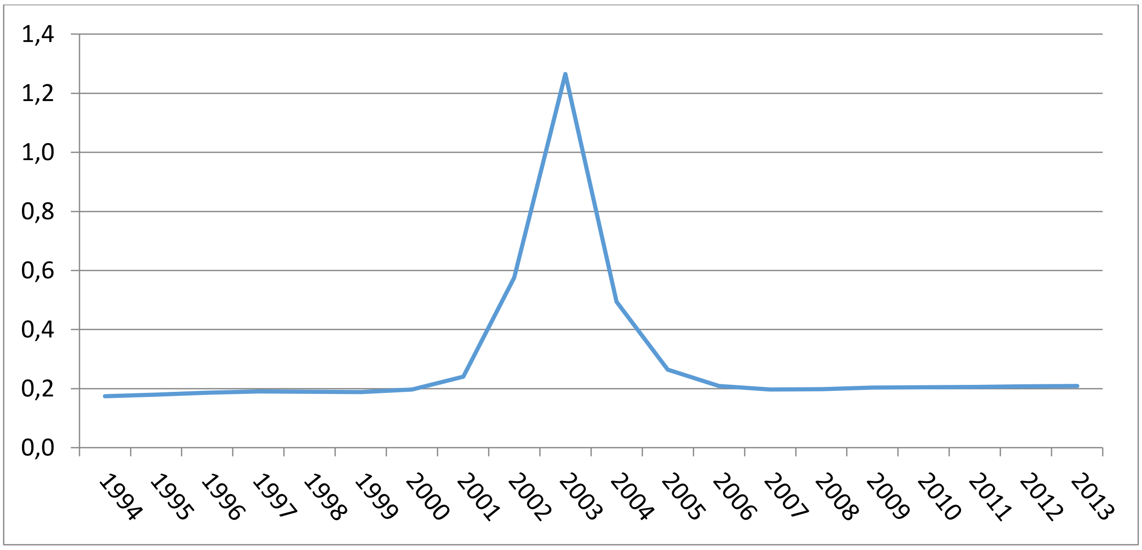

Figure 6.4. Pelagic to demersal biomass ratio.

6.2.7 Fishing revenue

The fishing revenue indicator requires the price per tonne of the targeted functional groups. These values are currently being gathered. Fishing revenue will be calculated for each functional groups targeted by fishing by multiplying the landings (in tonnes) by the price (in €/tonne).

6.3 References

de Leiva Moreno J.I., Agostini V.N., Caddy J.F., Carocci F., 2000. Is the pelagic-demersal ratio from fishery landings a useful proxy for nutrient availability? A preliminary data exploration for the semi-enclosed seas around Europe. ICES Journal of Marine Science 57:1091–1102

Levine, S (1980) Several measures of trophic structure applicable to complex food webs. Journal of Theoretical Biology 83, 195–207.

Williams, R. J. and Martinez, N. D. (2004) Limits to Trophic Levels and Omnivory in Complex Food Webs: Theory and Data. American Naturalist 163, 63, 458–468.

6.4 Appendix

Table 6.3. Functional groups list and names

Code	Long Name	Name
ENG	*Engraulis encrasicolus*	Anchovy
SAR	*Sardina pilchardus*	Sardine
HAK	*Merluccius merluccius*	Hake
MUL	*Mullus barbatus*	Mullus
PAG	*Pagellus erythrinus*	Pagellus
TRA	Trachurus spp	Trachurus
SPL	Other Small pelagics	S_Pelagics
MPL	Medium pelagics	M_Pelagics
LPL	Large pelagics	L_Pelagics
PSH	Pelagic sharks	Pel_Shk
MSC	Mesopelagic fish slope crustacean feeders	MesoPel_Fish_Sl_Crust
MSG	Mesopelagic fish slope jelly feeders	MesoPel_Fish_Sl_Jelly
MSP	Mesopelagic fish slope piscivorous	MesoPel_Fish_Sl_Pisc
SB	Seabirds	Seabird
MM	Marine mammals	Mammals
TUR	Sea turtles	Turtles
EPI	Epipelagic fish	Epipelagic_Fish
DFS	Demersal fish slope	Dem_Fish_Sl
DFH	Demersal fish shelf crustacean feeders	Dem_Fish_Shelf_Crust
DSM	Demersal fish shelf mixed food	Dem_Fish_Shelf_Mix
DSP	Demersal fish shelf piscivorous	Dem_Fish_Shelf_Pisc
DSR	Demersal fish shelf rocky	Dem_Fish_Shelf_Rocky
RSH	Demersal rays shelf	Dem_Sel_Sh
RSS	Demersal rays slope	Dem_Sel_Sl
SSH	Demersal sharks shelf	Dem_Shk_Sh
SSS	Demersal sharks slope	Dem_Shk_Sl
ARF	*Aristaeomorpha foliacea*	PWN_Red
PWL	*Parapaeneus longirostris*	PWN_Pink
CPH	Pelagic cephalopod shelf	Cep_Pelagic_Sh
CPS	Pelagic cephalopod slope	Cep_Pelagic_Sl
CBH	Benthic cephalopod shelf	Cep_Benthic_Sh
CBS	Benthic cephalopod slope	Cep_Benthic_Sl
DNH	Natant decapods shelf	Dec_Nat_Sh
DRH	Reptant decapods shelf	Dec_Rep_Sh
DNS	Natant decapods slope	Dec_Nat_Sl
DRS	Reptant decapods slope	Dec_Rep_Sl
BC	Benthic Carnivore	Benthic_Carniv
BO	Meiobenthos	Meiobenth
MBH	Macrobenthos shelf	MB_Sh
MBS	Macrobenthos slope	MB_Sl
EUP	Euphausiids	Euphausiids
SUH	Suprabenthos shelf	Supra_Sh
SUS	Suprabenthos slope	Supra_Sl
PB	Pelagic Bacteria	Pelag_Bact
BB	Sediment Bacteria	Sed_Bact
ZG	Gelatinous zooplankton	Gelat_Zoo
PS	Picophytoplankton	PicoPhytopl
PL	Diatom	Diatom
DF	Dinoflagellates	DinoFlag
ZS	Microzooplankton	MicroZoo
ZM	Mesozooplankton	Zoo
ZL	Large zooplankton	Carniv_Zoo
MA	Macroalgae	Macroalgae
MB	Microphtybenthos	MicroPB
SG	Seagrass	Seagrass
DL	Labile detritus	Lab_Det
DR	Refractory detritus	Ref_Det
DC	Carrion	Carrion

7. The North Sea case study

7.1 Introduction

The broad strategy of the North Sea case study is to provide simple interactive models that allow stakeholders to explore management scenarios and to explore the trade-offs between management decisions. Since the interactive models must by their nature be approximations to more complex models the solutions they suggest can then be further checked against more detailed models. The essence of such simple interactive models is that they rapidly respond to changes in inputs. So the GES criteria shown in these models must be robust and quick to calculate. They should at least show the correct direction of changes in GES criteria even if they are not quite precise as to its absolute level. This may at times require plausible proxies to be chosen.

The most recent guidance on the MSFD descriptors that are of most relevance to fisheries management (descriptors 3, 4 and 6) is provided by three Workshops organised by ICES in February 2015 (ICES 2015a,b,c).

Descriptor 3 is concerned with achieving a healthy status for exploited fish and shellfish species, descriptor 4 with achieving a healthy status for marine foodwebs and descriptor 6 with maintaining the integrity of the sea floor. This report is concerned with calculating how these descriptors might vary under management action. This is approached by exploring the historic time series of descriptors in and indicating how best these might be calculated or approximated in forward projections. Since the MAREFRAME project is dedicated to adopting a multispecies approach to fisheries management the MSFD descriptors are, where appropriate, estimated in a multispecies fashion. At times these may differ with descriptors that are seen in a single species context.

7.2 MSDF Descriptor 3. Healthy status for exploited fish and shellfish species.

7.2.1 MSDF Descriptor 3.1: Pressure Descriptor.

Fishing mortality rate is normally regarded as the appropriate measure of fisheries pressure on a stock. ICES 2013 provides estimates of Multispecies Fmsy under assumptions of fixed F for cod and saithe. These are generally higher than the equivalent single species Fmsy (Table 7.1). Since cod and saithe are important predators these seem more realistic than the single species equivalents.

Using these values of Fmsy and the estimates of fishing mortality provided by the SMS run from ICES 2011 (WGSAM) gives the 5 year running average time-series of F/Fmsy for each of the species seen in Figure 7.1.

Table 7.1. Single species and multispecies Fmsy

Species		Single-species	Multispecies
		FMSY	FMSY (target F above Bpa)
Cod		0.19	0.50
Whiting			0.30
Haddock		0.30	0.35
Saithe		0.30	0.45
Herring		0.24-0.3	0.55
Sandeel*			0.55
	Norway pout*		0.60
Sprat*			0.55

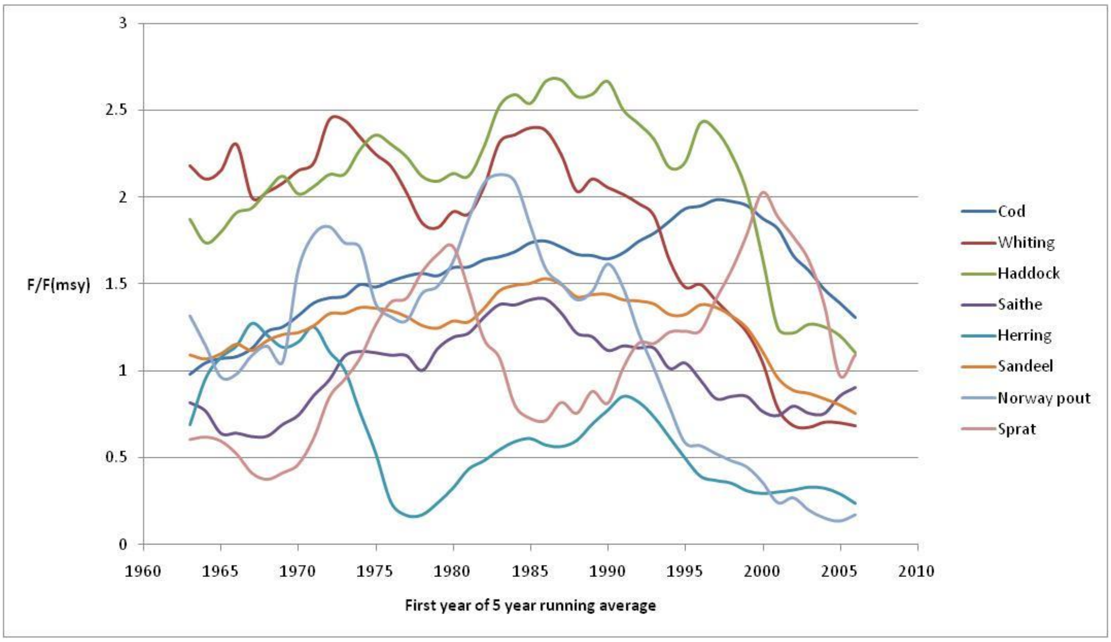

Figure 7.1. Five year running averages of F/F(msy).

Five year running averages were chosen because annual results are variable and make the annual figures difficult to read and also because extended periods of sustained pressure are more likely to reduce stocks than odd spikes in mortality rate. These pressure measures from SMS are used in the quadratic approximation model that provides the interactive model of how long term yield might respond to changes of fishing pressure and are also used as inputs to the simple sized based model. Alternative estimates of fishing mortality rate estimated from an alternative multispecies model will emerge when the planned GADGET model becomes operational.

7.2.2 MSDF Descriptor 3.2 State Descriptor.

ICES 2013 also provides estimates of Blim and Bpa. These may not be realistic as multispecies limit levels as they do not reflect some likely interactions between the pelagic and demersal components of the system. Those for gadoids may reflect optimal biomass at the time of the gadoid outburst which occurred when herring and mackerel were at low levels. Thus they may need rethinking for a multispecies setting. Their current values are given in Table 7.2.

Table 7.2

Species	Blim/Lower trigger biomass	Bpa/Higher trigger biomass	Average SSB at FMSY
	(thousand tonnes)	(thousand tonnes)	(thousand tonnes)
Cod	70	150	168
Whiting	200	250	150
Haddock	100	140	128
Saithe	106	200	207
Herring	800	1000	1303
Sandeel*	787	1098	859
Norway pout*	263	440	130
Sprat*	157	213	221

Five year running averages of the ratio of spawning stock biomass (SSB) to Blim are shown for the main North Sea species in figure 7.2. Again 5 year running means were used to reduce inter-year variations that otherwise obscure the main trends. The figure also shows the steady state levels of SSB expected at current levels of fishing mortality. These formed the basis for predicting the consequence to SSB of changing the exploitation levels of the different species. Current exploitation levels are predicted to bring cod, haddock, saithe, herring and sprat to SSB levels comfortably above Blim but leave whiting, sandeel and Norway pout below Blim.

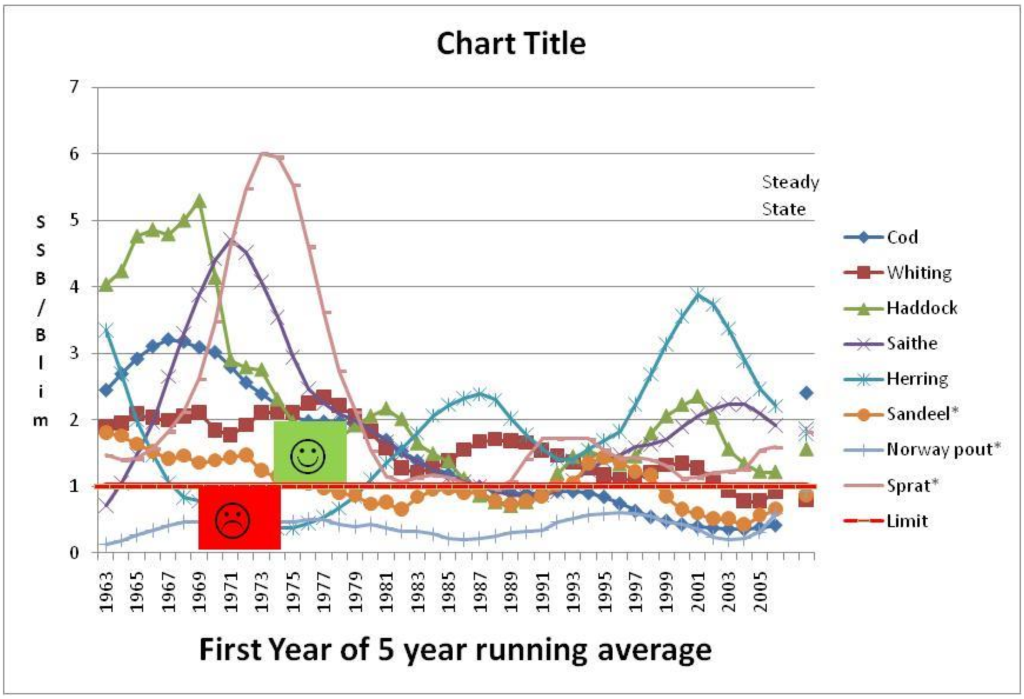

Figure 7.2. Five year running averages of SSB/Blim for the main North Sea fish species.

7.3 MSDF Descriptor ¤4. Descriptors of the marine foodweb

These descriptors are less easy to interpret as good or bad GES but show ranges of viable states that have occurred during the availably time series.

7.3.1 MSDF Descriptor 4.1: Foodweb Structure.

Figure 7.3 shows the changes in the biomass of the 3 major functional groups of fish that are estimated in SMS. There seems some increase in piscivore and benthivore biomass in the period from the mid 1960's to about 1980 when planktivore biomass was dropping and a subsequent decline after that period as planktivore biomass increased. This is particularly associated with the decline and subsequent recovery of herring in these periods.

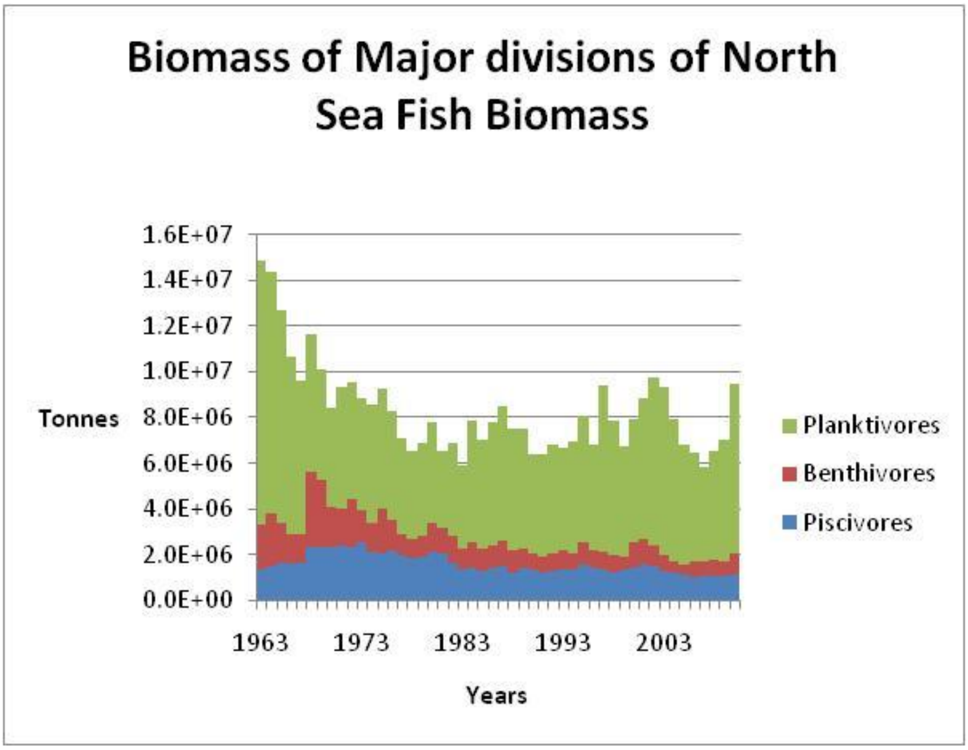

Figure 7.3. Biomass through time of fish species in 3 major fish functional groups in the North Sea that have their biomass estimated in SMS.

Figure 7.4 shows biomass by year estimated by the charmingly simple model (CSM) for species with Loo> 40cm (these species roughly equate to the combined piscivores and benthivores in fig. 7.3) and with Loo<40cm (these species roughly equate to the planktivores in fig. 7.3). The charmingly simple model (CSM) is a much simpler model which utilises a common stock recruitment function for all species and therefore does not account for year to year or inter-decadal variations in species recruitment. It is simply driven by species specific fishing mortality rate, predation and the common average stock recruitment relationship. Nor is it tuned to species catch or survey results (except the LFI). It is therefore remarkable that figures 7.3 and 7.4 show broadly similar trends. This may suggest that we may not need to look much beyond fishing mortality rate and predation to explain the broad trends of the North Sea fisheries.

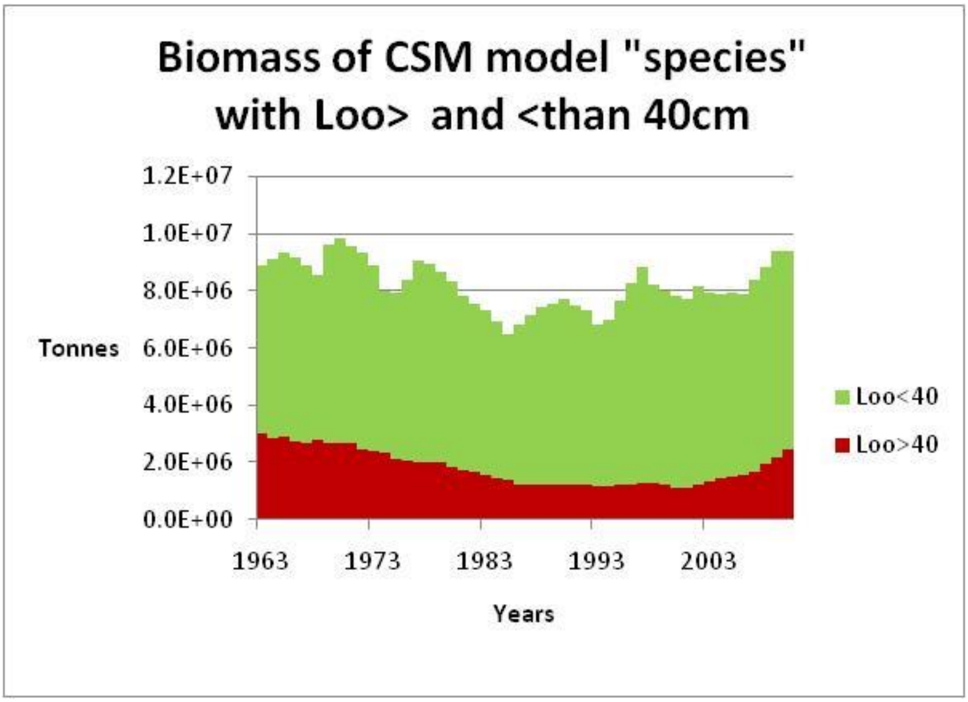

Figure 7.4. Biomass through time of CSM species with Loo> 40cm (roughly equate to piscivores and benthivores in fig. 7.3) and with Loo<40cm (roughly equate to Planktivores in fig. 7.3).

7.3.2 MSDF Descriptor 4.2 Foodweb Structure.

The most relevant foodweb structure measure for the North Sea is the Large Fish Index (LFI), Greenstreet et al (2012). The LFI shows annually the proportion the biomass of fish above 40cm that are found in the IBTS Q1 survey, form of the total (measured here for all fish above 20cm length). Figure 7.5 shows modelled results from the Stochastic Multi-Species (SMS) and the CSM models compared to the LFI. While the LFI was used to tune the CSM this tuning only influences the general steepness of the trend, not its shape. CSM results appear to fit rather well after about 1980. The divergence between the CSM and SMS in the early years may in part be a “burn in” problem with the CSM since the fishing mortality rates used pre 1963 in the CSM were those of 1963. It may be possible at a later date to reconstruct fishing mortalities for these earlier years using published fishing mortality rates for cod, haddock, whiting (Pope and Macer (1991) and for Herring and Plaice (ICES Working Groups) and with intelligent guesses for other species to see if this will resolve these differences.

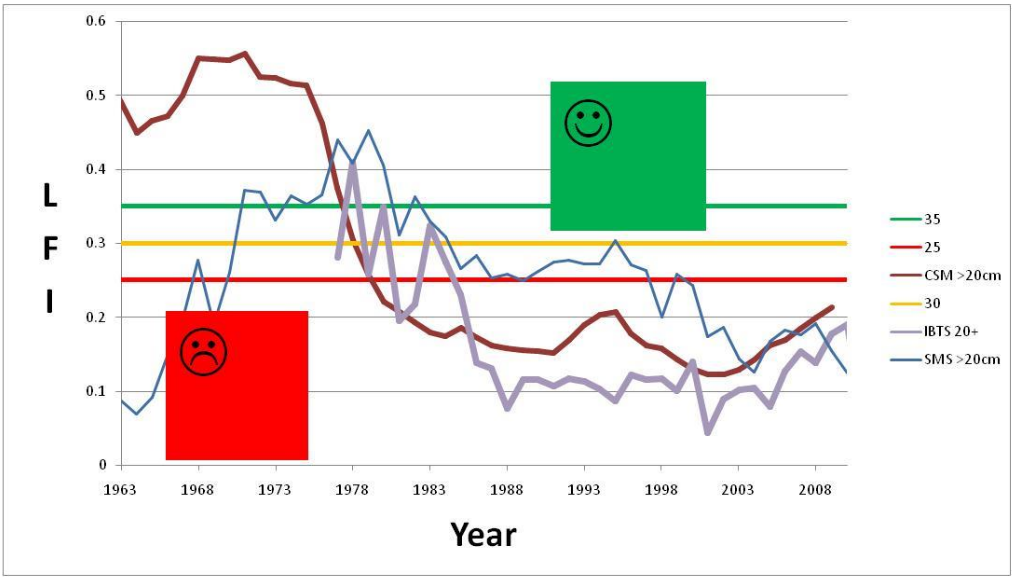

Figure 7.5. Comparing the LFI based upon fish >20cm from the IBTS Q1 survey of the North Sea with equivalent results from CSM and SMS.

Size spectrum slope is an alternative measure of foodweb structure. Figure 7.6 shows a comparison of size spectrum slope found from the IBTS Q1 survey of the North Sea with results from the CSM. The fit need a slightly modified parameter set compared to that used to fit the LFI equivalent result (fig. 7.5)

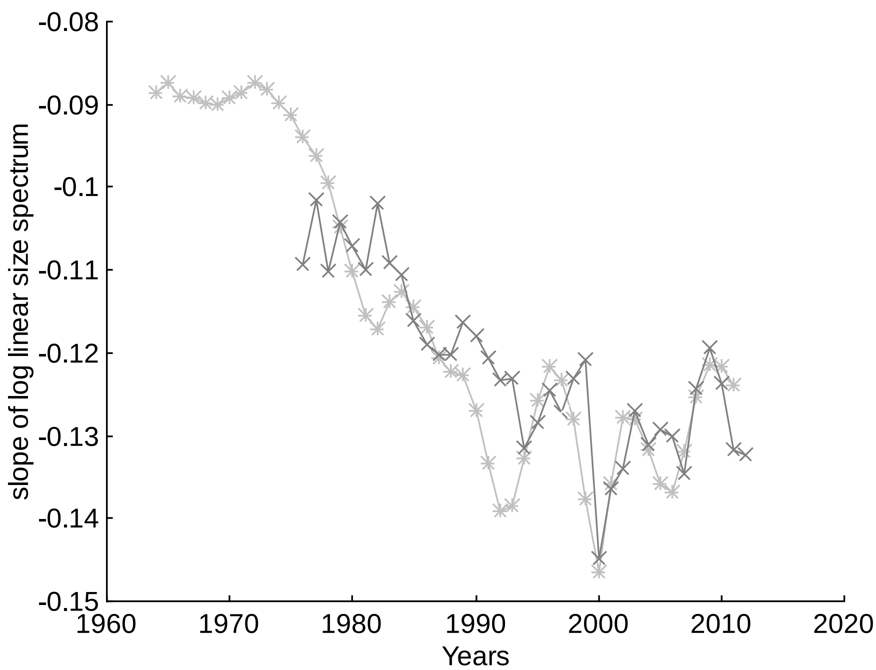

Figure 7.6. Comparison of annual log-linear size spectrum slope for the North Sea as estimated from the IBTS Q1 survey (Cyan crosses) and from the CSM (Green asterisks).

7.4 MSDF Descriptor ¤6. Descriptors of Seafloor integrity.

The impact of fishing on the sea floor of the North Sea depends primarily on the gears used, the intensity with which they are used and the vulnerability of the different places they are used. Fishing effort data by rectangle by gear is available at the STECF data site (http://datacollection.jrc.ec.europa.eu/dd/effort). However this is only available for the most recent years and is still not complete. Moreover, it only provides data for EU vessels and data for the Norwegian fleets must be sought elsewhere. It is intended to use this data as inputs to a spatial explicit model of the North Sea. For this it should therefore be possible to give estimates of impacts on the seabed. These will however be data derived rather than model derived. The North Sea models so far considered do not model area and so cannot model area vulnerability. However, for these simpler models a pragmatic measure of seabed effect might be a weighted average of the fishing mortality on demersal species with heaviest weightings given to the mortality rates of the flat fish species that are caught by beam trawls. Figure 7.7 shows such an index. This index increases from about 1970 to 2000 but then declines sharply. Dredges and beam-trawls used to harvest some shellfish species also create a seabed disturbance but since these species are not included in the current models they are not included in the current index. If their usage remained unchanged they might be thought of as adding a constant to this index.

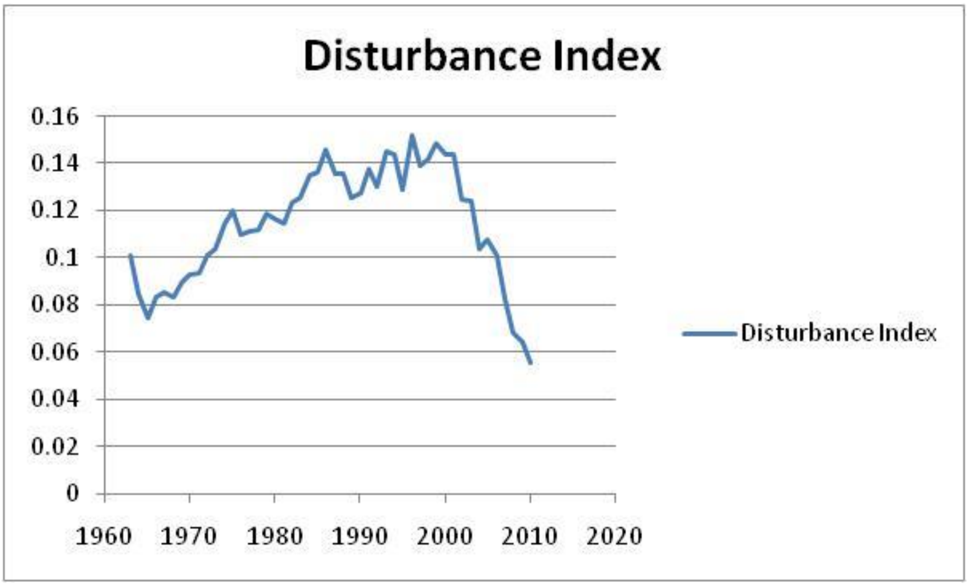

Figure 7.7. A pragmatic Seabed fishing disturbance index based on a weighted average of the average fishing mortality rate on demersal fish species.

7.5 Conclusions

It will be possible to provide at least simple measures of GES descriptors 3.1, 3.2, 4.1, 4.2 and 6 in the proposed simple Interactive models of the North Sea. These can be further elaborated as more detailed models of the North Sea come on stream later this year.

7.6 References

Greenstreet, S. P. R., Fraser, H. M., Rogers, S. I., Trenkel, V. M., Simpson, S. D., and Pinnegar, J. K. 2012. Redundancy in metrics describing the composition, structure, and functioning of the North Sea demersal fish community. – ICES Journal of Marine Science, 69: 8–22.

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8. South Western Waters

8.1 Introduction

The SWW case study is comprised of two different subcases with two models: (1) in the whole Atlantic Iberian peninsula a model for cetacean fishery interactions where the strategy is modelling the population trajectories of hake, once predators (small cetaceans) and other prey are included in the model as other food and, (2) in the Gulf of Cadiz, with the aim of modelling the anchovy dynamics including fishing and the environmental factors that mainly affect its early life-stages. In both sub-cases, the main objective of these models is to evaluate management trade-offs and conflicting objectives such as single species, ecological, social or economic targets.

8.2 GES for Iberian Peninsula hake – dolphins model

In this Case Study we have focused on the southern stock of the European hake and two cetacean species: common dolphin and bottlenose dolphin. By modelling cetacean abundance, predation and the mortality caused by their interaction with the fishery we can explore the effects of fisheries management measures. The model will allow us to explore the interactions between GES indicators (in our case indicators for D1 - Biodiversity, D3 - Commercial species and D4 - Food webs) and explore the effects of trying to achieve the GES as defined for one descriptor into our ability to achieve the GES for other descriptors, responding to the MAREFRAME goal of adopting a multispecies approach to fisheries management.

The modelling strategy limits our option to explore different GES indicators. In our case, a MICE model was developed including a dynamic model for the two dolphin species and for the hake; other pelagic species were also incorporated as other food. The model tracks the abundance and mortality of these 3 species under fishing pressure and predator-prey interaction.

8.2.1 Dolphin models

Dynamic models for both dolphin species were developed quarterly, from 1982 to 2014. This time range matches the GADGET hake model allowing the study of interactions in the past and future. Dolphin models include the following process: maturity, growth, breeding, natural mortality and by-catch mortality. To allow a consistent estimation of breeding the model was split in 3 sub-stocks: immature stock, mature males and mature females. Both the lack of annual catch data and the high variability of the available estimated abundance, limit the model ability to track the cetacean annual changes in abundance.

The only absolute abundance estimates available for common and bottlenose dolphin populations in the study area were obtained by the SCANS-II survey (SCANS, 2006), carried out in July 2005 (Hammond et al., 2013). Additionally, since 2007, a sampling program for cetaceans was implemented on the PELACUS survey in the N and NW of the Iberian Peninsula (Saavedra et al., 2015). Common dolphin sightings from 2007 to 2014 were analysed with the Distance Sampling software to estimate relative population size. Bottlenose dolphin abundance estimates were calculated similarly, although unrealistic patterns were detected due to an unexpected increase of sighting over the last years. The observed trends in bottlenose dolphin sightings were not considered to fit the model that was fit only to the SCANS abundance. The analysis of the survey series showed a slight increase of the common dolphin abundance in the surveyed area; however, abundance estimates typically have wide confidence limits and the power to detect even relatively strong trends may thus be limited. Furthermore, this increasing trend was not apparent in the strandings time-series and both results contradict each other. Therefore, in our dolphin models we have considered a constant abundance for both populations, without any trend, fitted to the mean of the available abundance time-series (Figure 8.1). For such purpose, fishing mortalities were estimated at a rate that keeps populations stable.

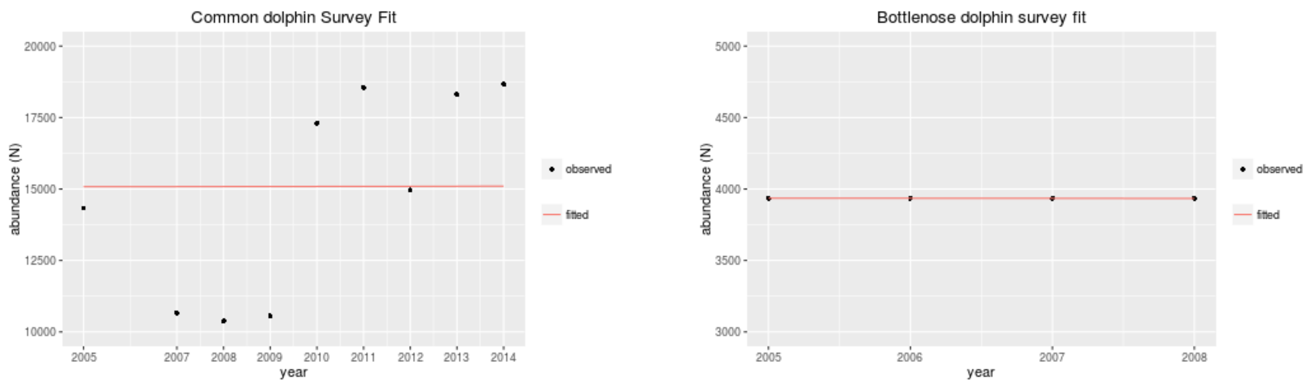
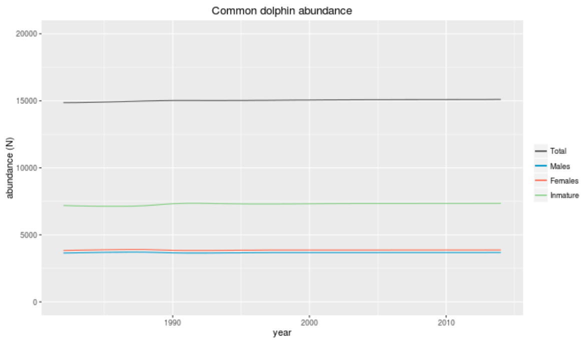


Figure 8.1. Abundance data used to calibrate the model. Time-series of abundance for common dolphin from SCANS and PELACUS surveys (left). Bottlenose dolphin estimated abundance from SCANS (right). The later was replicated 4 times to stabilize the model.

Member States were required to report the assessment for Descriptor 1 at three separate ecological levels: species, habitats and ecosystems. For the species level, marine mammals were included as a functional group where common and bottlenose dolphins are the main and most abundant species in the study area. The MSFD required Member States to develop indicators, designed to measure progress towards the achievement of the environmental targets. Spain defined three indicators relevant to marine mammals: distribution (range), abundance and demographic characteristics (e.g. mortality rate) (Santos & Pierce, 2015 for a detailed explanation of the process). Our GADGET model allows us to address the abundance and the by-catch indicators for both dolphin species.

As stated above, because of the lack of accurate abundance information and mortality rates for the studied dolphin populations, the time-series of abundance from 1982 until 2014 have been keep stable. Trends will be assessed against the proposed targets detailed in ICES (2014a) advice to OSPAR, which suggested that a suitable indicator target for some cetacean species could be “For each assessment unit, maintain population sizes at or above baseline levels, with no decrease of ≥30% over a three-generation period” or “over any ten-year period” in the case of bottlenose dolphins. There are no data prior to human impacts in this area, so it is not possible to set a historical baseline; therefore, the baseline abundances were set for this exercise as the mean of the estimated abundances of the last years as explained above with a fishing mortality which keeps populations stable (Figure 8.2).



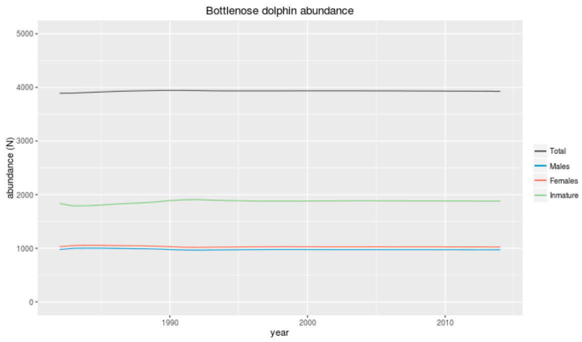


Figure 8.2. GADGET modelled trends on abundance for total, males, females and the immature stock of common dolphin (left) and bottlenose dolphin (right) models, set as baselines.

Fishery bycatch has been identified as the main anthropogenic threat to many populations of marine mammals worldwide (e.g. Lee et al., 2006) and particularly important in certain areas of the Iberian Peninsula (notably in the North western (Galician) waters. For the mortality rate due to the by-catch indicator, the method to calculate the reference points for our case of study was a percentage of abundance of the best population estimates, following a similar approach as the used to the establishment of the 1.7% proposed for harbour porpoise by the International Whaling Commission (IWC, 2000) and the Agreement for the Conservation of Small Cetaceans of the Baltic and North Seas (ASCOBANS) (IWC, 2000). This removal rate would allow populations of harbour porpoises to reach and/or be maintained at 80% of carrying capacity. In our case of study, we assumed that the abundance of our modelled cetacean populations is below its carrying capacity, which cannot be accurately estimated; therefore, the maximum removal rate was established as the proportion which keeps stable the abundance of the populations (Figure 8.3).

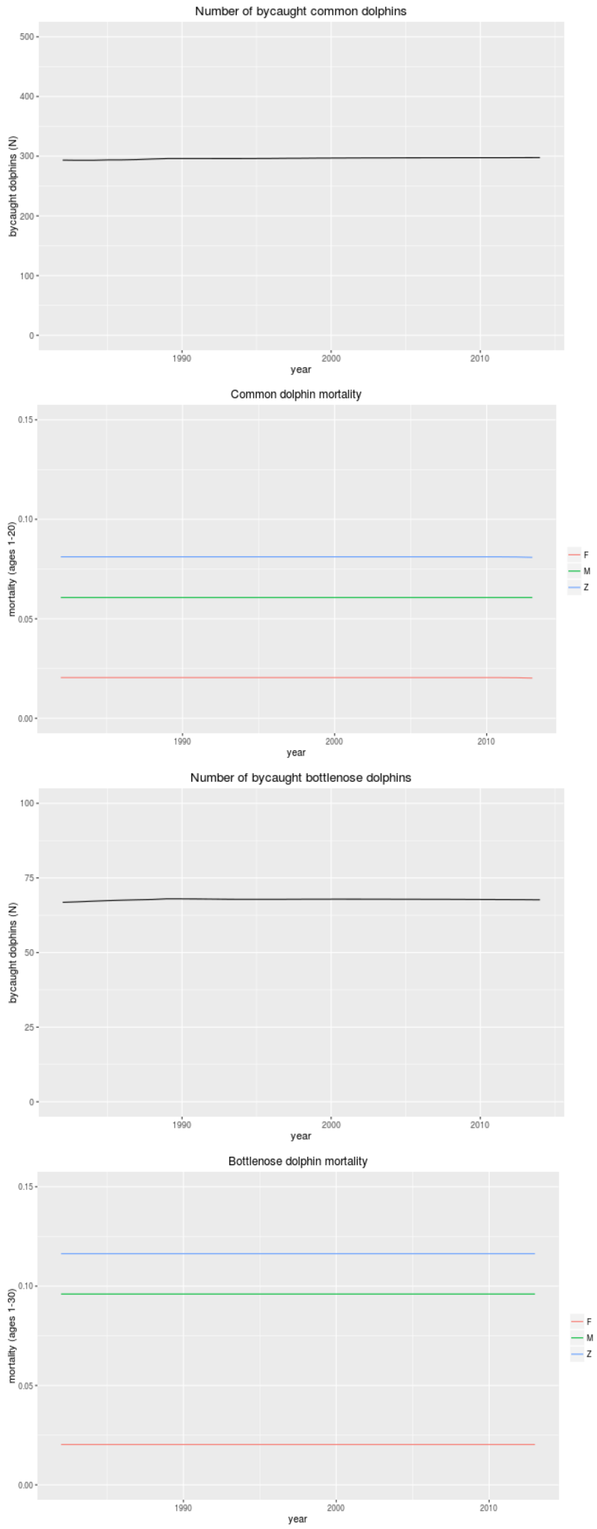


Figure 8.3. GADGET maximum modelled removals from by-catch (upper plots) and maximum total mortality (F) by-catch or fishing mortality (F) and natural mortality (M) (lower plots) for common dolphins (left) and bottlenose dolphins (right) populations.

8.2.2 Hake model with trophic link

Both dolphin population models have been joined with hake using diet data obtained from the analysis of 512 stomach contents of common dolphins and 82 of bottlenose dolphins stranded on the Galician coasts over the last 20 years (Santos et al., 2007; 2013 and unpublished data). To estimate the daily consumption of individual cetaceans various energy indices developed for odontocetes were used. Hake length distribution in dolphin stomach was used for modelling a selectivity Andersen function for the size of hake consumed by dolphins. In addition to the hake outputs (as dolphins prey), other main dolphin prey (sardine and blue whiting) were included in the model, with data derived from their annual assessments incorporated into an "otherfood" category.

The individual hake model is the same that was approved by ICES to provide advice on catch options (ICES, 2015). It is a quarterly forward projection model from 1982 to 2014. It includes information from landings and discards, both total weight and length distribution. The model is calibrated with survey series and LPUEs. Biologically the growth model was set as a constant von Bertalanffy parameters (Linf=130 cm and k estimated by the models = 0.17). In the original model natural mortality was set equal to 0.4 for all ages and years. When the trophic link with cetaceans is implemented in the multispecies model, the hake natural mortality has two different components: M1 that is a constant estimated by the model and M2 that is the mortality caused by cetacean predation. This new total natural mortality (M1+M2), which can be variable over the time and age, is the main difference compared with the ICES hake model. This difference affects the trends in fishing mortality and abundance (Figure 8.4), related with the MSDF Descriptor 3 "Healthy status for exploited fish and shellfish species". Some proposed indicators for this Descriptor are the Indicator 3.1 (Pressure Indicator), where fishing mortality rate is normally regarded as the appropriate measure of pressure and the Indicator 3.2 (State Indicator), where SSB is considered the best option.

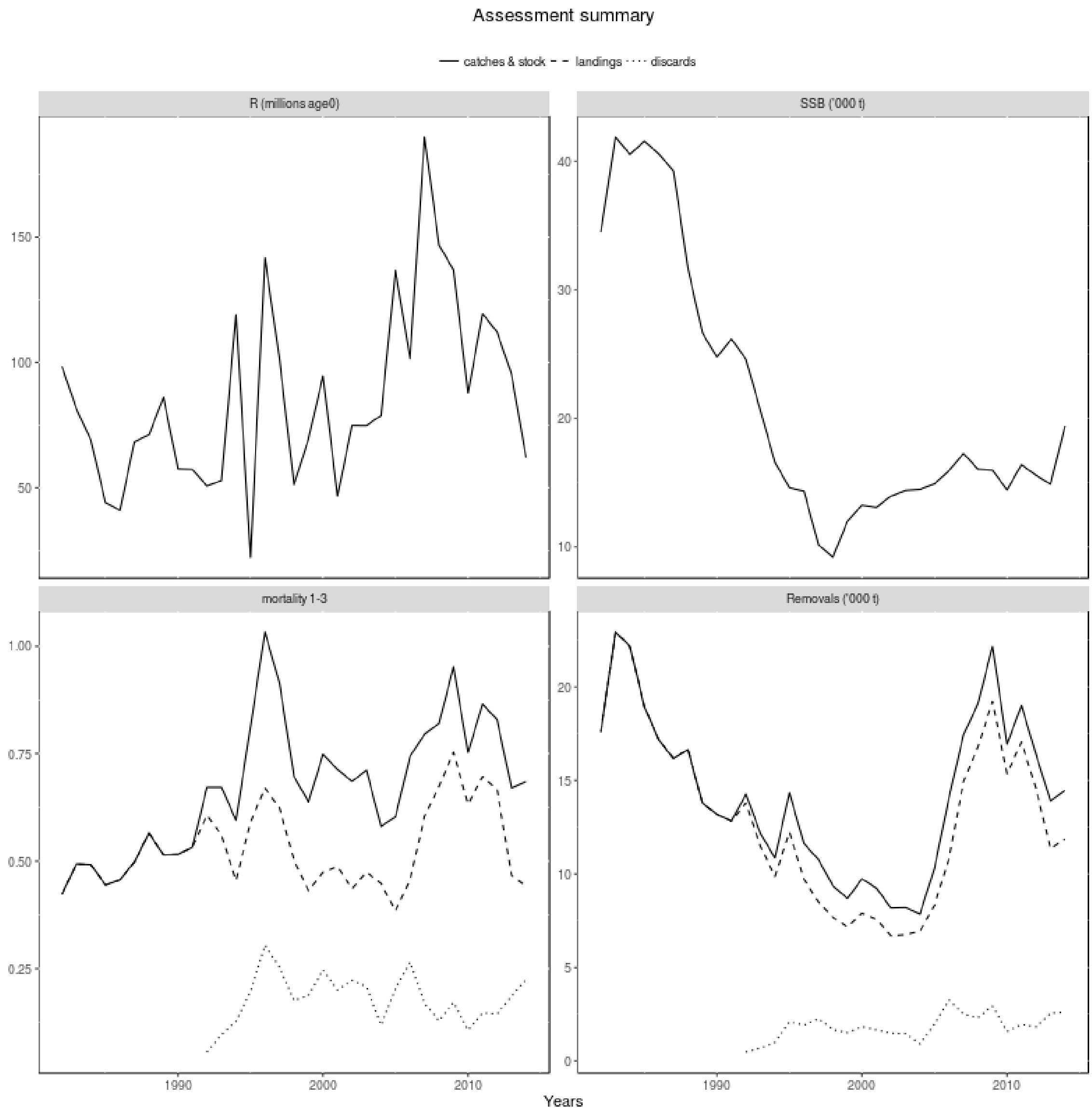


Figure 8.4. Hake trends for recruitment (R), spawning biomass (SSB), fishing mortality (ages 1-3) and catches.

8.2.3 Conclusions

Figures for the metrics of the Indicators selected to evaluate the GES of the functional group of marine mammals, belonging to the Descriptor 1 (The biodiversity is maintained) and for the hake included in the Descriptor 3 (The population of commercial fish species is healthy) have been provided for the period 1982 to 2014. Descriptor 4 (Elements of food webs ensure long-term abundance and reproduction) were not considered for this model and the GES of the key predators (dolphins and hake) will be only tested using the Indicators of Descriptors 1 and 3

This multispecies model has been fitted and the contribution of the cetaceans' predation to the hake dynamics estimated. However, the adjustment and parameterization of the multi-species model is still being improved and further changes can be expected in the near future. Particularly we will consider the uncertainty in abundance and fecundity which will be evaluated with alternative scenarios. Other work that is required is the re-estimation of the hake MSY reference points following the ICES recommendations (ICES, 2016). The change in hake dynamics after including the cetaceans could have modified these references and new figures are required to evaluate GES.

The approach considered, where the abundance of dolphins was set as constant, was understood as a valuable compromise with the information available. The lack of a continuous monitoring for by-catch estimates and abundance trends are the main limitation. Given this limitation, the multispecies model developed is an important contribution to evaluate the interaction between dolphins and fisheries. Regarding the historic performance, we have estimated constant parameters for dolphin abundance and by-catch mortality and we have estimated the hake dynamics with a more realistic natural mortality. Regarding the options to explore alternative management scenarios, the dolphin by-catch mortality could be linked with the fishing effort, so scenarios where fishing mortality is modified can be useful to quantify conflicting objectives and tradeoffs may be evaluated.

8.3 GES indicators for Gulf of Cadiz anchovy's GADGET model

The physical environment impacts fish stocks and landings (Erzini, 2005;Lloret et al., 2001), particularly for short-lived small pelagic species (Basilone et al., 2006; Guisande et al., 2004; Lindegren et al., 2013; Nakata et al., 2000). This effect is observed at different time-scales (Fréon et al., 2005). Short-term synoptic events affect mostly the early life stages engendering recruitment failures which are thought to drive inter annual fluctuations of catches more than variations in fishing effort (Cingolani et al., 1996; Dimmlich et al., 2004). Variability and instability characterize the dynamics of small pelagics (Fréon et al., 2005). Their position in the food web and the prominent role of recruitment in the population dynamics partly explain the aforementioned dynamics.

Intense easterlies, sea surface temperature and the influence of the Guadalquivir river have been identified as the main environmental factors influencing anchovy (*Engraulisencrasicolus*) early life stages (Ruiz et al., 2006, Prieto et al., 2009) in the Gulf of Cadiz.Sea temperature is associated to the spawning (Motos et al.,1996, García and Palomera, 1996) and strong winds are linked to recruitment variability (Rincón et al.,2016), while discharges from the river are related to extreme events, like the collapse in 1995 and a huge recovery in 1997, corresponding to a severe drought that forces discharges to drop below 10 Hm^3/month during 1995 and the raise of water flow in 1996 and 1997, respectively. Since then, due to agriculture demands, discharges have been stabilized near 100 Hm^3/month inducing a small variability on recruitment.

Anthropogenic pressure is reflected in the length distribution of the landings. A pattern is observed before year 2000, when there are some quarters with landings below 6 cm. The official regulation appears in 1995 that forbids catches below 12 cm, but until 2001 it wasn't effective.

The period from 2001 to 2013 is thus a stable period for anthropogenic and environmental forces in order to measure the impact of fishing mortality on biomass.

8.3.1 The Model

A quarterly GADGET model was implemented in R from 2001 to 2013 using *Rgadget* and *mfdb*, supported by the following likelihood components extracted from ICES reports:

- Length distribution of landings
- Length distribution of survey ECOCADIZ0813 (August 2013)
- Age distribution of landings
- Survey indexes from PELAGO survey (Once a year from 2001 to 2013 during the first semester)
- Survey indexes from SAR survey (April 2001, 2007 and 2012)
- Survey indexes from ECOCADIZ survey (February 2004 and March 2006, 2007, 2009, 2010, 2013)
- Length-age relationship for landings

8.3.2 Reference points

There are no reference points provided by ICES for this stock but it is possible to make some approximations based on available publications.

8.3.3 Fishing Mortality

When the fishing mortality is fixed at a constant value, the environment makes recruitment fluctuate along the years. Given such sources of environmentally driven variability, a constant fishing mortality regime in comparison with the current management with a fixed quota, corresponds to a scenario where landings do not achieve the TAC owing to lack of enough stock biomass. The time series of landings evidences that the level of the quota is frequently unachieved (ICES, 2014b).

A maximum average value calculated with a fixed F could be used as an approximation to a reference point because the notion of FSMY has difficulties for its application to small pelagic heavily fluctuating with the environment. Figure 8.5 from Ruiz et al. (submitted) displays the average and standard deviation of catches obtained for 1000 simulations of 30 years in a minimum realistic model developed by Rincón et al. (2016). It shows a maximum average catch at monthly F value close to 0.2.

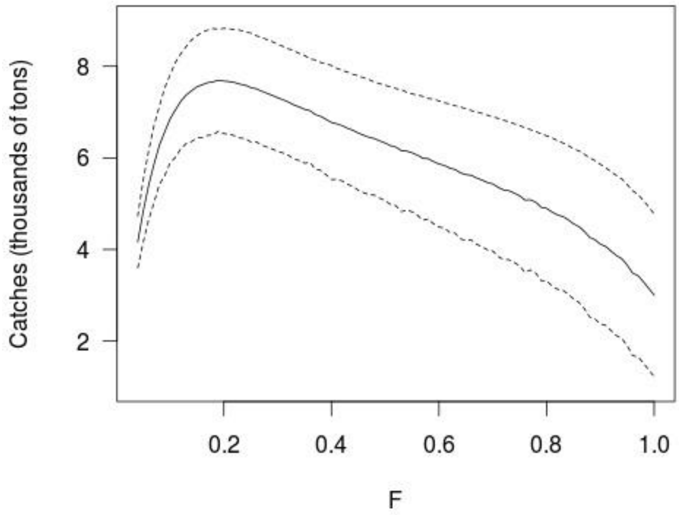


Figure 8.5. Mean (solid line) and standard deviation of catches when monthly F is fixed for 1000 simulations of 30 years. Upper and lower dotted lines are the mean plus and minus standard deviation, respectively.

8.3.4 Biomass

Dynamics under a fixed quota are simulated by setting F in a value (e.g. 0.5 month-1) that ensures maximum captures but decreasing this value when necessary to prevent more landing than allowed by the quota (6500 tons in year 2015). An increment of the TAC over 6.5 tons reveals a higher risk of collapse (Figure 8.6 [From Ruiz et al. submitted]), and this threshold may be taken into account.

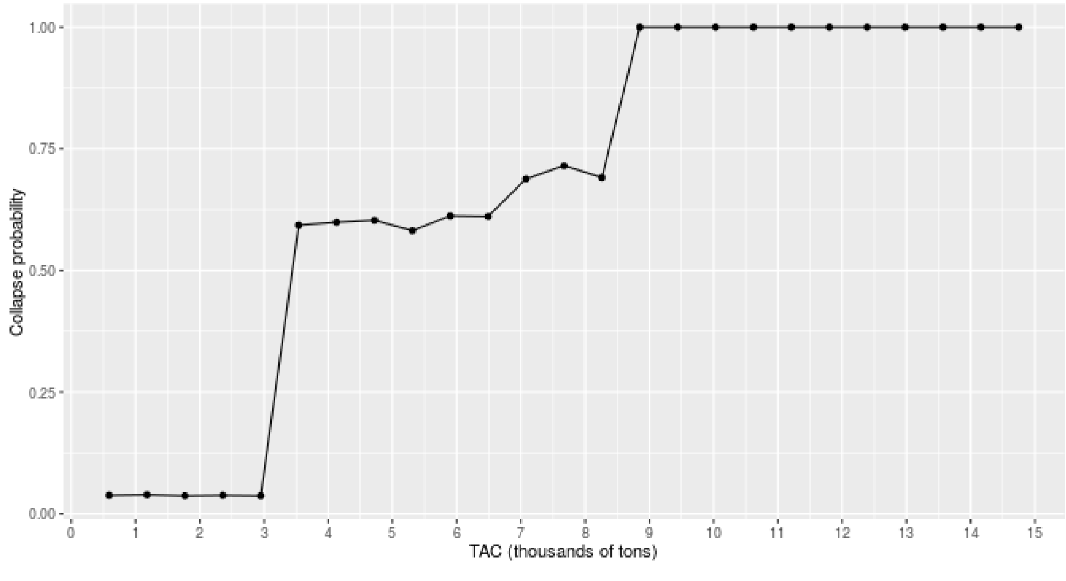


Figure 8.6. Probability of collapse under different levels of fixed TAC

8.3.5 Results

Gadget estimations for GES indicators are displayed in Figure 8.7.

Figure 8.7. GADGET's estimations for GES indicators (red lines), Catches biomass (black line), reference points (blue line).

There is an inverse relationship between F and the number of recruits from 2001 to 2007, when F increases, the recruitment decreases (Figure 8.7) but this pattern is broken from 2007 to 2013 when a direct relation is observed.

As Ruiz et al. (submitted) remarks, a fixed quota implies to decrease F when the stock is high (and *vice versa*), which is observed in the relation of F with biomass and catches during years 2007 and 2009.

Estimated quarterly length distribution of the population is presented in Figure 8.8 where it can be observed that residuals are small except for the first two years. Median length of the population is over 10 cm in most of the quarters. Considering that mean size for maturity is close to 11 cm, this could be an indicator of having enough old individuals in the population.

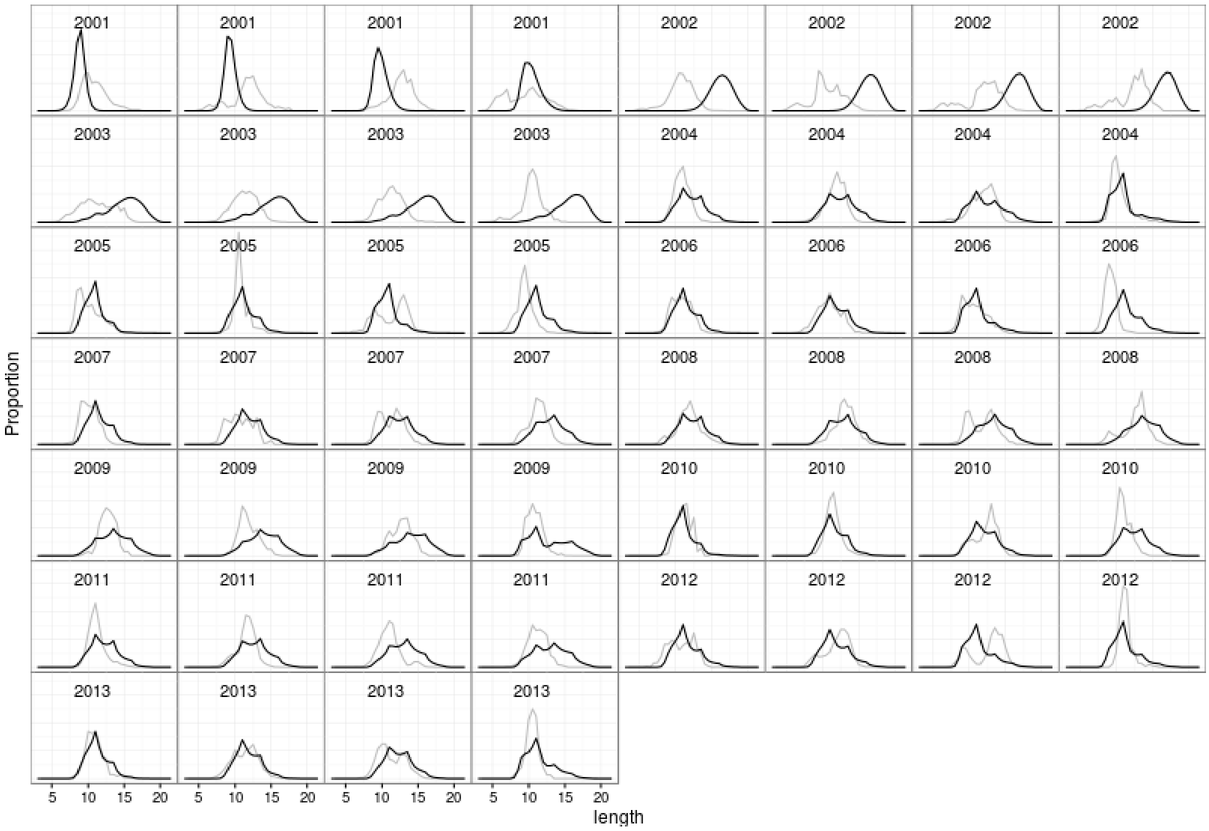


Figure 8.8. Estimated quarterly length distribution of the population

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9. Black Sea

9.1. Introduction

With reference to the commitments under the Marine Strategy Framework Directive (MSFD), Romania has uploaded a final set of reporting sheets by the 30 April 2013 deadline set by the Commission for the submission of reporting sheets following the completeness check. Romania has uploaded its two paper reports on Articles 9 & 10 (GES and targets) and on Article 8 (initial assessment) to ReportNet on 15 October 2012. It has uploaded the initial assessment report again on 30 April 2013, but there does not seem to any difference between the two IA reports. In the present assessment, the second report, uploaded on 30 April, was used.

The two paper reports of Romania are the following:

- Initial Assessment of the Marine Environment, July 2012: This is a Report prepared by the National Institute of Marine Research and Development "Grigore Antipa" and the National Authority "Romanian Waters", containing the initial assessment required according to the art.8 (including the economic and social analysis). The report is available only in the Romanian language.

- Defining the GES and establishment of environmental objectives for the Romanian waters of the Black Sea of July 2012: This report presents the efforts of Romania to establish the GES and it is available only in the Romanian language.

Romania has not defined GES except for horse mackerel, where it seems to be implied that this stock is currently at GES. The targets seem to be specific to reducing the effort so that those stocks will also be at GES although it is not specified what GES is. The initial assessment, however, states that sprat is exploited below the FMSY reference point, which should imply that fishing effort is currently at a sustainable level, and the target aims for a further reduction in fishing effort. It is therefore not clear what the fishing effort reduction advice is based on. The information provided in the reporting sheets and the paper report is not the same (Mililieu, 2015).

In the following Sections we describe define GES for Descriptor 3 in the Black Sea.

9.2. Computing GES indicators for the Black Sea case study

The first ecosystem model to be employed in the Black Sea case study was built using the Gadget modelling framework (Begley & Howell, 2004). Taking into account that Gadget is a powerful and flexible framework that has been developed to model complicated statistical marine ecosystems within a fisheries management and biological context, while taking many features of the ecosystem into account, we included a number of features of the Black sea ecosystem into the model, such as:

- several species divided into multiple components;
- multiple areas with migration between areas (Romanian area, West Black Sea area and all Black Sea);
- predation between and within species;

- growth;

- maturation;

- reproduction and recruitment;

- multiple commercial and survey fleets taking catches from the populations.

The outputs from the Gadget model are:

- Total biomass (for all stocks/stock components)
- Biomass by age, length, area, time step and stock component
- Catches and landings (both total and by model dimensions)
- Predation (both total and by model dimensions)
- Recruitment (by length, area, time step and stock component)
- Mortality
- Numbers by any model dimension (i.e. by age, length, area, time step and stock component)
- Length distributions
- Stock (component) proportions
- Fitted values on the same dimensions as the observations

The following GES indicators were calculated based on the output from Gadget:

Trends in biomass

Recruitment

Trends in landings

Fishing mortality

Pelagic to demersal fish ratio

Harvest rate

Shannon index

Large fish indicator

Mean maximum length

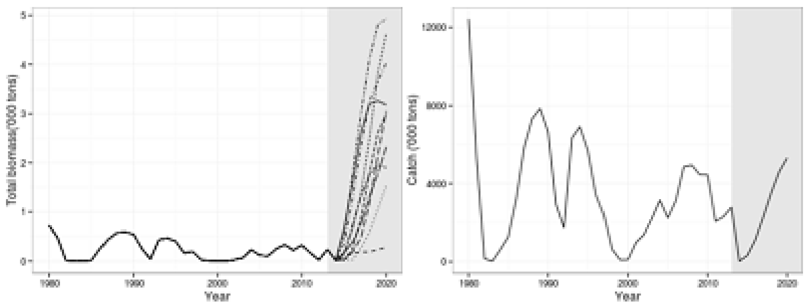

Fig. 9.1. Biomass and Catch for turbot

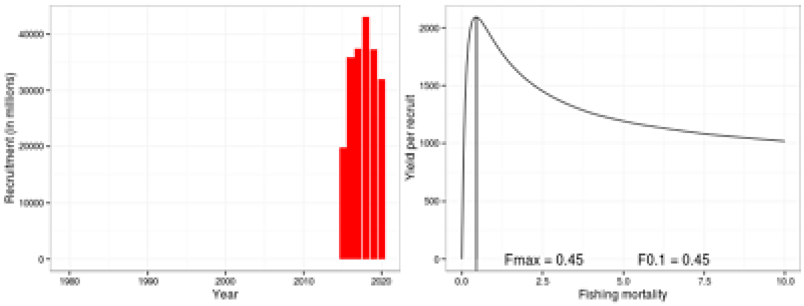

Fig. 9.2. Recruitment and Fishing Mortality for turbot

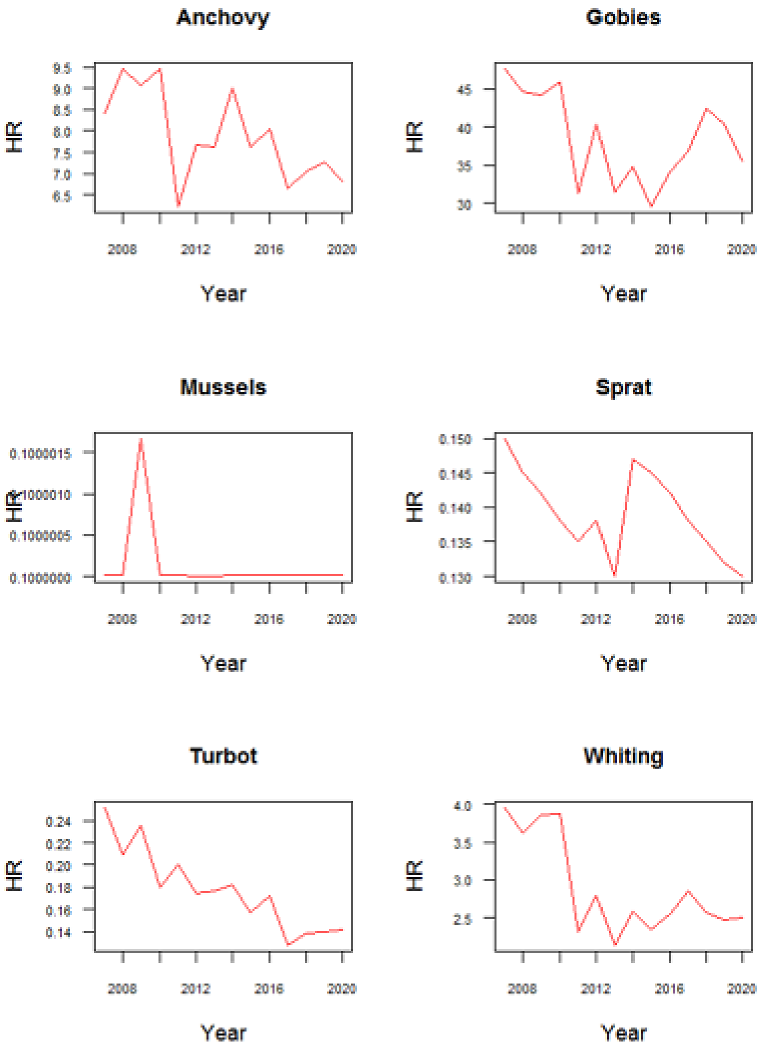

Fig. 9.3. Harvest rate

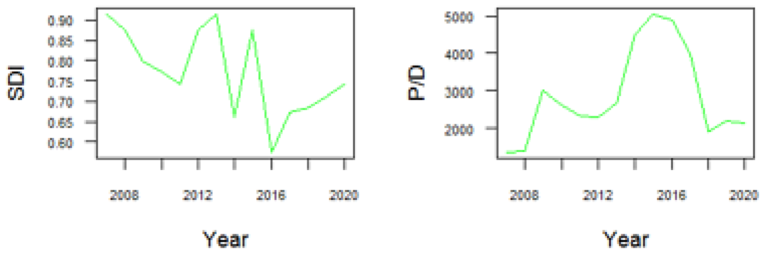

Fig. 9.4. Shannon's Diversity Index and Pelagic to Demersal fish ratio

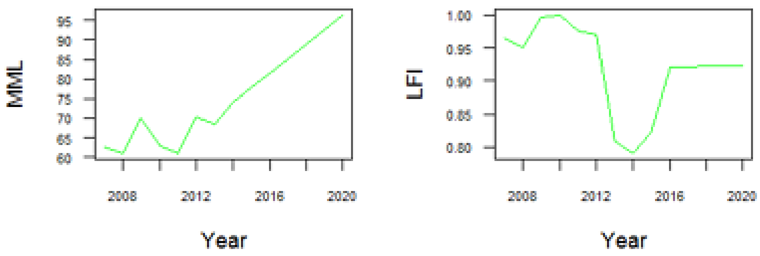

Fig. 9.5. Mean Maximum Length and Large Fish Indicator

The EwE model developed in the Black Sea case study considers 10 species or pool of species (turbot, anchovy, sprat, whiting, gobies, mussel, cetaceans, zoobenthos, zooplankton and phytoplankton) (Christensen & Walters, 2005; Bănaru & Harmelin-Viviena). Trophic relationships are modelled with a diet matrix representing the proportion of a prey in the diet of the predator (Cortes, 1997). Other data used in the EwE model are: biomass (t/km^2), commercial landings (t/km^2/year), IUU catches (t/km^2/year), P/B= Z (total mortality), Q/B (consumption rate).

The GES indicators taken into consideration are:

- Harvest rate
- Pelagic to demersal fish ratio
- The Shannon's diversity index (SDI)
- The mean trophic level (MTL) of all fish caught during the survey indicates the effect of fishing on the food web. It was calculated as:
- The marine trophic index (MTI) reflects the trophic structure of the fish assemblage where fishing is expected to affect mostly the upper part of the food web, that is, predatory fish. It is defined as the mean trophic level of predatory fish caught during each survey, taking into account only species whose trophic level is higher than or equal to 3.25.
- The mean maximum length of fish (MML) reflects the species composition of a fish assemblage, where fishing is expected to cause a decrease in the proportion of species with large asymptotic body size, slow growth rate, late age and large size at maturation. This indicator was calculated based on the asymptotic total length of each species as: MTL = ∑(TLS*WS)/∑WS, where TLS is the mean trophic level of species s (from Fishbase) and WS is the total weight of species s caught during the survey.

- The large fish indicator (LFI) reflects the size structure of the fish assemblage, which is assumed to be primarily affected by size-selective exploitation but is mediated by species composition as well as the fishing-induced reduction of life expectancy of each exploited species.

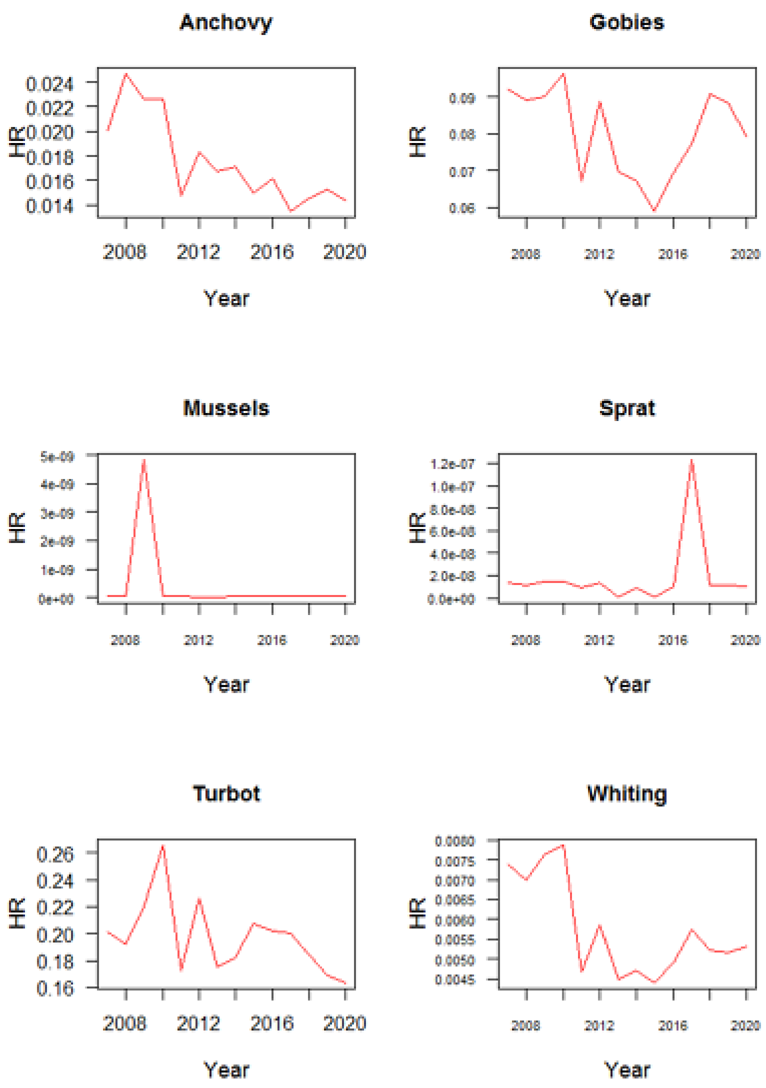

Fig. 9.6. Harvest rate

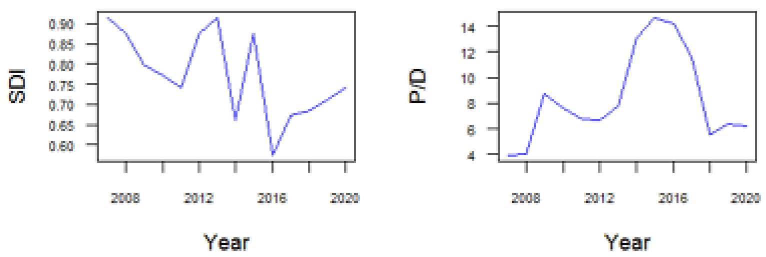

Fig. 9.7. Shannon's Diversity Index and Pelagic to Demersal fish ratio

- Trophic-based indicators

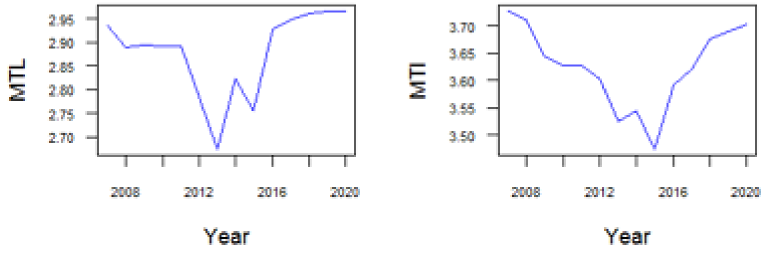

Fig. 9.8. Mean Trophic Level and Mean Trophic Index

- Size-based indicators

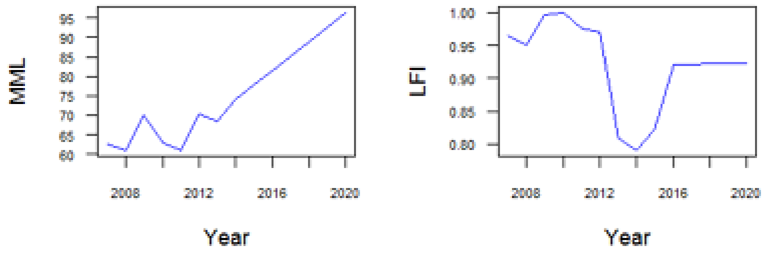

Fig. 9.9. Mean Maximum Length and Large Fish Indicator

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