Stock Annex: Turbot (*Scophthalmus maximus*) in Subarea 4 (North Sea)

Stock specific documentation of standard assessment procedures used by ICES.

Stock:	Turbot
Working Group:	Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak (WGNSSK)
Created:	
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Last updated:	May 2015
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A. General

A.1. Stock definition

Genetic studies within restricted geographical areas had illustrated the presence of distinct turbot populations in the Baltic and Irish Seas using neutral markers (e.g. Delbare and Declerck, 1999; Nielsen *et al*., 2004). Over the period 2009–2012, a genetic study of turbot population structure all over the species' distribution area has been conducted using both neutral and gene-associated genetic markers by Vandamme *et al.* (in prep). The neutral marker panel confirmed the break-up between the Baltic and Northeast Atlantic clusters. Within the latter, a more detailed pattern of genetic differentiation could be observed when gene-associated markers were also included in the analysis; results soon to be consulted on https://fishreg.jrc.ec.europa.eu/web/**fisheries-genetics**). This full analysis suggests a break between the southern and central parts of the North Sea, making turbot from the southern North Sea genetically more similar to those from the Western Waters. However, because it is unknown whether there are also differences in life history within the North Sea, and information on the number and location of spawning aggregations is missing, the break between 4.c and 7.d is insufficiently supported to be recommended for management purposes. Additionally, it is logistically difficult to split the North Sea into several management and assessment units. The proposed stock structure is represented in Figure A.1 below.

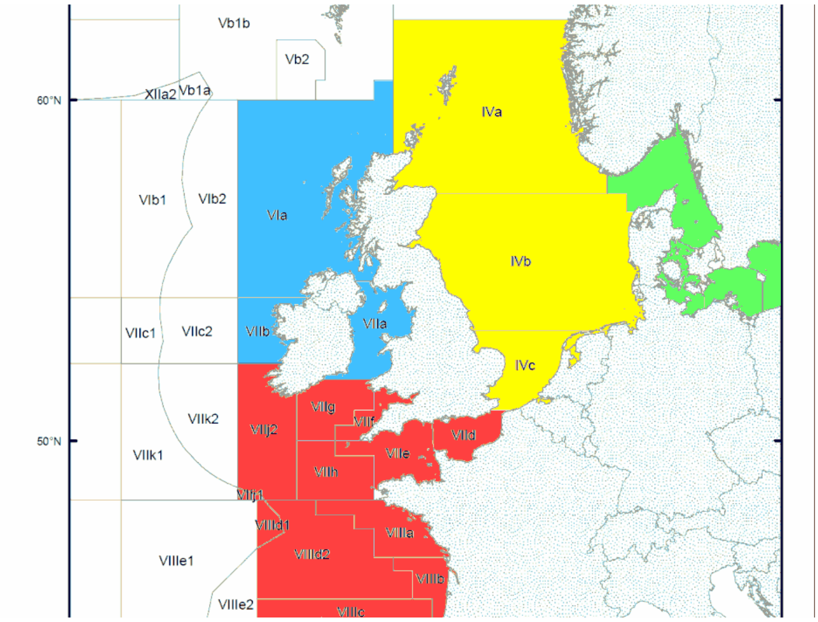

Figure A.1. Stock structure of turbot in the Northeast Atlantic as proposed by IBPNew 2012.

A.2. Fishery

In the 1950s the UK was the biggest contributor to the landings, with almost 50% of the landings coming from this country. In that early period, the landings fluctuated around 6000 tons per year. Currently, the landings are around 2700 tons per year. Most of the landings stem from the Netherlands that contributes between 50 and 60%. Within the Netherlands most of the landings come from the 80 mm beam trawl fleet fishing for flatfish species sole and plaice. Also in most other countries turbot is caught in mixed fisheries trawls. The second largest contributor to the landings in the last decade is Denmark. In Denmark there is a directed fishery for turbot using gill-nets.

Within the Netherlands, most of the landings come from the Southern Bight and the German Bight. In Belgium, turbot is mainly caught in mid-class (301–900 Hp) and large (>900 Hp) beam trawlers. These vessels are mostly flatfish directed (particularly towards plaice and sole, together with the associated bycatch species such as turbot, brill, dab, lemon sole, anglerfish and some roundfish. In Denmark turbot is taken only as bycatch in Danish fisheries. In the North Sea, where most of the Danish landings of turbot are taken, the gillnet fishery accounts for almost half of the landings.

Little information is known about discarding in the different fisheries catching turbot. The only available information comes from the Dutch beam trawl fleet in the period 2002–2007. It indicates very low estimates of discarding. No information is available for the period 1975–2002. In at least part of that period an EU-wide minimum landings size (MLS) of 30 cm was enforced. However, this minimum landings size was abandoned and member states have their own MLS rules and regulations. For example, Belgium now has a MLS of 30 cm, while in the Netherlands a minimum size of 25 cm exists, set by the producer organizations. Hence, despite the indications of low discarding in the Dutch fleets in the last decade, more MLS discarding may occur in other fleets, or have occurred in other periods.

Conservation schemes and technical conservation measures

Fishing effort has been restricted for demersal fleets in a number of EC regulations (EC Council Regulation No. 2056/2001; EC Council Regulation No 51/2006; e.g. N°40/2008, annex IIa). For example, for 2007, Council Regulation (EC) No 41/2007 allocated different days at sea depending on gear, mesh size, and catch composition: Beam Trawls could fish between 123 and 143 days per year. Trawls or Danish seines could fish between 103 and 280 days per year. Gillnets could allowed to fish between 140 and 162 days per year. Trammelnets could fish between 140 and 205 days per year.

Several technical measures are applicable to the flatfish fishery in the North Sea: mesh size regulations, minimum landing size, gear restrictions and a closed area (the plaice box).

Mesh size regulations for towed trawl gears require that vessels fishing north of 55°N (or 56°N east of 5°E, since January 2000) should have a minimum mesh size of 100 mm, while to the south of this limit, where the majority the plaice fishery takes place, an 80 mm mesh is allowed. In the fishery with fixed gears a minimum mesh size of 100 mm is required. In addition to this, since 2002 a small part of North Sea plaice fishery is affected by the additional cod recovery plan (EU regulation 2056/2001) that prohibits trawl fisheries with a mesh size <120 mm in the area to the north of 56°N.

The maximum aggregated beam length of beam trawlers is 24 m. In the 12 nautical mile zone and in the plaice box the maximum aggregated beam-length is 9 m. A closed area has been in operation since 1989 (the plaice box). Since 1995 this area was closed in all quarters. The closed area applies to vessels using towed gears, but vessels smaller than 300 HP are exempted from the regulation.

B. Data

B.1. Commercial catch

The landings of turbot are available through the EuroStat database. This database holds the officially recorded landings for all countries landing turbot in the North Sea. There are no records for the Dutch landings in the EuroStat database between 1984 and 1987. However, for the North Sea these missing landings have been estimated in a Dutch/Belgian research project, and have been used to fill in the gaps (Boon and Delbare, 2000). In the 1950s the UK was the biggest contributor to the landings, with almost 50% of the landings coming from this country. In that early period, the landings fluctuated around 6000 tons per year. Currently, the landings are around 2700 tons per year. Most of the landings stem from the Netherlands that contributes between 50 and 60%. Within the Netherlands most of the landings come from the 80 mm beam trawl fleet fishing for flatfish species sole and plaice. Also in most other countries turbot is caught in mixed fisheries trawls. The second largest contributor to the landings in the last decade is Denmark. In Denmark there is a directed fishery for turbot using gillnets.

There is no long-term continuous programme for age sampling of landings in any of the countries. Therefore, the age structure of the landings is estimated using data from different sources in different time periods. Starting in 1975, there is a four year time period for which the age structure of the landings have been estimated by Weber (1979). The age structure is estimated from market samples taken in Cuxhaven and Hamburg and research vessel surveys. Most of the samples represent landings in the eastern part of 4.b. The structure is based on a total of 9360 length and 6389 weight measurements combined with 6788 age samples. Samples are combined with the quarterly landings for England, the Netherlands and Germany and subsequently with the overall landings on an annual basis. The second dataset spans the period 1981–1990, is derived from landings in the Netherlands and available in the "Datubras" project report (Boon and Delbare, 2000). A stratified sampling scheme was used to collect the samples, using quarters, auctions, and market categories as stratification levels. Between 398 and 862 age samples were taken annually for age-determination of fish. Most of the samples represent Area 4.b and 4.c. The Dutch data are subsequently raised to the total international landings. The third dataset spans the period 2000–2002. It was supplied by Cefas and based on the UK landings of turbot. These were raised on an annual basis to the total landings. The fourth and final dataset stems again from the Netherlands. It spans the years 1998 and 2004–present. The age structure is estimated from stratified sampling accounting for auctions, quarters and market categories. Samples are predominantly taken from the main 80 mm beamtrawl (BT2) métier, though in some years enough samples are available to raise numbers-at-age for the 80 mm otter trawl métier. These are raised to total Dutch landings by quarter. Between 494 and 1921 age samples were taken per year. The total Dutch landings are subsequently raised to the total international landings per year.

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There is an important need for more representative sampling of the variety of métiers fishing this stock. In particular it is likely that the larger mesh gillnet métiers (mainly Danish) would have a different age structure in their catches than the Dutch trawl métiers.

B.2. Biological Data

B.2.1. Weight-at-age

Weight-at-age data in the catch for this stock are available for most but not all of the years during which there is age sampling of the landings (Figure B.1). Data are available for the period 1981–1990 from the DATUBRAS database (Boon and Delbare, 2000), and then again for the years 1998, and 2004 to present from Dutch market sampling. Stock weights are estimated as the catch weights in Q2, coinciding with peak spawning of the stock. Hence stock weights estimates are available for the same time period, but excluding the years 2005 and 2006 where no samples were available in the second quarter. In addition to this average weights-at-age for the stock during the period 1976–1979 are available from Weber (1979). For both the catch and stock weights, estimated values for ages 6 and greater tend to show large interannual fluctuations, due to the limited number of fish sampled at these ages. The vast majority of landings are for ages 4 and younger and this is reflected in the number of samples for these ages.

With no data except a single year available in the 1990s (1998) modelling was required to infer the trend in weight-at-age over the period 1991 to 2003. The group decided that using a constant annual weight-at-age vector over the entire period as input to the stock assessment models would be inappropriate, especially since significant increases in weight-at-age have been observed for other flatfish species in the North Sea during this time. Hence a time-varying growth model was included in the assessment. This growth model determines the catch weights-at-age and stock weight-at age. Stock weights-at age are defined in a two-step process. First, time varying length-at-age is modelled using a von Bertalanffy growth model where length-at-age a (in m) in a given year t is calculated:

$$L_{a,t} = L_{\infty t}\,(1\text{-}\exp(\text{-}K(a + a_0)))$$

where $L_{\infty t}$ is the asymptotic length in year t, K is a curvature parameter, and a_0 determines the point in time when the fish has zero length. Stock weights-at-age in a given year $W^S_{a,t}$ (in kg) are calculated using an allometric growth model:

$$W^S_{a,t} = \alpha\, {L_{a,t}}^{\beta}$$

With parameters α= 0.00001508 and β=3.090, as estimated by Bedford *et al.* (1986). Catch weights-at-age $W^C_{a,t}$are linked to stock weights-at-age by a simple age-independent scaling factor such that $W^C_{a,t} = \gamma W^S_{a,t}$.

Linking the weights-at-age model to data

The weights model has three scalar parameters: K, a_0 and γ. In addition, there is a vector $L_{\infty t}$ that needs to be estimated. This vector is a complex function of time and specifying an *a priori* shape may not fully address the multitude of processes that take place in shaping its functional form. Therefore, we used a smooth function of time, constructed using a number of b-spline basis functions (de Boor, 2001). These functions can be viewed as transformations of the explanatory variable t. For simplicity, the number of parameters (and the flexibility of the resulting $L_{\infty t}$) is taken to be equal to the number of parameters used for the spline describing the variation of fishing mortality over time.

The parameter fitting is done in the likelihood function of the assessment model. In short, the available observations of catch weights-at-age and landings weights-at-age are used in a likelihood component of the model that assumes a normal distribution of errors in the observations, with age-dependent standard deviations σ^S_a and σ^C_a for the stock and catch weights, estimated for each age separately.

Results for the fitted landings weights–at-age and stock weights-at age for the assessment model with nine ages are found in Figure B.1. Clearly *L∞* has changed over time, increasing in the period 1975–1990, and decreasing in the period 1995–2010. This pattern is also observed in other flatfish in the North Sea. Residual variance appears to increase with age. Most of the data appear to fit the model quite well, apart from the Weber data for which the older ages are overestimated by the model.

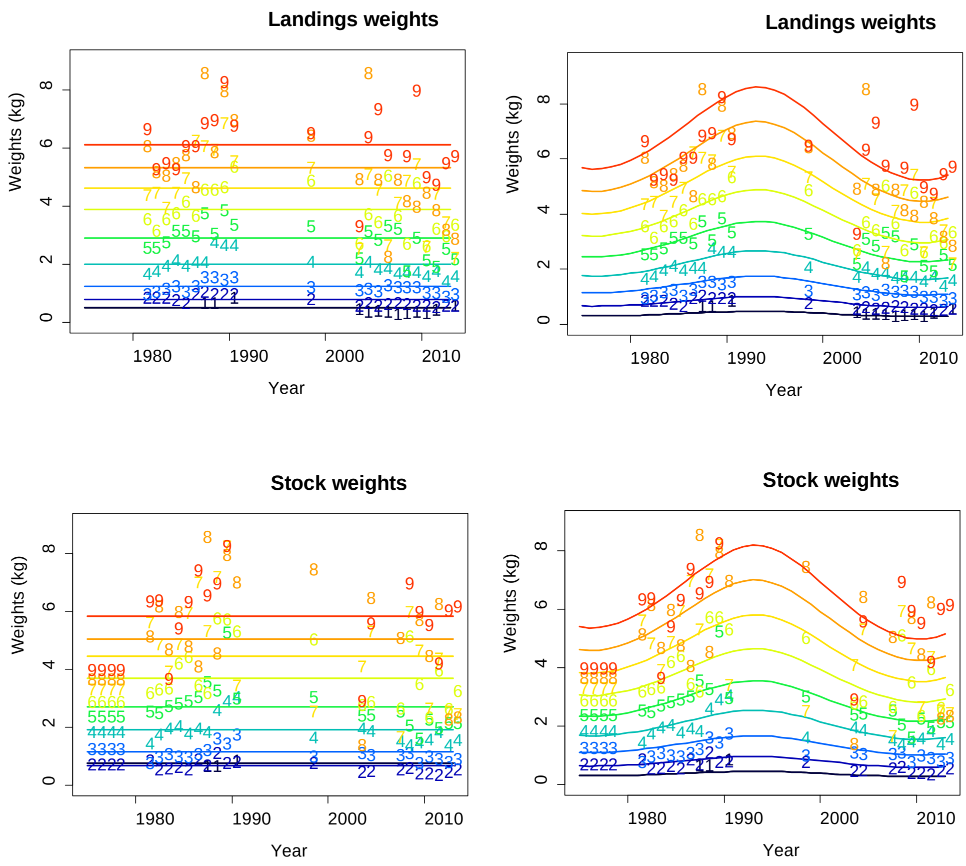

Figure B.1. (Top left) Landings weights assuming a constant mean weight-at-age, (Top right) Landings weights assuming gradually changing weights-at-age, following a von Bertalanffy growth curve, (Bottom left) stock weights assuming a constant mean weight-at-age, (Bottom right) Stock weights assuming gradually changing weights-at-age, following a von Bertalanffy growth curve. L∞t is a 5 parameter spline in this example.

B.3. Surveys

Two survey-series catching turbot are available. The Beam Trawl Survey (BTS ISIS), and the Sole Net Survey (SNS). The BTS index uses a beam trawl to catch demersal species. The index is based on the catch in one of the two nets. The BTS-ISIS index is based on catches between 52 and 239 individuals per year. The number of individuals used to generate an age–length key can be larger than the number of individuals used for the index, because the index is based on only the catch in one of the two nets, while age samples can be taken from both nets.

The procedure to create an age-structured index series from the BTS-ISIS was updated prior to the working group. Previously, the each individual fish caught was linked to an age–length key based on its length. The age–length key was based on all age samples in the BTS survey since 1991. The updated procedure first links the individual fish from which otoliths are taken to the length sample. This allows direct ageing of the fish in the cpue. Those fish for which no direct age sample is available are then assigned to ages using the age–length key based on all fish in the period 1991–present.

B.4. Commercial cpue

In addition to the survey based indices, there is also an index based on the Dutch 80 mm beam trawl fleet lpue. The potential bias in this lpue series as an indicator for stock abundances because of spatial targeting of the fleet has been addressed in van der Hammen *et al.*, 2011. There, a procedure was developed to obtain an age-structured index from the lpue, while trying to remove the spatial aspects of targeting. The resulting index series shows an increase of older ages over time, and a fairly good cohort structure.

Prior to IBPTurbot the Dutch BT2 lpue index was used as an age-structured index of abundance. Following IBPTurbot and WGNSSK 2015 it was decided to rather use this index and age-aggregated index of exploitable biomass. This was decided upon since the same catch-at-age data was used to raise the catch-at-age matrix and the Dutch BT2 index. It was felt that feeding the same data into the model for both the catch and the index would inherently bias the assessment in favour of this index since it follows very close the catch information used in the model.

C. Assessment: data and method

The state–space model SAM (Nielsen and Berg, 2014) offers a flexible way of describing the entire system, with relative few model parameters. It allows for objective estimation of important variance parameters, leaving out the need for subjective *ad-hoc* adjustment numbers, which is desirable when managing natural resources.

The total vector of model parameters for this model is:

$$\vartheta = (Q_{s=1,\,a=1\text{–}6+},\, Q_{s=2,\,a=1\text{–}6+},\, Q_{s=3},\, \sigma^2_R,\, \sigma^2_{S,a=1,2+},\, \sigma^2_{F,\,a=2,(1,3\text{–}10)},\, \sigma^2_{\circ,\,a=1,2,3+},\, \sigma^2_{s=1,\,a=1,2+},\, \sigma^2_{s=2,\,a=1,2+},\, \rho)$$

The Q parameters are catchabilities corresponding to the survey fleets (these parameters are survey- and age-specific for the SNS and BTS-ISIS, covering ages 1–6+, and a single value for the NL_BT2 exploitable biomass index). The variance parameters σ^2_R, $\sigma^2_{S,a=1,2+}$, and $\sigma^2_{F,\,a=2,(1,3\text{–}10)}$ are process variances for recruitment, survival, and development in fishing mortality respectively (the survival separately for age 1 and 2+ and the fishing mortality separately for age 2 and the remaining ages (1, 3–10+). The remaining σ^2 parameters are describing the variance of different observations divided into fleet and age classes. Finally ρ is the correlation parameter (among the ages) for the random walks on the fishing mortalities.

The WKNSEA benchmark introduced an extension to allow for varying correlation between different ages by setting the correlation of the log F annual increments to be a simple function of the age difference (AR(1) process over the ages). By doing this, individual log F processes will develop correlated in time, but in such a way that neighbouring age classes have more similar fishing mortalities than more distant ones. This correlation structure does not introduce additional parameters to the model, and is referred to below as an AR correlation structure (see Nielsen and Berg, 2014 for more details). This approach is used in the turbot assessment as well.

C.1. Model used

SAM

Software used: Source code and all scripts are freely available at http://www.stockassessment.org [Username: guest; Password: guest]. Stock = '**TUR-nsea_2015-an1**'

Model Options chosen:

A configuration file is used to set up the model run once the data files, in the usual Lowestoft format, have been prepared. The file has the following form:

SAM configuration file

```
# Min Age
1
# Max Age
10
# Max Age considered a plus group (0=No, 1=Yes)
1
# The following matrix describes the coupling  of fishing mortality STATES
# Row represent Catch, Columns represent ages.
1    2    3    4    5    6    7    7    7    7
# Use correlated random walks for the fishing mortalities
# ( 0 = independent, 1 = correlation estimated, 2=AR1)
2
# Coupling of catchability PARAMETERS (Surveys)
# Row represent fleets (SNS and BTS only; lpue age-aggregated), Columns represent ages.
1    2    3    4    5    6    6    0    0    0
7    8    9    10   11   12   12   0    0    0
# Coupling of power law model EXPONENTS
(not used)
# Coupling of fishing mortality RW VARIANCES
1    2    1    1    1    1    1    1    1    1
# Coupling of log N RW VARIANCES
1    2    2    2    2    2    2    2    2    2
# Coupling of OBSERVATION VARIANCES
# Row represent fleets (Catch, SNS, BTS), Columns represent ages.
1    2    3    3    3    3    3    3    4    4
5    6    7    7    7    7    7    0    0    0
8    9    10   10   10   10   10   0    0    0
# Stock–recruitment model code (0=RW, 1=Ricker, 2=BH, ... more in time)
0
# Years in which catch data are to be scaled by an estimated parameter
(Catch not scaled)
# Define FBAR range
2–6
```

This configuration has the following features:

- Fishing mortality states are the same for ages 7+. There is no survey data for ages older than 8 and the catch numbers at these ages are low and highly variable (in part due to limited samples used in raising the data).
- Random walks for fishing mortality at-age are correlated based on an AR correlation structure
- The catchability of the two oldest ages of the two age-structured assessments are linked.
- The variance on the fishing mortality random walks is estimated separately for age two. This was done to account for the fact that the change in MLS for this stock would likely have had a big impact on F for this age.
- The variance on the log N random walk for age 1 is estimated separately.
- Observation variance for the catch and age-structured indices are estimated seperately for the young ages (1 and 2). For the catch the last two ages (9 and 10+) and estimated together, separate from the rest.
- No stock–recruit function is used in the model (recruit follows a random walk).
- No catch scaling is done.

Input data types and characteristics:

Type	Name	Year range	Age range	Variable from year to year Yes/No
Canum	Catch-at-age in numbers	1975–1978, 1981–1990, 1998, 2000–2002, 2004–now	1–10+	Yes
Weca	Weight-at-age in the commercial catch	1981–1990, 1998, 2000–2002, 2004–now	1–10+	Yes – modelled values used in assessment
West	Weight-at-age of the spawning stock at spawning time.	1981–1990, 1998, 2000–2002, 2004, 2007–now	1–10+	Yes – modelled values used in assessment
Mprop	Proportion of natural mortality before spawning	1975–now	1–10+	No, assumed 0
Fprop	Proportion of fishing mortality before spawning	1975–now	1–10+	No, assumed 0
Matprop	Proportion mature at age	1975–now	1–10+	No, assumed constant over years
Natmor	Natural mortality	1975–now	1–10+	No, assumed constant over ages and years

Tuning data:

Type	Name	Year range	Age range
Tuning fleet 1	SNS	1975–now	1–7
Tuning fleet 2	BTS ISIS	1985–now	1–7
Tuning fleet 3	NL Beam trawl fleet	2002–now	Exploitable biomass

Assessment settings used in the final assessment:

Year	2015 (IBPTurbot proposal)
Model	SAM
First tuning year	1975
Last data year	2014
Ages	1–10+
Plus group	Yes
Stock weights-at-age	von Bertalanffy growth curve with time varying Linf
Catch weights-at-age	von Bertalanffy growth curve with time varying Linf
Total Landings	Not used
Landings-at-age	1975–1978, 1981–1990, 1998, 2000–present
Discards	Not used (assumed 0)
Abundance indices	BTS-Isis 1985–2013 SNS 1975–2002, 2004–2013
	NL-BT2 lpue age-aggregated catchable biomass 2002–2014
Catchability independent of age for ages >=	7

D. Short-term projection

Due to the uncertainty in the final year estimates of fishing mortality, the WG agreed that a standard (deterministic) short-term forecast is not appropriate for this stock. Therefore, stochastic projections are performed, from which short-term projections are extracted.

Forecasting takes the form of short-term stochastic projections. A total of 1000 samples are generated from the estimated distribution of the final estimates, with recruitment being sampled with replacement from the year 2002 to the final year of catch data (a period during which recruitment is assumed to be better estimated). These replicates are then simulated forward according to model and forecast assumptions (Table D.1), using the usual exponential decay equations, but also incorporating the stochastic survival process (using the estimated survival standard deviation) and subject to different catch-options scenarios.

Table D.1. Forecast assumptions. [Note that the values that appear in the catch options table of the advice sheet are medians from the distributions that result from the stochastic forecast.]

Initial stock size	Starting populations are simulated from the estimated distribution at the start of the intermediate year (including co-variances).
Maturity	Constant
Natural mortality	Constant
F and M before spawning	Both taken as zero.

Weight-at-age in the catch	Average of final 3 years of the modelled data used in the assessment.
Weight-at-age in the stock	Average of final 3 years of the modelled data used in the assessment.
Exploitation pattern	Fishing mortalities taken as a three year average scaled to the final year.
Intermediate year assumptions	F = Fsq (i.e. constant F). There is no limiting TAC for this stock (shared TAC with Brill).
Stock–recruitment model used	Recruitment for the intermediate year onwards is sampled, with replacement, from 2002 to the final year of catch data.

E. Biological reference points

The standard ICES protocol developed at WKMSYREF3 (ICES, 2014) was used to calculate reference points based on the results of the final accepted assessment (See Figure E.1). The period prior to 2002 was excluded due to a suspected change in selectivity since then.

There is no clear stock–recruit relationship in the stock–recruit pairs from the latest SAM assessment. Hence the lowest observed biomass is used by default as a proxy for B_{lim}. B_{PA} is derived as being 40% above B_{lim}. MSY $B_{trigger}$ is set to B_{PA} by default.

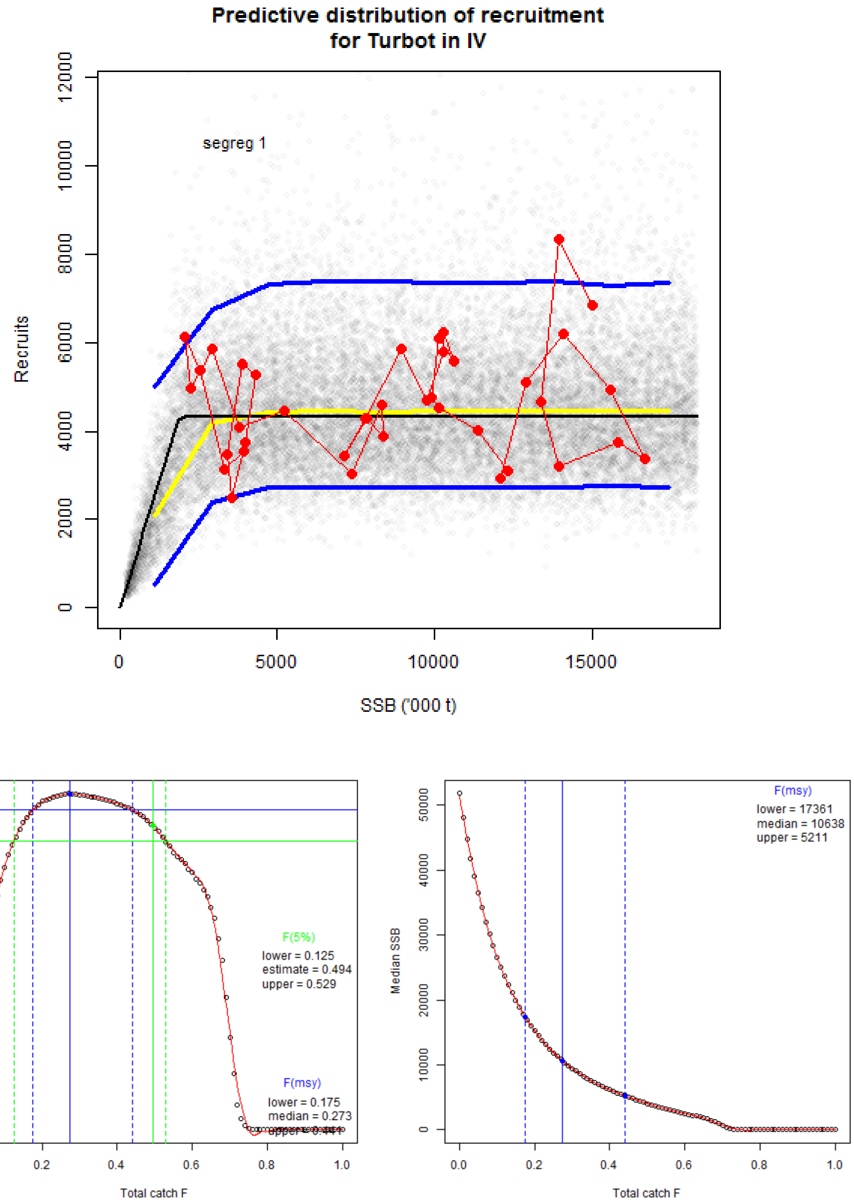

Figure 18.6.1. Turbot in Subarea 4. Top: stochastic stock–recruit relationship (segmented regression. NOTE: though all data are plotted, the curves are only fitted to data from 2002–2014. The difference from the whole period is minor). Bottom: Median yield and SSB at different levels of F. Blue vertical lines indicate estimates of F_{MSY} (solid) and F_{lower} and F_{upper} (dashed). In the yield plot, the solid green vertical line indicates the F that leads to a 5% probability of SSB<B_{lim} in the long term.

The proposed reference points for this stock based on the EQSIM analyses are given below:

Reference point	Value	Technical basis
FMSY	0.27	EQSIM results using a segmented regression stock–recruit relationship only. Range: 0.18–0.44.
Blim	2070 t	Bloss, the lowest observed biomass in 2005 as assessed in 2015.
BPA	2900 t	Blim×1.4
MSYBtrigger	2900 t	Default to value of BPA.

F. Other issues

The final assessment we propose uses an lpue series for tuning. For species with strong targeting, this may lead to biased estimates of stock abundance. Previously an age-structured index was used. Given the low catches of older fish in the survey time-series, the lpue series was the best indicator for stock abundance of older fish. Currently it is proposed to use this index as an age-aggregated index of exploitable biomass. This removes the information on older fish and leads to the survey being heavily downweighted in the assessment.

The BTS ISIS age-structured survey time-series used in the assessment has been revised prior to the benchmark working group. Previously, the length-structured catch per unit of effort was age structured using an age–length key that was composed of all sampled individuals in the time-series. The update linked the age estimates to length estimates for individual fish, where possible. The SNS survey is not updated and still uses an age–length key that is composed of all individuals in the time-series. Future research should study if using age–length keys collated by year do not give better results in the assessments. Using age–length keys by year has the advantage that the information of age structure within a year is better preserved. Such a procedure would also be more like the assessment procedure used for the other flatfish species sole and plaice.

There is little knowledge of the natural mortality of this stock. For other flatfish species we have natural mortality estimates that are empirically derived from the cease in fishing during WWII. Using the statistical relationship as estimated by Gislason *et al*. (2010), we derived estimates for natural mortality that are higher than those for sole and plaice. The reason for these high estimates are the high K and L_∞. The benchmark group then decided to use M=0.2 per year, as is used for many other fish in the ICES areas. Further exploration of M for turbot would improve the appropriateness of the ICES advice that will result from using the assessment.

The data collected prior to 2003 clearly shows a lower selectivity for the younger ages in the landings-at-age table compared to the more recent period. By interpreting the landings-at-age data as catch-at-age information, the change in landings of young fish was interpreted by the benchmark working group as an increase in the catchability for those ages. This can be justified, with the knowledge of the abandoning of the 30 cm MLS by the EC. The alternative explanation for the change in catch-at-age table is that those age were discarded previously and hence an unobserved part of the catch-at-age prior to 2000. Having more catch-at-age information available from different countries would provide more insight in the landings-at-age and discards-at-age, and possibly give more insight in what caused the changes in the landings-at-age information that is now available from single countries only.

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