Stock Annex: Turbot (*Scophthalmus maximus*) in Division 3.a (Skagerrak and Kattegat)

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:	April 2020
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A. General

A.1. Geographical boundaries of ICES Area 3.a.

The geographical area of Skagerrak is bounded to the west by a line running between the Hanstholm lighthouse in Denmark and the Lindesnes lighthouse in Norway, and to the south by a line running between the Skagen lighthouse in Denmark and the Tistlarna lighthouse in Sweden and from this point to the nearest point on the Swedish coast. The southern boundary of Skagerrak forms the northern boundary of Kattegat. The southern boundary of Kattegat is constituted by a line running from Hasenøre on the east coast of Denmark and across the Great Belt to Gniben on the west coast of Zealand in Denmark. From there, the line runs along the northern coast of Zealand to Gilbjerg and further in a northeastern direction to Kullen on the west coast of Sweden (Fig. A.1).

Figure A.1. Boundaries of ICES Division 27.3.a. ICES subdivisions and codes: Skagerrak (Subdivision 27.3.a.20), Kattegat (Subdivision 27.3.a.21), Belt Sea (Division 27.3.c), Sound (Division 27.3.b), Baltic Sea (Division 27.3.d), Northern North Sea (Division 27.4.a), Central North Sea (Division 27.4.b), Southern North Sea (Division 27.4.c).

A.2. Stock definition

Turbot lives in the eastern North Atlantic and occurs from the Mediterranean Sea in the south to Iceland and Lofoten in Norway in the north. More centrally, turbot is distributed in the North Sea, Skagerrak, Kattegat and large parts of the Baltic Sea, including ICES Area 3.a. At a large scale, population genetic studies by Vandamme *et al.* (2014) indicated an Atlantic group, a Baltic Sea group, a group on the Irish Shelf and an additional break in the North Sea, subdividing southern from northern Atlantic individuals. Similarly, Nielsen *et al.* (2004) reported a sharp cline in genetic differentiation going from the low saline Baltic Sea to the high saline North Sea (Fig. A.2, A.3). The data were explained best by two divergent populations connected by a hybrid zone (Nielsen *et al.*, 2004). However, Florin & Höglund (2007) found low genetic differentiation and no evidence of isolation by distance in the Baltic Sea and Kattegat.

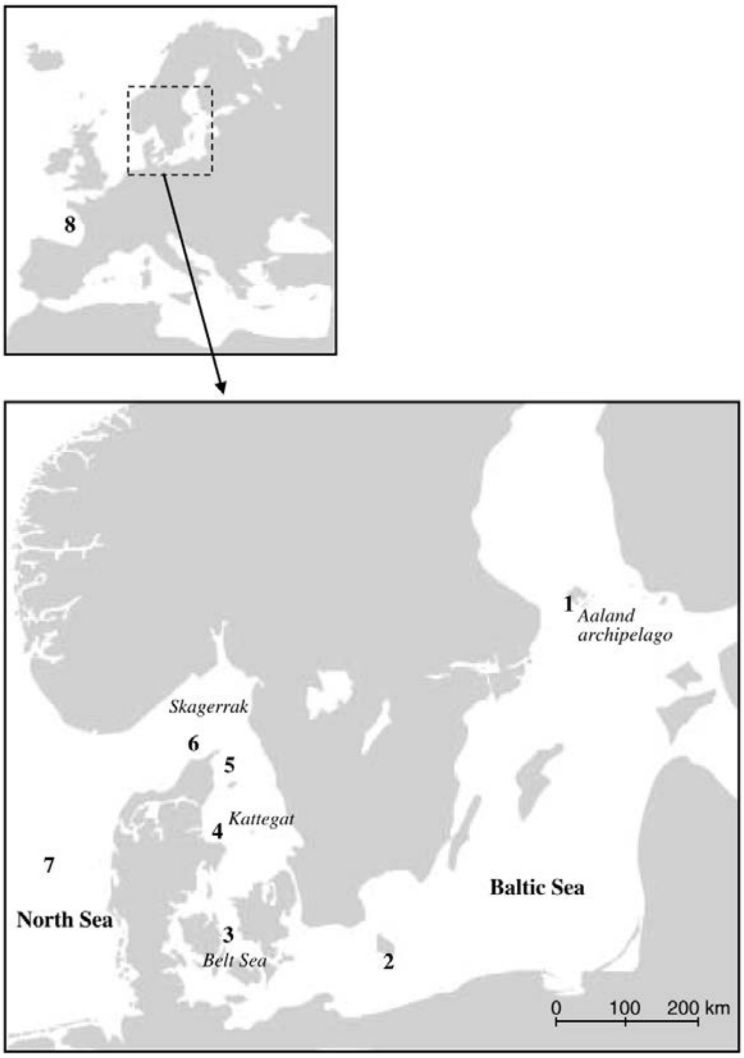

Figure A.2. Map of sea areas and sampling locations used by Nielsen *et al.* (2004).

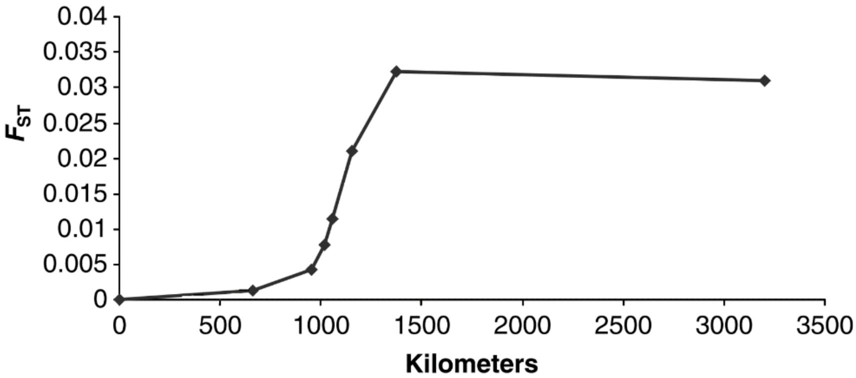

Figure A.3. Genetic differentiation between the Northern Baltic Sea sample (1) and all other samples of turbot (2–8; Fig. A.2). Samples are included following a geographical transect going from the Northern Baltic Sea to the Atlantic Ocean, French Biscay. The steepest clines in genetic differentiation occurs through Kattegat. Modified from Nielsen *et al.* (2004).

Consistent with two previous studies (Nielsen *et al.*, 2004; Vandamme *et al.*, 2014), Le Moan (2019) recently reported distinct genetic differences between the Baltic Sea and the North Sea (Fig. A.4). Areas sampled included the Western Baltic Sea and Kattegat, but not Skagerrak. Individual turbot sampled in Kattegat were often intermediate compared to fish sampled in the Baltic Sea and the North Sea. Frequently, however, individual fish sampled in Kattegat matched individuals sampled in the Baltic Sea or in the North Sea.

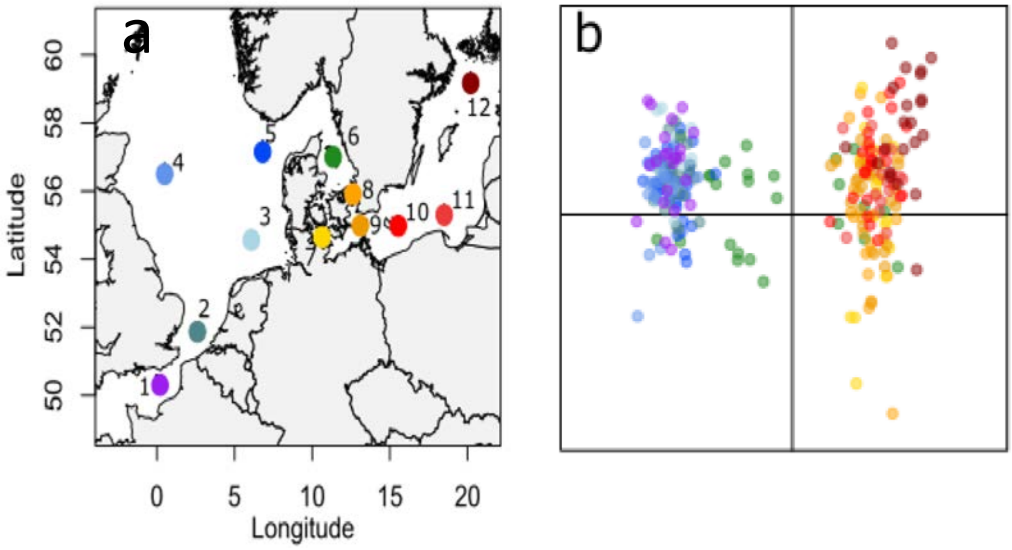

Figure A.4 Geographical sampling of turbot in a), and corresponding population structure in b) based on principal component analyses. The colours of the individual fish in b) correspond to the colours of the sampling sites in a). The North Sea is clearly separated from the Baltic Sea, whereas individual fish from Kattegat (green circles) mainly occur in between but are also matching both the North Sea and the Baltic Sea individuals. Modified from Le Moan (2019)

In addition, at the geographical scale of the ICES Area 3.a., historical evidence indicates that the stock has been composed by two major spawning components, including one in the Eastern Skagerrak and one in the southern part of the Kattegat (Cardinale *et al.*, 2009).

A.2. Fishery

In the North Sea area, turbot has been considered a highly prized fish ("prime") since the middle of the 1800s. Historically, turbot has been exploited within a multi-species fishery targeting turbot together with brill (*Scophthalmus rhombus*) and sole (*Solea solea*) (Mackinson, 2002). In ICES Area 3.a., targeted fisheries for turbot may have occurred when the stock was larger (i.e. before 1960s; Cardinale *et al.*, 2009), while today turbot is mainly caught as bycatch in the trawl, trammelnet and gillnet fisheries, although due to its high economic value, targeted fisheries might occur in specific areas and seasons.

The following countries are, or have been, exploiting turbot in ICES Area 3.a.: Belgium, Germany, Denmark, Great Britain, Netherlands, Norway and Sweden. Over the period 1950–2018, total landings in ICES Area 3.a. ranged from 64 t to 736 t per year, with the lowest landings during the late 1960s and the beginning of the 1970s, and the highest peaking in the late 1970s and the early 1990s. The peak is linked to exceptionally high records from the Netherlands for four years. Conversely, the lowest landings at the beginning of the period are linked to an absence of catch records from Sweden in the period 1962-1974. Between 2016 and 2018, ICES advised a catch no more than 80 – 90 tonnes (ICES, 2019). In contrast, ICES estimated catches were approximately two times as high and ranged between 170 - 220 tonnes (ICES, 2019).

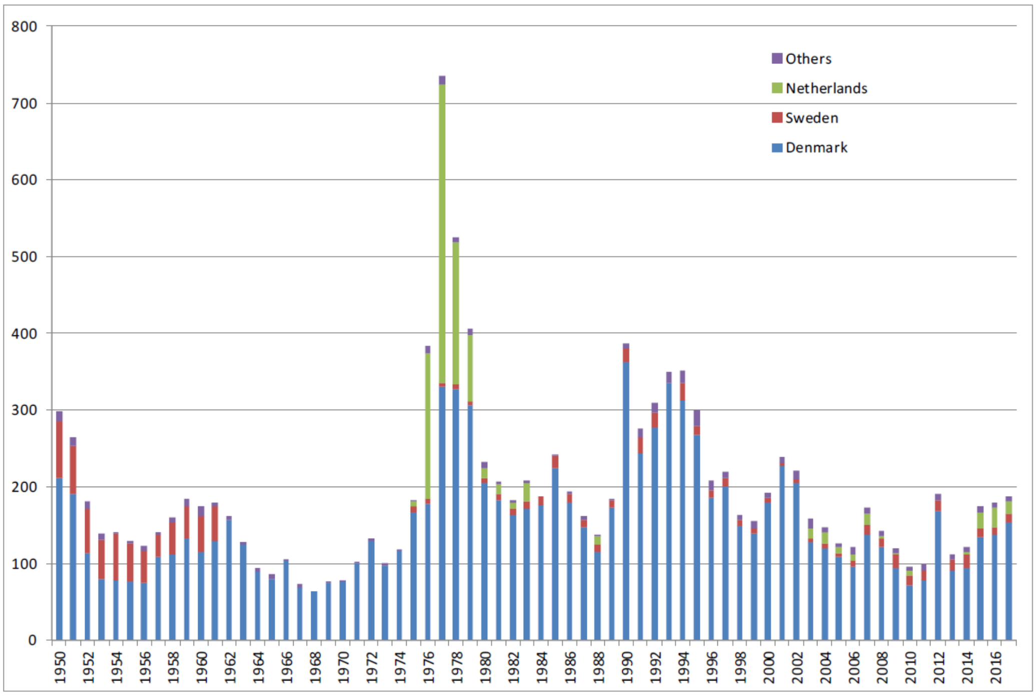

Figure A.5. Country specific landings from Skagerrak/Kattegat ICES Area 3.a.

The Danish fleet catches the largest share and are present throughout the time series without a trend ranging between 70 - 370 t per year. In the most recent decades, total annual official landings of turbot in ICES Area 3.a. have mostly ranged between 100 and 200 t per year.

Across the years 2005–2018, the Danish commercial fishery predominantly landed turbot in the southwestern part of Skagerrak, between the waters of Hanstholm in Denmark and Kristiansand in Norway. The landings were adjacent to the border of the Central North Sea (Division 27.4.b) and are relatively consistent across years. In Kattegat, landings are less aggregated with relatively high landings in the more southern parts of Kattegat, particularly southeast of Anholt and east of Ebeltoft in Denmark. The stock is subjected to recreational fisheries using gillnets or rod and line; however, the extent of the recreational fisheries remains unknown. In the neighbouring Baltic Sea, turbot is rarely the main target of recreational fisheries.

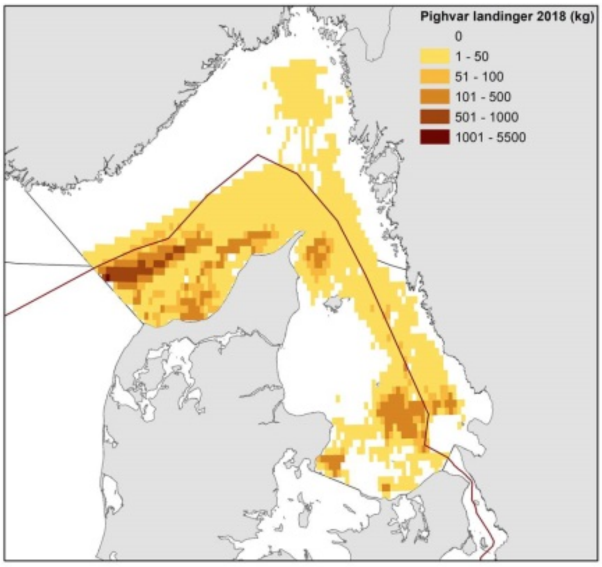

Figure A.6. Locations of Danish commercial landings in 2018 compiled from VMS data. Colours indicate landings in kg. Compared to other countries, Danish landings represent the largest share of turbot landings in ICES Area 3.a. (Figure A.5).

A.3. Ecosystem aspects

Discards: Discarding of turbot in ICES Area 3.a. is considered low due to the high value of the species. Additionally, survival rates of discarded turbot are likely to be high. There is no official EC minimum landing size (MLS) on turbot. In the Netherlands, various restrictions, as well as MLS for North Sea turbot, have been applied by Dutch Producer Organisations over time, which may also affect the Dutch discarding of turbot caught in ICES Area 3.a. A MLS of 30 cm leads to the landing of many immature individuals, in particular females, while increasing the MLS to higher lengths leads to higher discarding percentages. According to catch data from 2016 and 2017, turbot up to 30 cm are fully discarded (ICES 2018).

B. Data

B.1. Commercial catch

From 2002 onward, detailed landing and discard information on turbot catches in Area 3.a is available in InterCatch. The information is available in strata representing a combination of country, area, gear and season. Strata that lack discard information are multiplied by a factor that corresponds to the weighted mean of sampled discards-to-landings ratios in comparable strata. The total landings (CATON) of sampled strata are used as weights. The following scheme is used to group sampled and unsampled strata together:

Group	***Raising of discards***
All fleets from the Netherlands	Weighted mean of all sampled strata
All strata from subdivision 3.a.20	Weighted mean of all sampled strata in 3.a.20
All strata from subdivision 3.a.21	Weighted mean of all sampled strata in 3.a.21
Industrial bycatch and Norwegian fleet	No discards

Before 2002, only the official nominal catches submitted by countries that have fisheries in the area are available from 1950 and onwards. To get a homogenous time series of catches, an assumption is made that about the discard rate before 2002 that it is equal to the mean discard rate of the period 2002—2018 estimated from InterCatch data equal to 13.44%.

B.2. Biological

Available biological information on turbot in ICES area 3.a. that is not used in the stock status estimation is briefly described here. Length distributions from the commercial fleet and scientific surveys are used in order to derive an exploitable biomass index.

Some catch-at-age data (catch numbers-at-age, mean weights-at-age in the catch, mean length-at-age) are available, but it is unclear if the sampling is adequate in the area, especially in recent years. . Maturity information is available from the International bottom trawl surveys in the area and the common six-point maturity scale is used (WKMSTB, Workshop on Maturity Staging of turbot and brill; ICES 2012a).

The stock has been poorly sampled for length distributions since 2017, owing to changes in the Danish sampling program following Commission implementing decision (EU) 2016/1251, considering that the total annual landings are less than 200 tonnes. Only 9% of the landings had length distribution sampled in 2017, against 65% in 2016. For discards, around 50% had sampled length distribution in previous years, with 2018 peaking at 69%. Turbot is fully discarded up to 30 cm (ICES, 2018).

B.3. Surveys

Getting accurate survey indices of abundance for turbot in ICES Area 3.a. is problematic, because it is a relatively rare species and because most of the available trawl surveys do not cover the area very well. High resolution standardized abundance indices were derived based on five different bottom trawl surveys (Figure B.1). Three of these surveys are available in the ICES DATRAS database, namely the beam trawl survey (BTS), the North Sea International Bottom Trawl Survey (NS-IBTS), and the Baltic International Trawl Survey (BITS). The final two surveys (TN and TOR) are Danish national surveys that specifically cover the ICES Area 3.a.

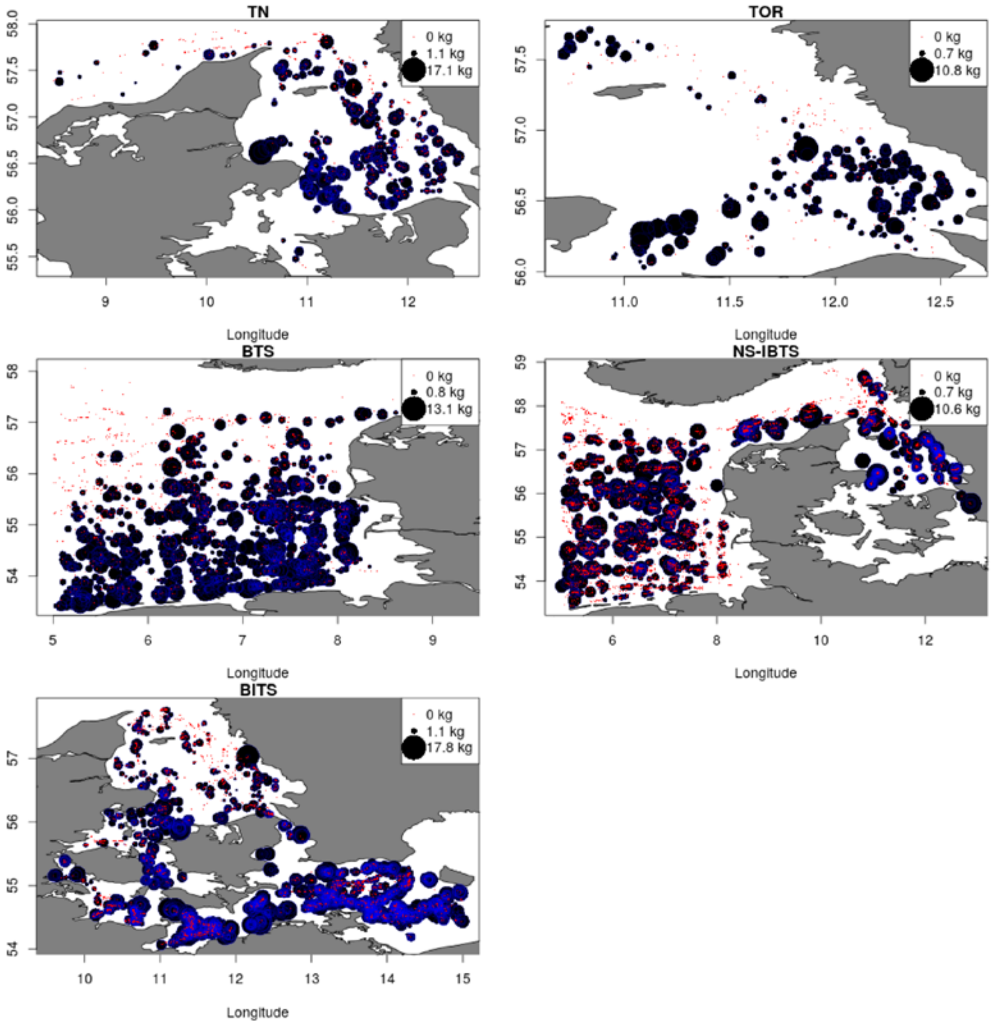

Figure B.1. Biomass or turbot per haul and survey in ICES Area 3.a. and adjacent waters.

The DATRAS surveys were filtered to exclude hauls far from the area of interest (ICES Area 3.a.) to reduce the computation time. Specifically, hauls west of 5° longitude and east of ICES area 24 (approx. 15° longitude) were excluded. Likewise, gear types with less than 100 hauls were not included. Analyses accounted for the fact that turbot has been named both *Psetta maxima* and *Scophthalmus maximus*, and some surveys are using one or the other or a combination. The ratio of total commercial catch at length to survey catch at length for the period 2012–2018 was used to down-weight the smaller length groups in the survey, such that the survey can be considered representative for the exploitable stock biomass and thus suitable for use in a biomass production model. The observed numbers-at-length were multiplied with a weighting factor (a number between 0 and 1) before the numbers-at-length were converted to biomass by multiplying with a length-weight relationship and summing over length groups. The weighting factor resembled the maturity-at-length curve for turbot, so exploitable stock biomass and spawning stock biomass are similar. Survey indices were calculated using the methodology described by Berg *et al.* (2014), although the response variable was exploitable stock biomass of turbot rather than numbers-at-age.

The approach applied a Tweedie-GAM that included: i) spatio-temporal smoothers that are decomposed into a time invariant spatial effect, a spatial seasonal effect and a space-time effect that can capture smooth changes over longer time scales, ii) smooth function of depth, iii) fixed gear effect, iv) random effects on the interaction of ship and gear, and an offset term equal to the logarithm of haul duration (following the assumption that the catch is proportional to fishing duration). The smooth functions used for space, time and depth are Duchon splines with first derivative penalisation, except the seasonal smooth function that uses cyclic cubic spline to achieve a repeating seasonal pattern. The link function is the natural logarithm.

The exploitable biomass index is calculated by taking the sum of predicted catches over a fine grid of the area; nuisance parameters (e.g. gear, ship, haul duration) are set to constants in this process. The Q1 biomass index (Figure B.2) is used in the SPiCT assessment as it had the lowest uncertainty.

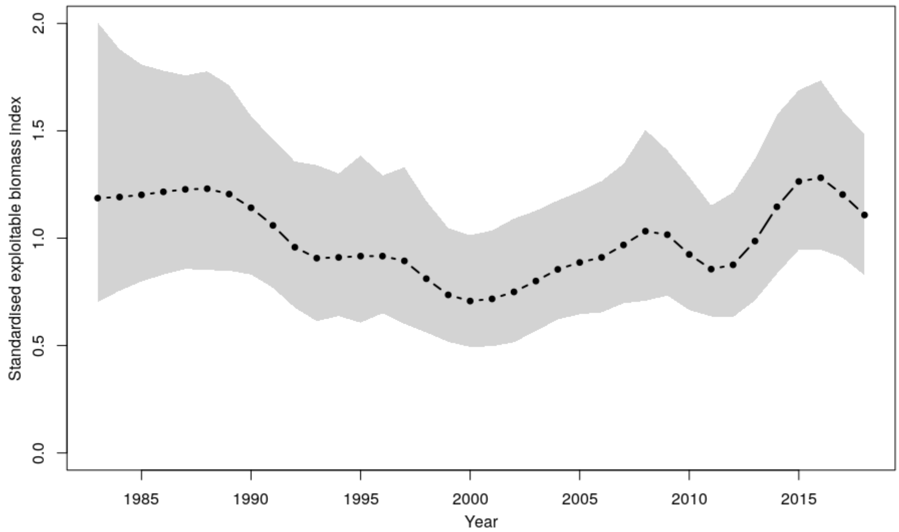

Figure B.2: Exploitable biomass index (Q1) of turbot in ICES Area 3.a for 1983—2018.

Visual inspection of residuals showed no problems in the fit of the model to the data. The influence of leaving one international survey or both Danish surveys out shows a different NS-IBTS signal (Figure B.3). A retrospective analysis was done to check the robustness of the method. The biomass index was estimated after successively removing the last 1-4 years from the end of the time series (Figure B.4). The results showed no problematic patterns.

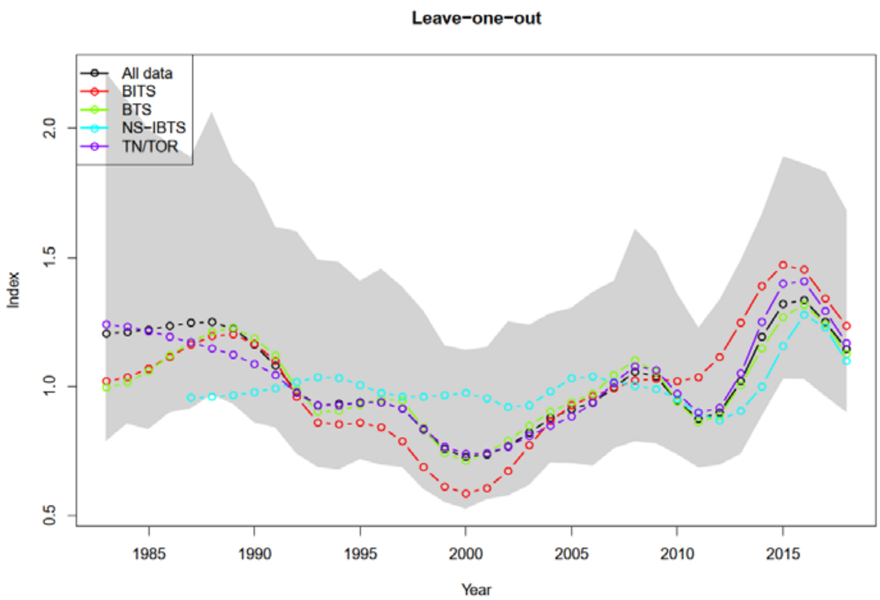

Figure B.3: Leave-one-survey-out analysis for turbot in ICES Area 3.a. Q1 index.

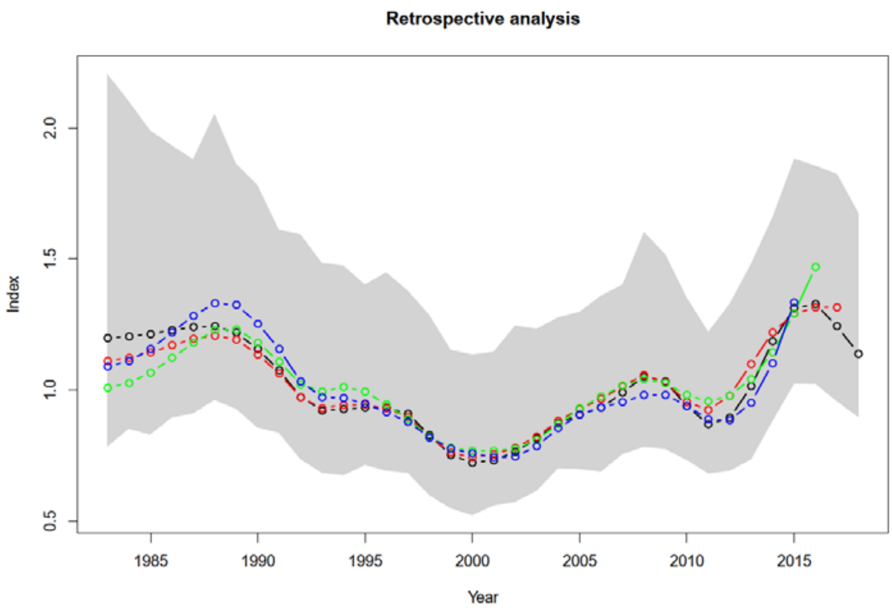

Figure B.4: Retrospective analysis of the exploitale biomass index for turbot in ICES Area 3.a.

B.4. Commercial cpue

Not used for this stock.

C. Assessment: data and method

The following outlines the method currently used for the estimation of the stock status of turbot in ICES Division 3.a. The method was discussed and agreed upon during the benchmark of the stock in WKFlatNSCS (2020).

C.1. Stock assessment model

The surplus production model in continuous time (SPiCT, Pedersen and Berg, 2017) is used for assessing the stock status. The model is described in detail in the above referenced paper; the model configuration is presented below.

C.2. Assessment model configuration

Model used: Surplus production model in continuous time (SPiCT)

Software used: R package spict (https://github.com/DTUAqua/spict)

Model settings and input data:

Input data / option	***Notes***
Commercial catch: 1975-	Intercatch landings and imported and raised discards 2002—2018, official landings with raised discards 1975—2001
Exploitable biomass index(Q1): 1983-	See section B.3
Shape parameter (n)	Fixed, eqalt to 2, i.e. Schaefer model
Prior distributions	logbkfrac ~ *N*(log(0.5), 0.5^2) logalpha ~ *N*(log(1), 2^2) logbeta ~ *N*(log(1), 2^2)

D. Short-term projection

Short-term projections are not carried out for this stock.

E. Medium-term projections

Medium-term projections are not carried out for this stock.

F. Long-term projections

Long-term projections are not carried out for this stock.

G. Biological reference points

The ICES reference points for stocks that are assessed using biomas production models, like SPiCT, are: $F/F_{MSY} = 1$ and $B/B_{MSY} = 0.5$ for the fishing mortality and biomass status. A way to account for estimated uncertainty is to take a percentile lower than the 50^{th} (median) for B/B_{MSY} and higher than the 50^{th} for F/F_{MSY}. Following the ICES guidelines for SPiCT assessments, developedby WKLIFE (ICES, 2019), the 35^{th} and 65^{th} percentiles should be used for the biomass and fishing mortality reference points when estimating the stock status.

H. Other issues

H.1 Biology of the species in 3.a

Turbot lives on sandy, rocky or mixed bottoms and is one of the few marine fish species that also inhabits brackish waters. Turbot is a batch spawner, and in marine waters eggs are pelagic (. The spawning season generally ranges from April to August in the North Sea and the Baltic Sea (Stankus, 2003). Turbot is one of the fastest growing flatfish. During the juvenile phase growth rates are high, turbot can reach 30 cm in three years. Growth curves of males and females diverge markedly from about age three and onwards, females growing larger than males (Molander, 1964; Jones, 1974; Stankus, 2003). During the first years of life, females grow 8 to 10 cm a year. Females older than ten years still grow about 1-2 cm a year. In the North Sea, evidence suggests that 50% of the females are mature when they reach 46 cm in body length, and they are all mature at approximately 55 cm (Jones, 1974). In comparison, Stankus (2003) found that all females are mature when they reach 28 cm in body length in the Baltic Sea. Other life history traits also differ between the turbot in the North Sea and turbot in the Baltic Sea. For example, females in the Baltic Sea often carry about two million eggs kg^{-1} (Stankus, 2003), whereas females in the North Sea carry about one million eggs kg^{-1} (Jones, 1974). Likewise, turbot parameters of the von Bertalanffy growth equation differ between the North Sea and the Baltic Sea, including female $L\infty$, which is 64.8 cm and 53.5 cm in the North Sea and Baltic Sea, respectively. Corresponding parameters for ICES Area 3.a. have not been identified, but the parameters for ICES Area 3.a. could be intermediate to the parameters originating from the North Sea and Baltic Sea. Eggs and larvae of turbot from the Baltic Sea often tolerate brackish water better than turbot from the North Sea (Kuhlmann & Quantz, 1980; Karås & Klingsheim, 1997). Correspondingly, recent genome scans indicate that turbot is locally adapted to variation in salinity and temperature (Vilas *et al.*, 2015), especially concerning genes related to osmoregulation, growth and resistance to disease (do Prado *et al.*, 2018).

Turbot is a typical visual feeder and adults feed mainly on highly mobile prey like other bottom-living fish, small pelagic fish, and, to a lesser extent, on larger crustaceans and bivalves. Due to their larger mouth compared to other flatfishes; they eat macrofauna (>1 mm) from the beginning of their benthic lives. The diet of the juveniles has been shown to consist of copepods, shrimps, barnacle larvae and gastropod mollusc larvae (Jones, 1973).

Turbot is a rather sedentary species, although longer distance migratory patterns have been observed. In the North Sea, migrations from the nursery grounds in the southeastern part to the more northern areas have been recorded (ICES 2012). In the Baltic Sea, adults often start a spawning migration towards the coastal zones in April (Stankus, 2003). Nevertheless, tagging studies from three different parts of the Baltic Sea all showed that adult turbot are very stationary, have high spawning site fidelity and that 95% of the fish moved less than 30 km from tagging site, although a few individual specimens showed displacements of 100s of km (Johansen, 1916; Aneer and Westin, 1990; Florin and Franzen, 2010). Thus, turbot generally occur in spatially separated stock units as it spawns at specific localities in shallow areas during summer (Molander, 1964; Curry-Lindahl, 1985; Voigt, 2002; Iglesias *et al*., 2003; Florin and Franzén, 2010) and with restricted movements as adults (Aneer and Westin, 1990; Støttrup *et al*., 2002; Florin and Franzén, 2010), and exhibit strong spawning site fidelity (Florin and Franzén, 2010). Inspection of historical data from the Skagerrak–Kattegat area also indicates spatially separate stock structure, at least in terms of spawning components, which is persistent over time (Cardinale *et al*., 2009).

H.2. Stock dynamics, regulation and catches through 20th century

According to time-series of standardized survey cpue (Cardinale *et al*., 2009), the reduction of turbot in ICES Area 3.a occurred at the beginning of the industrialized fishery, which is usually considered to be the main cause of the decline of several stocks of many demersal species stocks in ICES Area 3.a (Cardinale *et al*., 2012), showing instead that the pre-industrial fishery had already had a significant impact on the stock. Historical survey data shows that biomass of turbot in ICES Area 3.a has declined at about 86% since 1925 with regard to initial values; the maximum individual body size has decreased around 20 cm from the beginning of the time-series (Cardinale *et al*., 2009). Moreover, the northern stock component within ICES Area 3.a has been eradicated. These trends are likely to be underestimated due to the conservative approach used by assuming a low level of "technical creeping" for such a long period of time, suggesting that the actual reduction in biomass might have been between 92% and 95% (Cardinale *et al*., 2009). These results indicated a depleted status of the stock in ICES Area 3.a and also different stock dynamics within the area (i.e. in comparison between the Skagerrak and the Kattegat) and also when compared to the estimated trends in the North Sea (ICES 2012).

An alternative interpretation to the overexploitation hypothesis is that the quantity and quality of the turbot nursery grounds has deteriorated due to pollution (in particular due to eutrophication) and increased frequency of hypoxia events occurring in the shallow sandy coastal waters of Denmark and Sweden (Pihl *et al*., 2005), affecting the productivity of the stock. However, the decline of biomass was also accompanied by a large decrease in average maximum length, with large individuals, more abundant at the onset of the last century, being the first to be fished out with the beginning of the industrialized fishery. Thus, the above considerations corroborate the hypothesis that observed trends in length and stock size over the first part of the last century are a result of overexploitation.

H.3. Current fisheries

There is no direct or target fisheries of turbot in ICES Area 3.a. The species is caught as bycatch in the trawl, trammelnet and gillnet fisheries, although due to its high economic value, targeting might occur for short period during the year in specific areas and seasons.

H.4. Management and ICES advice

Management plan

No management plan is considered for turbot in 3.a. Only stock status is provided for the stock.

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