

## 9 Northeast Arctic anglerfish<sup>1</sup>

### 9.1 General

Our present knowledge of anglerfish (*Lophius* spp.) in ICES subareas 1 and 2 is based on two masters' theses (Staalesen, 1995; Dyb, 2003), a report from a Nordic project (Thangstad *et al.*, 2006), working documents to the ICES ASC, WGN SDS, and WGCSE, and more recent catch data collected by the Norwegian Reference Fleet since 2006 (Anon., 2013; Clegg and Williams, 2021). In February 2018, anglerfish in ICES subareas 1 and 2 was subject to a benchmark assessment (WKANGLER 2018). After this benchmark assessment, it was determined that this stock (or rather a stock component and a management unit) is considered a category 3 stock, for which survey or other indices are available that provide reliable indications of trends in stock metrics, such as total mortality, recruitment, and biomass.

#### 9.1.1 Species composition

Two European anglerfish species of the genus *Lophius* are distributed in the Northeast Atlantic: white (or white-bellied) anglerfish (*Lophius piscatorius*) and black (or black-bellied) anglerfish (*Lophius budegassa*). *L. budegassa* are rarely caught in Nordic waters. In Norwegian waters, 1 out of about 2600 anglerfish landed from the Møre coast north of 62°N (2.a) and 1 out of about 1000 from the North Sea were *L. budegassa* back in 2003 (Dyb, 2003; K. Nedreaas, pers. comm.). In the most recent period (2014–2021), the ratio of *L. budegassa* in Norwegian waters has been up to 1 out of 200 anglerfish for some years, but usually about 1 out of 1000.

#### 9.1.2 Stock description and management units

The WGN SDS (Northern Shelf Demersal Stocks) considered the stock structure on a wider European scale in 2004, and found no conclusive evidence to indicate an extension of the stock area northwards to include Division 2.a. Anglerfish in 2.a have therefore been treated and described separately by the ICES Celtic Sea Ecoregion Working Group (WGCSE) who is now assessing the anglerfish in the neighbouring areas. Currently, anglerfish on the Northern Shelf are split into Subarea 6 (including 5.b (EC), 12 and 14) and the North Sea (and 2.a (EC)) for management purposes. However, genetic studies have found no evidence of separate stocks over these two regions (including Rockall) and particle-tracking studies have indicated interchange of larvae between the two areas and further towards ICES divisions 2.a, 5.a and 5.b (Hislop *et al.*, 2001). So, previous working groups assessments have been made for the whole Northern Shelf area combined, but exclusive ICES divisions 2.a, 5.a and 5.b. In fact, both microsatellite DNA analysis (O'Sullivan *et al.*, 2006) and particle tracking studies carried out as part of EC 98/096 also suggested that anglerfish from further south (Subarea 7) could also be part of the same stock. Hislop *et al.* (2001) simulated the dispersal of *Lophius* eggs and larvae using a particle tracking model. Their results also show the likelihood of *Lophius* around Iceland (Solmundsson *et al.*, 2007), Faroe Islands (Ofstad, 2013) and Norwegian waters north of 62°N (i.e. subareas 1 and 2) are recruited from the area west of Scotland including Rockall. This is also supported by research survey data as a migration east-/north-eastwards with size is seen in the International Bottom Trawl Survey (IBTS) and other survey data (e.g. Dyb, 2003).

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<sup>1</sup> Anglerfish (*Lophius budegassa*, *Lophius piscatorius*) in subareas 1 and 2 (Northeast Arctic); anf.27.1-2.

Results from the use of otolith shape analysis in stock identification of anglerfish (*L. piscatorius*) in the Northeast Atlantic (Cañas *et al.*, 2012) and previous references on *L. piscatorius* stock identification find no biological evidence to support the current separation of *Lophius* stocks in the Northeast Atlantic, but find substructures within the area.

Anglerfish were tagged during two IBTS surveys in the North Sea and five one-day trips using a small (15 m) Danish seiner off the Norwegian coast at around 62°40'N (Møre; Thangstad *et al.*, 2006; Otte Bjelland, IMR-Norway, pers. comm.). A total of 872 individuals were tagged with conventional Floy dart type tags, 123 in the North Sea (25–78 cm) and 749 at Møre (30–102 cm). Some of this is further described in Thangstad *et al.* (2006). The 2019 AFWG report shows the tagging locations and the hitherto recaptures. There are migrations in all directions, i.e. recaptures from the southern North Sea, at the Shetland/Faroes and northwards to Lofoten. Most of the recaptures were done at Møre where most of the fish were tagged.

In 2000–2001 a total of 1768 trawl caught *L. piscatorius* was tagged using conventional dart tags and released on inshore fishing grounds at Shetland (Laurenson *et al.*, 2005). Anglerfish between 25 and 83 cm total length were tagged. The overall recapture rate was 4.5% and times at liberty ranged from 5 to 1078 days. After Laurenson *et al.* (2005), Dr Laurenson reported to [www.fishupdate.com](http://www.fishupdate.com) a 104 cm anglerfish caught off the Norwegian coast near Ålesund in 2006. The fish had been tagged and released in the Scalloway Deeps on 13 September 2000 when it was 45 cm long and had hence been at liberty for five years and nine months. This is of particular importance as it may indicate a wider mixing of stocks and validate the growth rate of anglerfish.

WKANGLER (2018) considered that most recruitment in subareas 1 and 2 is from the more southerly stock unit, and this would require further R&D work in collaboration with ICES 3.a, 4, and 6 looking at egg and larval dispersion and transportation as well as tagging and genetic studies. To address stock structure, mixing rates, and growth estimates, WKANGLER (2018) recommended a tagging program coordinated between all countries harvesting *Lophius* and to align tagging methods, measurement protocols and outreach to industry. The WK further recommended a shared site for *Lophius* tagging data and other applicable research projects concerning *Lophius*. Until the true biological stock structure is better understood, WKANGLER (2018) recommends keeping the anglerfish in subareas 1 and 2 as a separate management unit for the time being.

### 9.1.3 Biology

Sex ratios in Subarea 2 show that females outnumber males (> 50%) above approximately 75 cm, and above 100 cm all fish were females (Thangstad *et al.*, 2006). This is very similar to the sex ratios reported from distant Portuguese and Spanish waters (Duarte *et al.*, 1997) and hence supports a sex growth difference independent of latitude.

Spawning has been documented to occur in ICES Division 2.a in spring, but the present abundance of anglerfish in subareas 1 and 2 seems to be dependent on the influx or migration of juveniles from ICES subareas 4 and 6. Estimates of GSI (gonad-somatic index) for females in Division 2.a indicate that ovaries develop from January to June. The highest values of GSI were found in June when some of the ovaries were 20–30% of the round weight. Only females bigger than 90 cm had elevated GSI values indicating developing or developed ovaries. Dyb (2003) found that the length at which 50% of the females were mature (L50) was between 60–65 cm and that all females above 80 cm were mature.

Some age readings exist for anglerfish in Division 2.a, and comparative analyses of different structures, preparations and methods used for age readings were done by Staalesen (1995) and Dyb (2003). The Norwegian Institute of Marine Research adopted the ICES age reading criteria using the first dorsal fin ray (*illicium*) as its routine method, but few fish have been aged since

the above-mentioned projects. The material collected and read was, however, considered sufficient for preliminary yield-per-recruit estimations (ICES, 2019). As a very simplified 'rule of thumb' one may divide the fish length by 10 get an approximate age, i.e. a fish of 100 cm is approximately 10 years old and 13 kg while a fish of 70 cm is about 7 years old and 7 kg.

Exploitation using gillnets with 300 mm mesh size will select for males and females in a more equal ratio than 360 mm gillnets (Dyb, 2003). However, a change to lower mesh size will, without additional regulations, not decrease the effort, but rather increase it, at least towards younger fish. A mesh size of 300 mm will catch more anglerfish down to 50 cm, i.e. more immature fish. Preliminary analyses have also shown that the maximum yield-per-recruit will be 22% less using 300 mm instead of 360 mm gillnets (Staalesen, 1995). A possible sudden increase in catch rates when going from 360 mm to 300 mm would therefore be of short duration. A mesh size of 360 mm is also more in line with the minimum legal catch size of 60 cm, the length at first maturity of females and the utilization of the species' (especially the females') growth potential.

Some basic biological input parameters for the current assessment approaches are shown in Table 9.3. Some of these are further described in WKANGLER (2018).

#### 9.1.4 Fishery

In autumn 1992 a direct gillnet fishery for anglerfish (*L. piscatorius*) started on the continental shelf in ICES Division 2.a off the northwest coast of Norway (Norwegian statistical area 07; Figure 9.1). The anglerfish had previously only been taken as bycatch in trawls and gillnets. Until 2010–2011 there was a geographical expansion of the fishery which was largely due to a northward expansion of the Norwegian gillnet fishery (Figure 9.2). It is not known to what extent this northwards expansion of the fishing area is caused by an expansion of favourable environmental conditions for the anglerfish or the fishers discovering new anglerfish grounds.

Near Iceland, Solmundsson *et al.* (2007) concluded that changes in the distribution of anglerfish and increased stock size have co-occurred with rising water temperatures that have expanded suitable grounds for the species. Another observed feature of the fisheries is that regional peaks in the landings of anglerfish representing northward migration become visible after multiple years of data collection (Figure 9.2). The recent increase in landings first happened along the coast of western Norway but did the last year expand to all subareas north of 62°N as well.

Norway is by far the largest exploiter of the anglerfish in subareas 1 and 2 accounting for 96–99% of the official landings (Table 9.1). The coastal gillnetting accounts for more than 90% of the landings (Table 9.2). The landings of anglerfish in subareas 1 and 2 have been about 1/4–1/3 of the total landings from the other Northern Shelf areas (3.a, 4, and 6), but was in 2017 only 7% of the total landings in these areas.

No TAC is given for subareas 1 and 2 of Norwegian waters. Catches of anglerfish in Division 2.a of the former European Union (EC) waters, now UK waters, are taken as a part of the combined EC/UK anglerfish quota for ICES areas 3, 4, and 6, or as part of the Norwegian 'others' quota in EC/UK waters. The Norwegian fishery is regulated through:

- A discard ban on anglerfish regardless of size.
- A prohibition against targeting anglerfish with other fishing gear than 360 mm (stretched mesh) gillnets.
- A minimum catch size of 60 cm in all gillnet fisheries, and maximum permission of 5% anglerfish (in numbers) below 60 cm when fishing with gillnets.
- 72 hours maximum soak time in the gillnet fishery.
- A maximum of 500 gillnets (each net being maximum 27.5 m long) per vessel.

- Closure of the gillnet fishery from 1 March to 20 May. This closure period was expanded to 20 December–20 May in the areas north of 65°N in 2008 and further expanded southwards to 64°N since 2009.
- A maximum of 15% bycatch (in weight) of anglerfish in the trawl- and Danish seine fisheries, and maximum 10% bycatch (in weight) of anglerfish in the shrimp trawl fishery. When fishing for argentine and Norway pout/sandeel a maximum of 0.5% bycatch is allowed within a maximum limit of 500 kg anglerfish per trip.
- A maximum of 5% bycatch (in weight) of anglerfish is allowed to be caught in gillnets targeting other species.

### 9.1.5 Scientific surveys

Anglerfish appear in demersal trawl surveys along the Norwegian shelf, but in very small numbers. The survey design has changed from single species to multispecies during recent years. The procedures for data collection on anglerfish have varied and, at present, no time-series from surveys in Division 2.a yields reliable information on the abundance of anglerfish. On the other hand, surveys in the North Sea and especially the SIAMISS (Scottish Irish Anglerfish Megrin Industry Science Survey; Figure 9.3), seem to be predictive for the recruitment of anglerfish to the ICES subareas 1 and 2 (Northeast Arctic). This is seen with the likely development of the large 2012 year class in the SIAMISS survey (Figure 9.4), which is corroborated with a subsequent decrease in mean catch length in Division 2a in 2017 and an increase in fishing effort at the same time.

The SIAMISS is a dedicated anglerfish survey (see ICES 2021). It covers much of the known distribution of the northern shelf anglerfish (ICES divisions 4a, 6a and 6b), with the exception of the central and southern parts of Subarea 4 and the Skagerrak and Kattegat (Division 3a). The survey began in 2005 and has been more or less carried out on an annual basis (usually in spring, but sometimes in November). The total biomass estimate for the Northern Shelf in 2021, the most recent survey year, was 48 355 t. This is a decrease of 19% compared to 2019 (there is no 2020 estimate due to incomplete survey coverage) and the lowest value since 2013. A large proportion of total population numbers consisted of individuals <30 cm in 2021, suggesting strong incoming recruitment (ICES 2021).

In Subarea 4, the International Bottom Trawl Surveys in the North Sea (indices NS-IBTS-Q1 and Q3) show declining mean weights per hour for the recent five years across all length groupings (ICES 2021). The IBTS surveys are currently not used in the assessment of anglerfish in ICES subareas 4 and 6, and in Division 3.a.

## 9.2 Data

### 9.2.1 Landings data

The official landings as reported to ICES for subareas 1 and 2 for each country are shown in Table 9.1. Landings decreased rapidly from 2010 to 2015, to the lowest since 1997, but has since shown an increase until last year. It is worth noting that the recent increase in landings first happened along the coast of western Norway, and then in the following years also subsequently further north in ICES Subarea 2. And likewise, the decrease seen in 2021 happened first in the south, i.e. both along the coast of western Norway and in the southern part of ICES Subarea 2 while the northern areas still showed an increase. Norway has by far the largest reported catches of the anglerfish in subareas 1 and 2, accounting for 96–99% of the official international landings. The coastal gillnetting accounts for more than 90% of the landings, of which about 90% are caught by the special designed large-meshed gillnets (360 mm stretched meshes; Table 9.2).

The Norwegian coastal reference fleet (see Appendix figure H1) provides us with length measurements and catch per gillnet days from ICES subareas through 4, from 2007–present and these have been presented for the AFWG in recent years. The catch rates vary spatially and temporally, and the WKANGLER (2018) therefore recommended to model and standardize the catch rates to better represent the general abundance trend of anglerfish in the entire ICES Subarea 2. The available material is shown in Tables 9.4 and 9.5 for the Norwegian statistical coastal areas (Figure 9.1) and total for ICES subareas 1 and 2.

### 9.2.2 Discards

The absence of a TAC in Norwegian waters probably reduces the incentive to underreport landings. Anecdotal evidence from the industry, observer trips and data from the self-sampling fleet (the Norwegian reference fleet; Anon. 2013; Clegg and Williams 2021) suggest that up to 8–9% of the catch (not marketable) is discarded. This happens when the soaking time is too long, mostly due to bad weather. The average percentage of discarded anglerfish was higher south of 62°N (ICES 3 and 4) than north of 62°N (ICES 2.a). Average length of discarded anglerfish was on average only 6–7 cm smaller than the landed anglerfish. This is also confirmed by Berg and Nedreaas (2021) who estimated the annual discards of anglerfish by the Coastal reference fleet in subareas 1 and 2 to vary between 11 and 32 tonnes during 2014–2018 (i.e. 1.5–2.5% of total gillnet catch) but went up to 178 tonnes (7.2%) in 2012.

### 9.2.3 Length composition data

Length distributions are available from the directed gillnet fishery during the period 1992–2021, but data are lacking for 1997–2001 (Table 9.3). The length data indicates a drop in mean length of 15–20 cm occurring during the period without length samples (Figure 9.5). Since then, the mean length increased steadily during the last decade to about 95 cm (about 10 years old and 12 kg) in 2014–2016, i.e. the same size level as seen during the 1990s. One-third of the anglerfish measured during the 1990s were above 100 cm, this proportion was between 1–6% for the early 2000s, 12–17% in 2006–2013 and 15% in 2021. This indicates strong recruitment into Subarea 2 during 1997–2001, which has not been observed again until 2017–2019 when a new drop in mean length is seen, again indicating some recruitment of smaller sized anglerfish to the area (ref. Figure 9.4).

Length distributions of retained anglerfish (*L. piscatorius*) caught by the reference fleet as target species during 2007–2021 by the specially designed-large-meshed gillnets, and as bycatch in other gillnets or other gears are shown in Appendix figures H2–H4. All subsequent analyses (in the methods and results section) have only used the length distributions from the target fishery since 2007 using the large-meshed gillnets which represent more than 80% of the international landings in subareas 1 and 2.

### 9.2.4 Catch per unit effort (CPUE) data

The Norwegian coastal reference fleet (see Appendix figure H1) has reported catch per gillnet soaking time (CPUE) from their daily catch operations. For the current modelling and hence standardization of the annual CPUE from subareas 1 and 2, we have used the following data:

- Only catch rates of retained anglerfish from the fishery using special large-meshed anglerfish gillnets (stretched meshes = 360 mm).
- Years 2007–2021.
- Discards excluded.
- Adding zero catches where gillnets are used, but anglerfish not present.

- All coastal areas (i.e. ICES 3.a, 4.a, 2.a, and 1) included in the model since it is documented (e.g. WKANGLER 2018) that anglerfish are migrating across the ICES area borders.
- The area (km<sup>2</sup>) of each subarea inside 12 nautical miles (covering most of the anglerfish distribution) is calculated and used as weighing factor when annual CPUEs are estimated for each subarea (Figure 9.6).

## 9.3 Methods and results

### 9.3.1 The length-based-spawning-potential-ratio (LBSPR) approach

The LBSPR method has been developed for data-limited fisheries, where only a few data are available: some representative sample of the size structure of the vulnerable portion of the population (i.e. the catch) and an understanding of the life history of the species (Hordyk *et al.*, 2016). The LBSPR method does not require knowledge of the natural mortality rate ( $M$ ) but instead uses the ratio of natural mortality and the von Bertalanffy growth coefficient ( $K$ ;  $M/K$ ), which is believed to vary less across stocks and species than  $M$  (Prince *et al.*, 2015) although individual estimates of  $M$  and  $K$  can be used if available. Like any assessment method, the LBSPR model relies on a number of simplifying assumptions. In particular, the model is equilibrium-based, assumes that the length composition data are representative of the exploited population at steady state, and logistic selectivity (see the results section below for more discussion).

The LBSPR model originally developed by Hordyk *et al.* (2015a; 2015b) used a conventional age-structured equilibrium population model and a size-based selectivity. As a consequence, this approach could not account for “Lee’s phenomenon” – the fact that larger specimens-at-age experience greater mortality than its cohort of smaller size because of the size-based selectivity. This is because the age-structured model has a ‘regeneration assumption’ i.e. it redistributes at each time-step the length-at-age using the same distribution. Hordyk *et al.* (2016) since developed a length-structured version of the LBSPR model that used growth-type-groups (GTG) to account for the above phenomenon and showed that the new approach reduced bias related to the “Lee’s phenomenon”<sup>2</sup>. GTG LBSPR is therefore used for all subsequent analyses.

Some of the life-history parameters for the analysis were originally taken from WKANGLER (2018) but kept the same as in AFWG 2021. Hordyk *et al.* (2015a; 2015b) showed that the LBSPR approach was sensitive to the input parameters. We, therefore, drew 1000 random samples for each input parameter (i.e. from a bivariate normal distribution for  $L_{inf}$  and  $K$ , a univariate normal distribution for  $M$ ,  $L_{50}$ ,  $L_{95}$  (see Table 9.3)) and rerun the model in order to account for the effect of uncertainty around the input parameters on the results. We will refer to it as the “stochastic LBSPR approach” hereon.

Once the stochastic LBSPR runs were finished, we conducted some simulations through the LBSPR package to calculate some target SPR value. To do this, we used the mean input values from the stochastic LBSPR, the average estimated parameters values (from the stochastic LBSPR approach) and set the “steepness” to a value between 0.7 and 0.9 to perform a YPR analysis and determine the target reference points (which gives the maximum yield). Steepness values between 0.7 and 0.9 were chosen based on a literature search (values close to 1 are also found in the literature but were not included in the test as it seemed unrealistic for the species). The analysis gave target reference points of  $SPR = 0.4$  (with  $F/M \sim 1$ ) and  $SPR = 0.25$  (with  $F/M \sim 2$ ) for steepness values of 0.7 and 0.9, respectively. What we obtained from the stochastic LBSPR runs instead are relatively stable annual estimates of SPR (between 0.15 and 0.5 (the IQR range)) and  $F/M$

<sup>2</sup> <https://github.com/AdrianHordyk/LBSPR>

(between 1.5 and 2.5; Figure 9.7). This suggests that—while there is a lot of uncertainty—fishing effort is probably slightly above but close to the effort that would lead to maximum yield.

The relationship between the biomass of reproductively mature individuals (spawning stock) and the resulting offspring added to the population (recruitment), the stock–recruitment relationship, is a fundamental and challenging problem in all population biology. The steepness of this relationship is the fraction of unfished recruitment obtained when the spawning-stock biomass is 20% of its unfished level. Steepness has become widely used in fishery management, where it is usually treated as a statistical quantity. If one has sufficient life-history information to construct a density-independent population model then one can derive an associated estimate of steepness (Mace and Doonan, 1988; Mangel *et al.*, 2010; 2013).

As mentioned in the introduction, the LBSPR approach is an equilibrium-based method (i.e. assumes that the fishery experiences constant recruitment and  $F$  over time) and violation of this assumption can lead to biased SPR estimates. However, some management strategy evaluations conducted by Hordyk *et al.* (2015) on harvest control rules based on SPR-based size targets showed that while annual assessments of SPR may be imprecise due to the transitory dynamics of a population's size structure, smoothed trends estimated over several years may provide a robust metric for harvest control rules. SPR estimates in our study were relatively stable, thus large recruitment fluctuations may not be an issue.

### 9.3.2 CPUE standardization

Raw CPUE data are seldom proportional to population abundance as many factors (e.g. changes in fish distribution, catch efficiency, effort, etc) potentially affect its value. Therefore, CPUE standardization is an important step that attempts to derive an index that tracks relative population dynamics.

In the data preparation step, we quickly noticed that there was not enough data from ICES Subarea 1 to perform model inference. Therefore, we decided to omit data from this Subarea from the analyses. ICES Subarea 1 is the northern margin of *L. piscatorius* distribution, and only 3 tonnes were caught in this area in 2019, mostly as bycatch in other fisheries.

Below, we defined some important terms we used for the CPUE standardization:

Standardized effort (gillnet day) = gear count x soaking time (hours)/24 hours

CPUE (per gillnet day) = catch weight/standardized effort

CPUE standardization was performed using the glmmTMB package (Brooks *et al.*, 2017) and the best model was chosen based on AICc and residuals checks using the DHARMA package (Hartig 2021) i.e. the most parsimonious model had the lowest AICc while showing no problematic residuals pattern (i.e. overdispersion, underdispersion, etc). If problematic residual patterns were found, we tried to address the issue by either reconsidering the input data, changing model parameterization, or changing the model distribution assumption.

Using the model investigation/selection steps as in the last assessment (AFWG 2021), the final model was based on the Tweedie distribution. The Tweedie distribution belongs to the exponential family and its variance term is modelled as a power function of the mean ( $\mu$ ) i.e.  $\phi\mu^p$ . This distribution is commonly used for generalized linear models (e.g. Jørgensen 1997) – with the following parameterization (for fixed and random effects):

$$\text{CPUE} = \text{year} + \text{subarea} + \text{month} + (1|\text{vessel}) + (1|\text{subarea\_year}) + (1|\text{month\_year}) + (1|\text{month\_subarea})$$

The expression (1|vessel) indicates that the vessel effect is considered a random effect and acts on the intercept. The expression (1|month\_year) indicates that the month and year variable was

concatenated into a single variable and considered as a random effect. In essence, this treatment models the interaction effect between year and month, but the approach only considers existing interaction (as opposed to all possible combinations of year and month which would be un-estimable)—which is an advantage in a data-limited situation such as ours.

Additionally, like the last two assessments (AFWG 2020, 2021), data were filtered to keep only vessels that had more than 10 observations (as these rare vessel observations were causing deviations in the residual patterns). Using the 10-minimum-observations criteria improved the residual pattern of the model but was not able to eliminate the residuals pattern (Figure 9.8). Such residual pattern started to appear in the last assessment (AFWG 2021) – though much less pronounced, thus not investigated – but was absent from the 2020 assessment (AFWG 2020). Therefore, another type of modelling approach, namely a delta model (or hurdle model), was briefly examined in this study to possibly correct for the observed residual pattern.

A delta model consists of a pair of models: one that models the species occurrence (presence/absence) and another that models the positive values.

$$\text{Presence} = (1|\text{year}) + \text{subarea} + \text{month} + (1|\text{vessel}) + (1|\text{subarea\_year}) + (1|\text{month\_year}) + (1|\text{month\_subarea})$$

$$\text{CPUE\_pos} = \text{year} + \text{subarea} + \text{month} + (1|\text{vessel}) + (1|\text{subarea\_year}) + (1|\text{month\_year}) + (1|\text{month\_subarea})$$

Anglerfish occurrence was modelled using a binomial model with logit transform and positive CPUE was modelled using a Gamma distribution with log link. All variables were kept the same as in the original Tweedie model except for the year effect in the occurrence model that was converted to a random effect due to some estimability issue. The delta model specification helped improve the residual behaviour but did not completely eliminate the pattern (Figure 9.8).

For all subsequent analysis, we therefore examined the sensitivity of the model results to using the delta model as CPUE standardization approach.

As in the AFWG 2021, the standardized annual CPUE index was created by summing up all predictions based on all possible combination of year (2007–2021), subarea (in ICES Area 2.a), and month (1–12) after weighting the prediction for each subarea by its surface (in km<sup>2</sup> within the 12 nautical miles as shown in Figure 9.6) relative to the total surface (sum of all subarea surfaces in the ICES area 2a). In this process, we removed the vessel random effect (assuming it equals 0, the mean value) as it only affects catch efficiency and does not represent the underlying fish abundance. We note that glmmTMB can handle any missing new levels for random effect variables when making prediction (it assumes it is equal to zero and inflates the prediction error by its associated random effect variance). The standard deviation of the summed prediction (for the original Tweedie model) was directly calculated in glmmTMB by modifying the source code ([‘glmmTMB.cpp’](#) file).

A similar approach was taken for the delta model to derive an abundance index except that model predictions were manually calculated while accounting for the covariance in fixed effect estimates. More precisely, fixed effect parameters were resampled 100,000 times based on their estimated mean and covariance for both components of the delta model (while random effect were kept at their MLE). These values were then used to predict the probability of occurrence and CPUE value for all combination of year, subarea, and month (as above) that were then multiplied together to calculate the expected CPUE. The final index was then calculated in a similar approach as in the original Tweedie model by weighted average of the predictions by area.

Figure 9.9 shows that anglerfish population in ICES Subarea 2a might have declined over the last decade (as well as the raw effort) but could be increasing again in more recent years. Nonetheless, there is a lot of year-to-year variability and uncertainty around the point estimates.



### 9.3.3 JABBA

JABBA stands for ‘Just Another Bayesian Biomass Assessment’ and is open-source modelling software that can be used for biomass dynamic stock assessment applications. It has emerged from the development of a Bayesian State-Space Surplus Production Model framework applied in stock assessments of sharks, tuna, and billfish around the world (Winker *et al.*, 2018). JABBA requires a minimum of two input comma-separated value files (.csv) in the form of catch and abundance indices (and SE; see Appendix table H1). The Catch input file contains the time-series of year and catch by weight, aggregated across fleets for the entire fishery. Missing catch years or catch values are not allowed. JABBA is formulated to accommodate abundance indices from multiple sources (i.e. fleets) in a single CPUE file, which contains all considered abundance indices. The first column of the CPUE input is year, which must match the range of years provided in the Catch file. In contrast to the Catch input, missing abundance index (and SE) values are allowed.

The catch data comes from the different fishing countries’ official reporting of annual landings to ICES (see Table 9.1) and the CPUE data (along with its standard deviation) comes from the CPUE standardization process described above with values in 1992–1994 imputed based on expert knowledge. We assumed that the CPUE index from ICES Subarea 2.a calculated using data from the anglerfish targeted fishery is representative of the stock status in ICES areas 1 and together.

In addition to these .csv files, JABBA also requires users to define the prior distribution for the model parameters which will be subsequently updated with data to form the posterior distributions (Figure 9.10). In addition to the base case, 10 additional scenarios were run to examine the sensitivity of the model results to the choice of priors (Table 9.6).

Figure 9.11 shows the trajectory of the population estimates from 1990–2021 based on the tested scenarios (Table 9.7). In general, population abundance has never fallen below  $B_{MSY}$  (at least the mean trajectory) but fishing mortality fluctuated above and below the  $F_{MSY}$  (Figure 9.12). Figure 9.13 is the Kobe plot from the base model run showing the estimated trajectories of  $B/B_{MSY}$  and  $F/F_{MSY}$  along with the credibility intervals of the 2021 estimates of biomass and fishing mortality. The percentage numbers at the top right indicate how much of the 2021 population estimates that fall within the green (not overfished, no overfishing), yellow (overfished, but no overfishing), orange (overfishing, but not overfished), and red (overfished and overfishing) zones, after accounting for all the parameter uncertainty (basically, the area under the oval-shaped density plot that falls into each coloured quadrant). The model estimates that there is roughly a 15% (23%) probability that the 2021 population estimate falls within the red zone, 30% (22%) in the orange, 0.5% (2%) in the yellow, and 54.5% (53%) in the green zone (in parentheses corresponding percentages from last year’s assessment). Finally, retrospective analysis on the base model run was slightly worse than the previous assessment cycle (AFWG 2021) overall (especially for  $F/F_{MSY}$ ; Figure 9.13, Table 9.7). In general, the error in parameter estimates was consistent (same sign) across peel 2–5 but changed sign in peel 1 (Table 9.7).

The sensitivity analysis says that  $MSY$  could be around or slightly above 2000 tonnes, with a  $B_{MSY} \sim 30\,000$  tonnes (Figure 9.14). Though the  $MSY$  value is quite sensitive to the choice of prior on  $r$  = population growth rate, which makes sense if population grows slowly, one cannot fish too hard, i.e. lower  $MSY$ .

However, the retrospective analysis (Figure 9.15) also shows that the estimate of  $MSY$  could be influenced by the addition of 1 year of data, i.e. the scaling of  $F/F_{MSY}$  is not very steady across time, and the figure suggests that it could be a bit lower, maybe between 1500–2000 t. Though the  $B_{MSY}$  still stays around  $\sim 30\,000$  tonnes. So an initial guestimate of  $MSY$  would be somewhere between 1500–2000 t.  $MSY$  of 1500 t was also the  $MSY$  estimate based on the low  $r$  scenario.

## 9.4 Management considerations and future investigations

The present abundance of anglerfish in subareas 1 and 2 seems to depend on the influx or migration of juveniles from ICES subareas 4 and 6. It is therefore expected that an effective discard ban on anglerfish in subareas 4 and 6 will have a positive effect on the abundance north of 62°N. Reduced mean size of the landed anglerfish in recent years (fishing with the same large-meshed gillnets) indicates a new influx of recruitment to the ICES subareas 1 and 2. Monitoring of the fishery will be important in the near future to protect the young specimens from recruitment- and growth- overfishing.

AFWG has previously recommended that the anglerfish stock component in subareas 1 and 2 is annually monitored and a 20% reduction in fishing effort per year (also as an uncertainty cap) should be imposed until the decrease in CPUE is stopped. Despite that the decrease in CPUE has stopped for time being, the current exploratory assessment shows that there is nothing to gain in increasing effort. The “2-over-3” rule used on the CPUE time-series, including both an uncertainty cap and a precautionary buffer, suggest a 10% reduction in effort or catch advice for 2023.

The standardized CPUE analysis shows that anglerfish population in ICES Subarea 2.a has declined over the last decade (as well as the raw effort) with an increase in the most recent year.

The spawning potential ratio, as calculated by the LBSPR method using input biological parameters and the estimated exploitation parameters suggests that—while there is a lot of uncertainty—fishing effort is probably slightly above but close to the effort that would lead to maximum yield.

The relative population stock status is around  $B_{MSY}$ , though fishing intensity could be close or slightly higher than  $F_{MSY}$ . Therefore, effort should not be increased at the risk of the population falling below the biomass and SPR targets. New promising recruitment seen from scientific survey in the northern North Sea is expected to contribute to the fishery north of 62°N after 3–4 years if it continues to develop as the observed recruits seen in the 2013–2014 surveys did. The quality of the current assessment was this year further evaluated by analysing another type of CPUE modelling approach (the Delta model), to possibly correct for an observed residual pattern. The AFWG considers the current assessment of sufficient quality to base catch advice on for subareas 1 and 2.

When it comes to reference points, it should be further discussed if and which defined values of  $F/M$ ,  $F/F_{MSY}$ , SPR and  $B/B_{MSY}$  may be used.

Any potential harvest control should take account of both recruitment- and growth- overfishing. LBSPR provides measures for both,  $F/M$  and SPR, with the SPR values being the transient SPR and thus an estimate of current stock status. While maximum sustainable catch is often a key management objective, it may not be the only one. In that case, it may be worth modifying a reference point to reflect other management objectives.

The AFWG supports that ICES subareas 1, 2, 3, 4, and 6 should be investigated together to get a more complete understanding of migrations and distributions.

## 9.5 Tables and figures

Table 9.1. Nominal catch (t) of anglerfish in ICES subareas 1 and 2, 2001–2021, as officially reported to ICES.

	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021*
DK	2	+	-	1	-	-	-	-	+	-	-	-	-	-	-	-	-	-	-	-	-
Faroes	1	1	2	5	11	4	7	4	2	1	+	+	1	+	+	1	1	+	+	1	-
France	-	-	-	-	-	1	-	-	-	-	1	3	2	-	4	2	4	3	8	5	4
Ger- many	65	59	55	70	55	+	+	0	+	82	70	0	-	+	+	+	1	1	50	-	-
Iceland	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-	-
Nor- way	3554	2000	2405	2907	2650	4257	4470	4007	4298	5391	5031	3758	2988	1655	933	1355	1473	1884	2750	2258	2584
Portu- gal	-	-	-	-	-	-	-	2	6	1	+	-	-	-	-	-	-	-	-	-	-
UK	2	11	15	18	19	86	114	138	152	40	3	3	111	2	105	76	5	15	+	16	13
Others												1	1	-	-	+	-	+	-	-	-
Total	3624	2071	2477	3001	2735	4348	4591	4151	4458	5515	5112	3765	3103	1657	1043	1435	1484	1903	2809	2280	2601

\*Preliminary.

Table 9.2. Anglerfish in ICES subareas 1 and 2. Norwegian landings (tonnes) by fishery in 2008–2021. The coastal area is here defined as the area inside 12 nautical miles from the baseline.

Fleet NORWAY	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021*
Coastal gillnet	3574	3934	4806	4557	3521	2758	1506	829	1231	1320	1727	2502	1939	2233
Offshore gillnet	240	171	391	319	115	158	95	52	62	87	68	153	168	229

Danish seine	75	68	40	26	16	19	11	12	17	23	28	26	35	78
Demersal trawl	34	36	48	19	11	8	7	3	5	6	10	5	3	2
Other gears	84	89	106	83	96	45	36	37	40	31	51	64	113	42
Total	4007	4298	5391	5031	3759	2988	1655	934	1355	1468	1884	2750	2258	2584

\*Preliminary per 5 April 2022.

**Table 9.3. Basic input parameters and parameters for resampling as used for the LBSPR analysis.**

Basic input parameters	Value
von Bertalanffy K parameter (mean)	0.12
von Bertalanffy Linf parameter (mean)	146
von Bertalanffy t0 parameter	-0.34
Length-weight parameter a	0.149
Length-weight parameter b	2.964
Steepness	0.8
Maximum age	25
Length at 50% maturity (L50; mean)	82
Length at 95% maturity (L95; mean)	100
$\Delta\text{Mat} = \text{L95} - \text{L50}$ (mean)	18
Length at first capture	40
Length at full selection	60
M (mean)	0.2

Basic input parameters	Value
M/k (mean)	1.67
Parameters for resampling	Value
N <sub>samp</sub>	1000
CV(M)	0.15
Cor (L <sub>inf</sub> _K)	0.9
CV(K)	0.3
CV(L <sub>inf</sub> )	0.15
CV(L50)	0.05
CV( $\Delta$ Mat)	0.05

Table 9.4. Number of coastal reference fleet fishing days with anglerfish, per national stat. subareas (0–7) and total for ICES subareas 1 and 2. Only large-meshed gillnets included.

Year/ area	0	5	6	7	ICES 1 and 2
2007	106	26		280	412
2008	62	37	6	171	276
2009	86	35	36	176	333
2010	14	41	37	143	235
2011	64	19	51	116	250
2012	49	12	24	21	106
2013	64	20	18	81	183
2014	5		19	107	131
2015	109		5	116	230
2016	92		22	35	149
2017	88			109	197
2018	108			89	197
2019	86	34		63	183
2020	74	28	52	104	258
2021	66		72	78	216

Table 9.5. Number of fishing days with length measured anglerfish (left) and number of length measured fish (right). Only large-meshed gillnets included.

Year	ICES 1 and 2	Year	ICES 1 and 2
2007	78	2007	2265
2008	43	2008	1407
2009	47	2009	2325
2010	67	2010	2171
2011	78	2011	2423
2012	39	2012	995
2013	52	2013	1305
2014	29	2014	546
2015	31	2015	1063
2016	45	2016	654
2017	74	2017	1593
2018	64	2018	1451
2019	50	2019	1486
2020	83	2020	2149
2021	75	2021	1608

Table 9.6. Eleven scenarios were run to examine the sensitivity of the model results to the choice of priors.

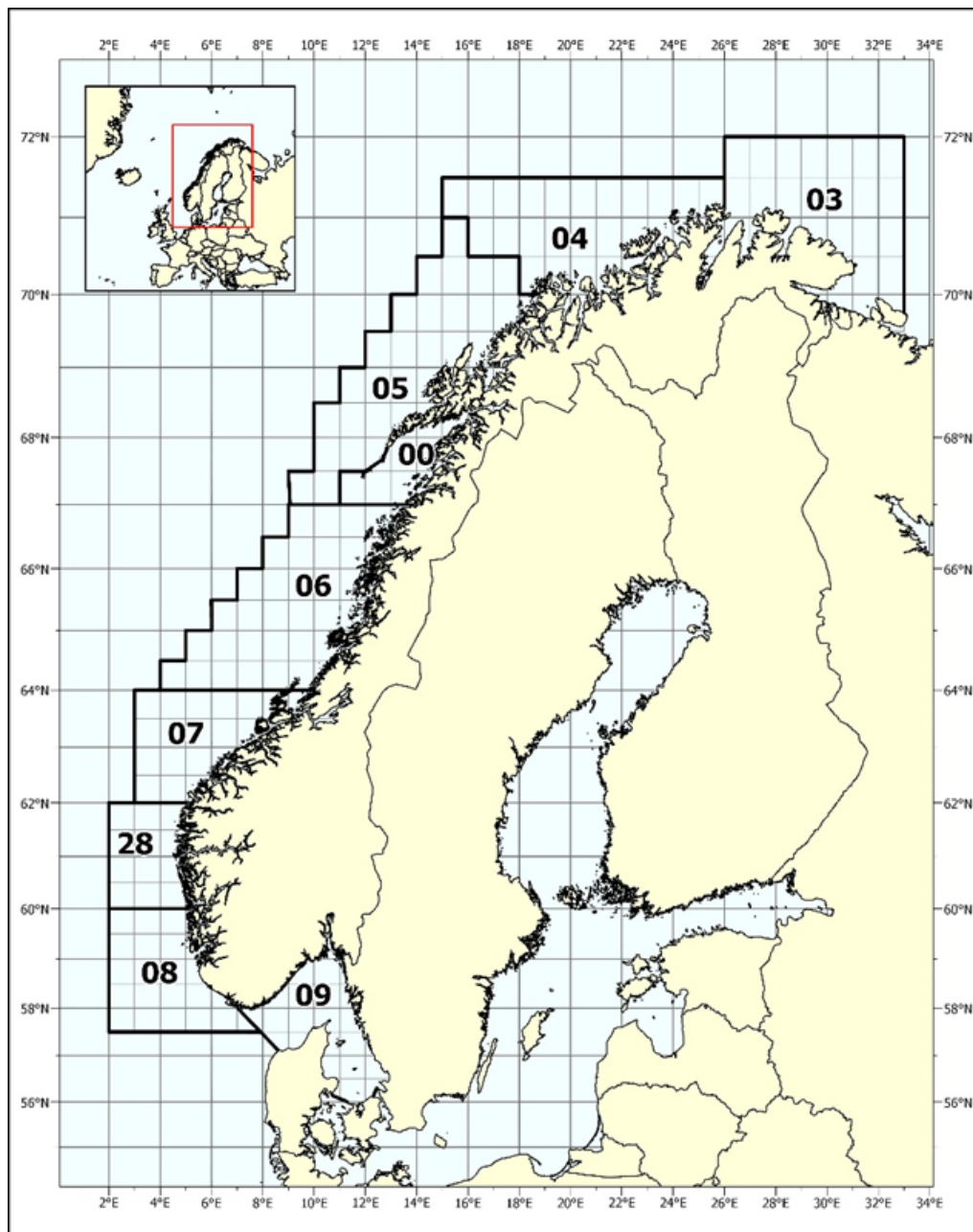
Scenario name	K	r	$\sigma_p$	Initial depletion	B <sub>MSY</sub> /K value
Base	LN(1e6,1)	LN(0.1,1)	IG(4,0.01)	LN(0.8,0.5)	0.35
Low_K	LN(5e5,1)	LN(0.1,1)	IG(4,0.01)	LN(0.8,0.5)	0.35

High_K	LN(1.5e6,1)	LN(0.1,1)	IG(4,0.01)	LN(0.8,0.5)	0.35
Low_r	LN(1e6,1)	LN(0.05,1)	IG(4,0.01)	LN(0.8,0.5)	0.35
High_r	LN(1e6,1)	LN(0.2,1)	IG(4,0.01)	LN(0.8,0.5)	0.35
Low_sigmaP	LN(1e6,1)	LN(0.1,1)	IG(4,0.005)	LN(0.8,0.5)	0.35
High_sigmaP	LN(1e6,1)	LN(0.1,1)	IG(4,0.02)	LN(0.8,0.5)	0.35
Low_initdep	LN(1e6,1)	LN(0.1,1)	IG(4,0.01)	LN(0.7,0.5)	0.35
High_initdep	LN(1e6,1)	LN(0.1,1)	IG(4,0.01)	LN(0.9,0.5)	0.35
Low_BmsyK	LN(1e6,1)	LN(0.1,1)	IG(4,0.01)	LN(0.8,0.5)	0.30
High_BmsyK	LN(1e6,1)	LN(0.1,1)	IG(4,0.01)	LN(0.8,0.5)	0.40

\*LN stands for lognormal and IG stands for inverse gamma distribution. B<sub>MSY</sub>/K value controls for the position of the inflection point of the surplus production curve with respect to K (a value from 0 to 1).

**Table 9.7. Relative error (RE) in parameter estimates between the base run with full dataset (Table 9.6) and the retrospective peels (1 to 5 years) and the associated Mohn's rho statistics (i.e. average RE from the 5 peels). Relative error is calculated as: RE = (peel-ref)/ref.**

	<b>B</b>	<b>F</b>	<b>B/B<sub>MSY</sub></b>	<b>F/F<sub>MSY</sub></b>	<b>B/B<sub>0</sub></b>	<b>MSY</b>
<b>RE_peel1</b>	-0.031	0.032	0.063	-0.025	0.063	-0.046
<b>RE_peel2</b>	-0.142	0.166	-0.211	0.779	-0.211	-0.324
<b>RE_peel3</b>	-0.112	0.127	-0.288	0.855	-0.288	-0.277
<b>RE_peel4</b>	-0.122	0.139	-0.084	0.295	-0.084	-0.173
<b>RE_peel5</b>	-0.092	0.102	-0.117	0.186	-0.117	-0.074
<b>Mohn's rho</b>	-0.100	0.113	-0.127	0.418	-0.127	-0.179



**Figure 9.1.** Map showing the Norwegian statistical coastal areas. Area 03 is part of ICES Subarea 1; areas 04, 05, 00, 06, and 07 are part of ICES Subarea 2; Areas 28 and 08 are part of ICES Subarea 4, and Area 09 corresponds roughly with ICES Subarea 3.



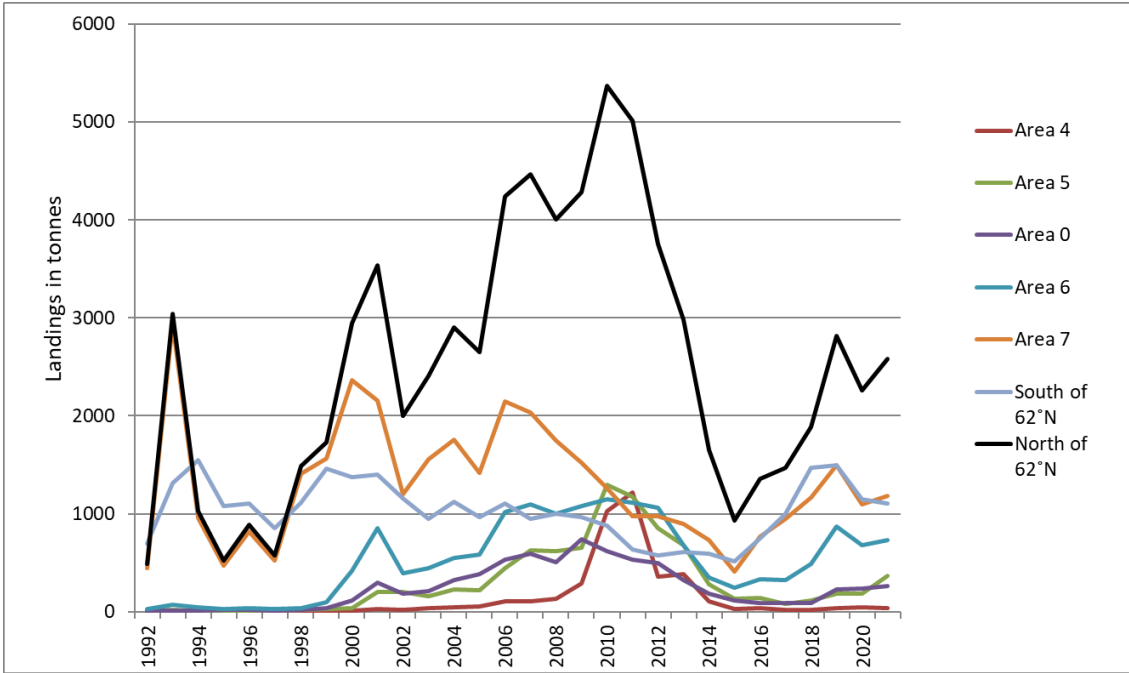


Figure 9.2. Norwegian official landings (in tonnes) of anglerfish (*Lophius piscatorius*) per statistical area (see Figure 9.1) within ICES areas 1 and 2 during 1992–2021. Norwegian landings from the area south of 62°N (ICES 4 and 3) are shown for comparison.

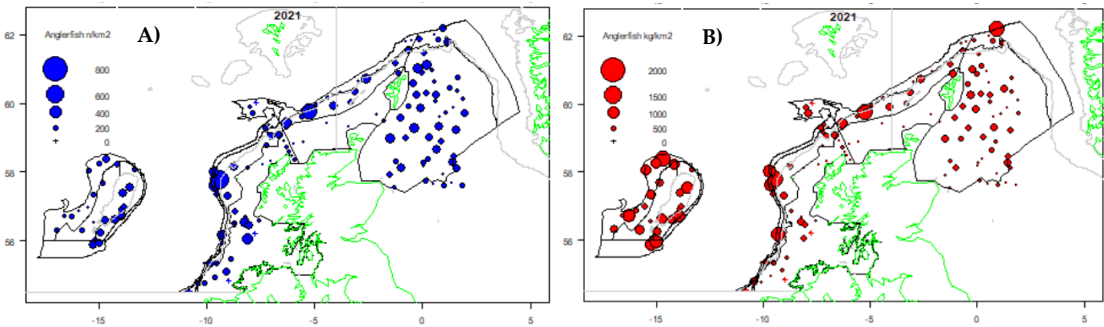


Figure 9.3. Excerpt from WGCSE 2021: A) WGCSE 2021 figure 4.16 - Numbers of anglerfish per km2 observed by SIAMISS surveys 2021. B) WGCSE 2021 figure 4.17 - Weight of anglerfish (kg) per km2 observed by SIAMISS surveys 2021.

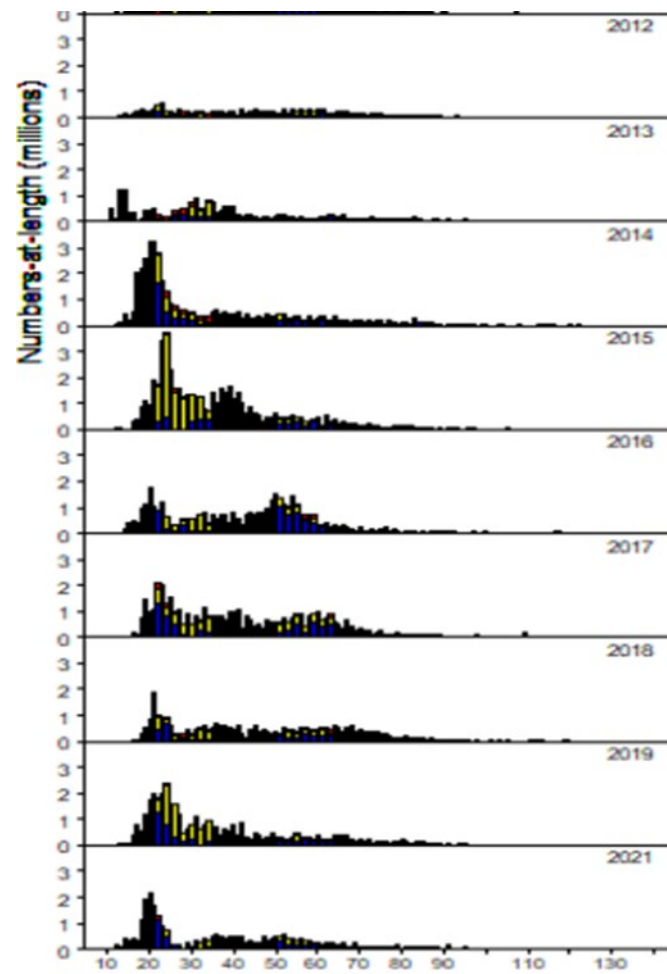


Figure 9.4. Excerpt from WGCSE 2021: Figure 4.8. SIAMISS-Q2 estimates of total numbers (millions) at-length (cm) for subareas 4.a (blue)–c and 6.a (yellow)–b (red) combined, 2012–2021.

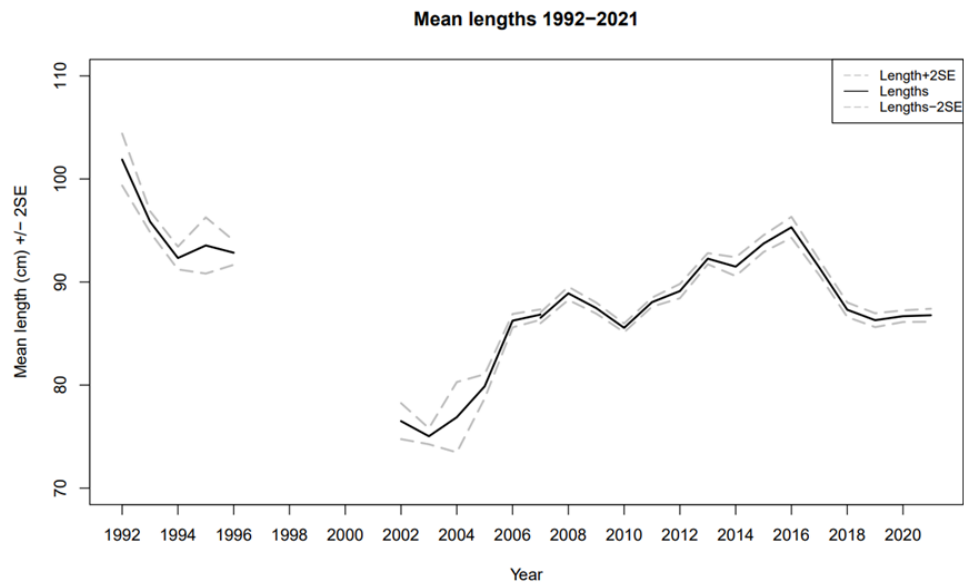


Figure 9.5. Anglerfish (*Lophius piscatorius*) in ICES Subareas 1 and 2. Mean lengths for anglerfish caught in the directed coastal gillnetting in Division 2.a during 1992–2021, dotted lines represent  $\pm 2SE$  of the mean. Note that data are lacking for 1997–2001. This illustrates pulses of new recruitment entering Division 2.a from ICES subareas 4 and 6; last time during 2002–2003, and to a lesser extent in 2017–2019.

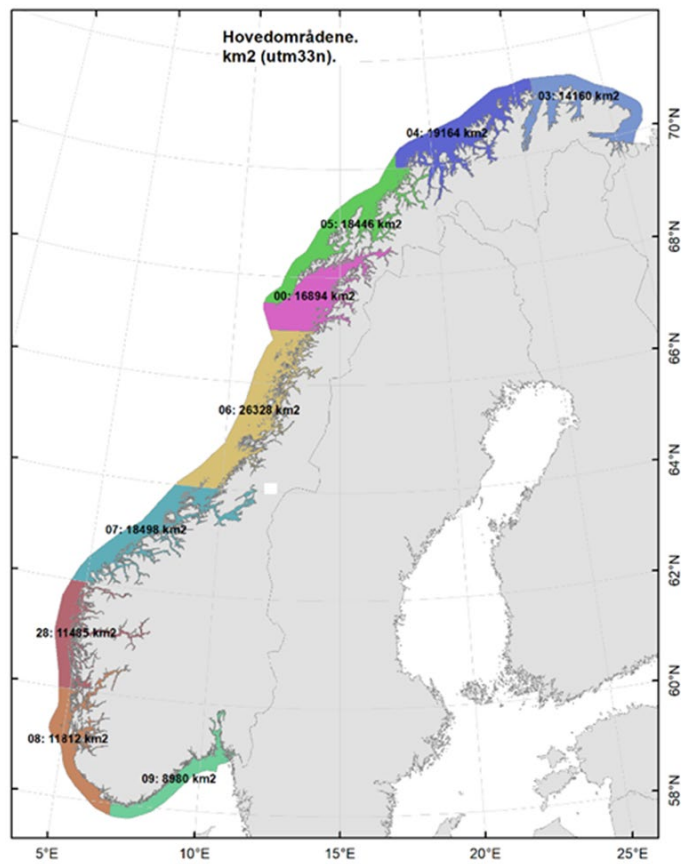


Figure 9.6. Map showing the area (km2) of each Norwegian statistical subarea inside 12 nautical miles. The subareas 4, 5, 0, 6, and 7 belong to the ICES Division 2.a.

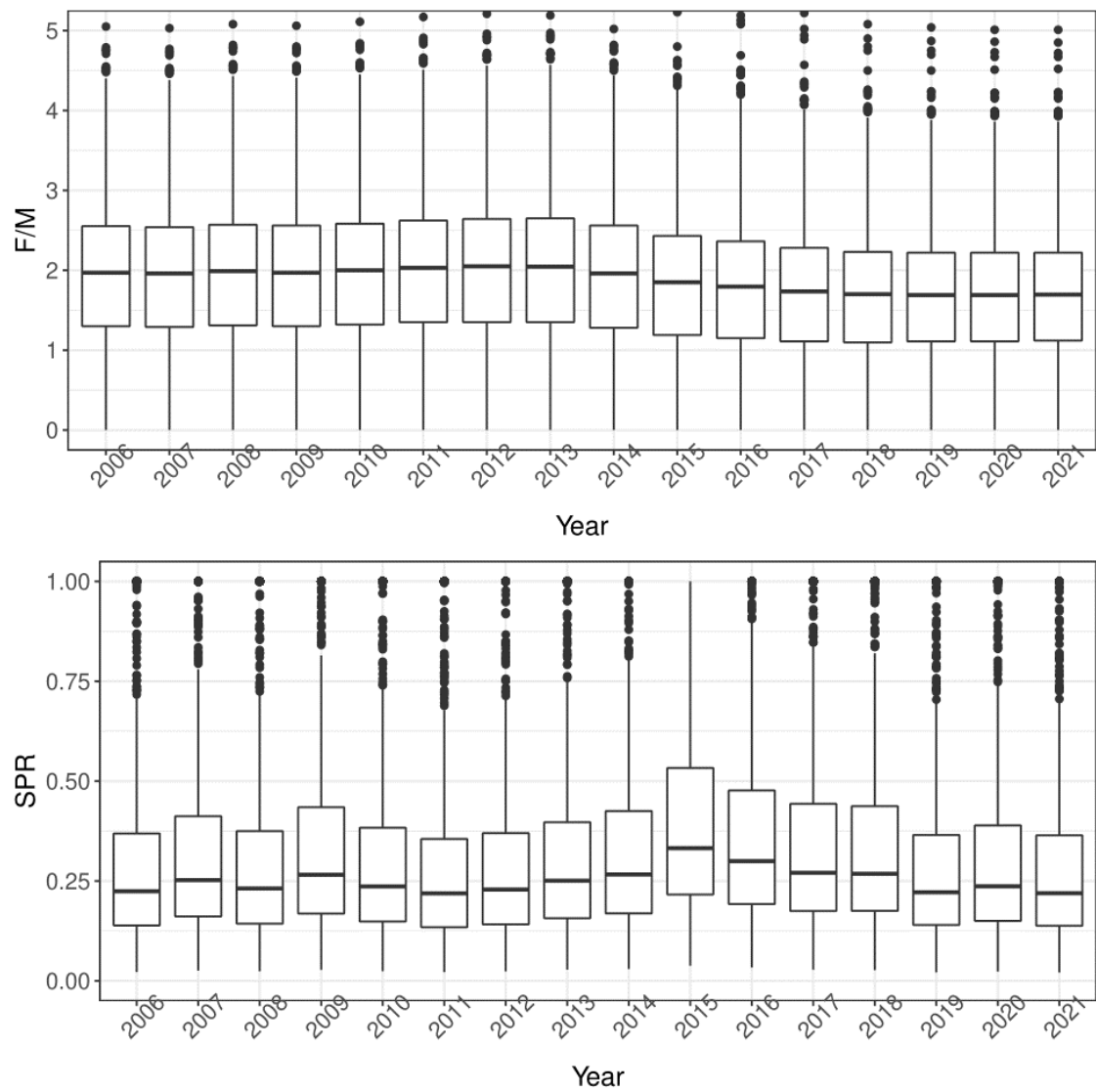


Figure 9.7. Annual estimates of F/M (above) and SPR (below) from the stochastic LBSPR approach using the length composition data from 2006- 2021.

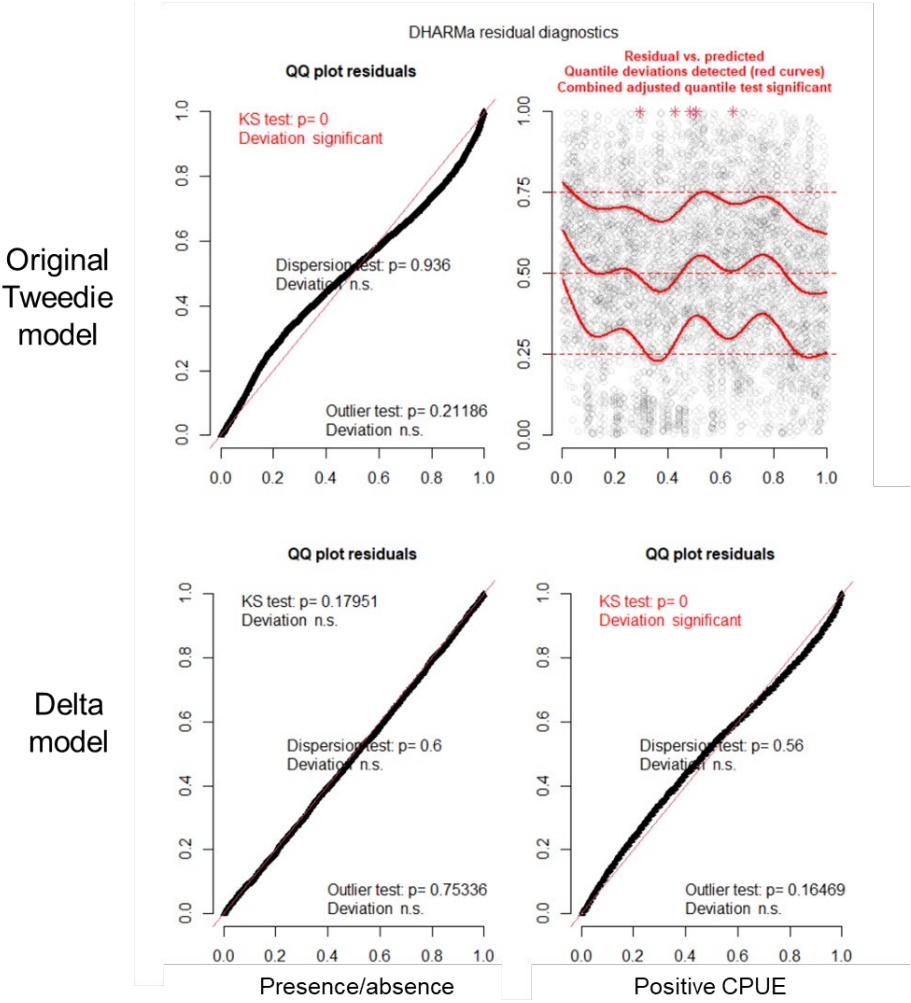


Figure 9.8. CPUE model residual diagnostics. Top panel shows the residual pattern in the original Tweedie model using the latest data. Bottom panel shows the results from the new delta model.

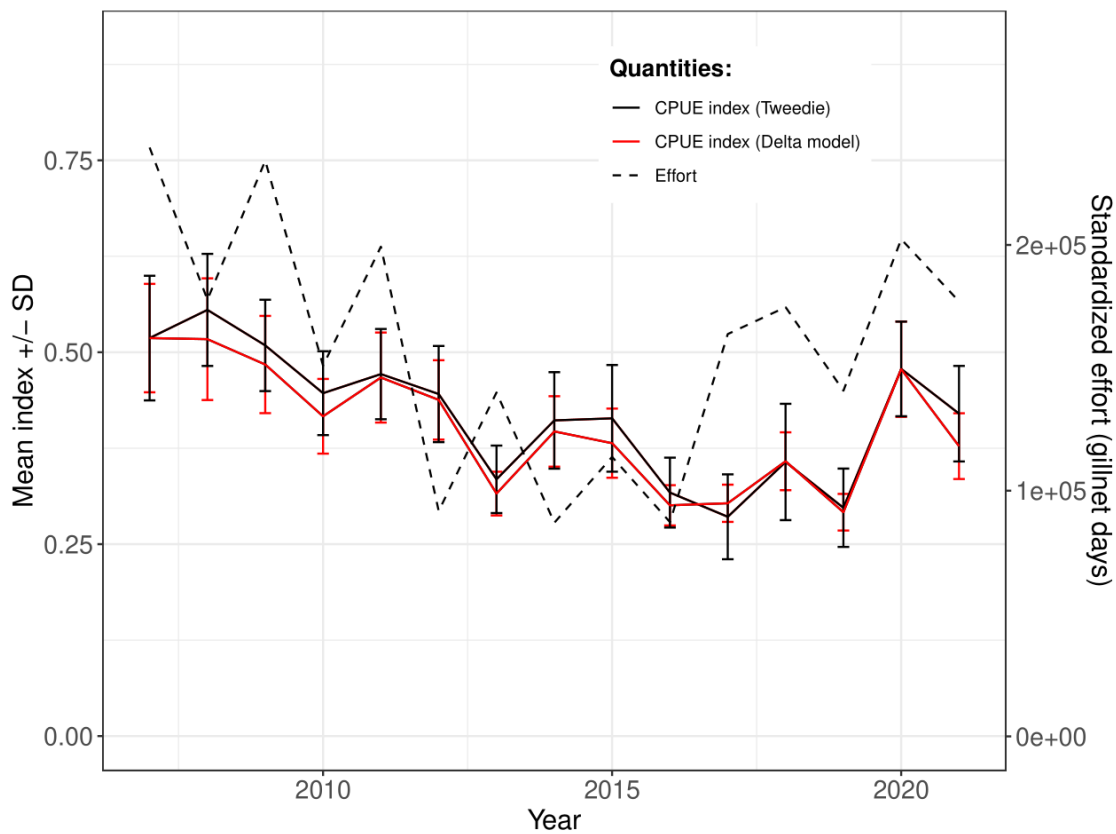


Figure 9.9. Standardized CPUE (kg per gillnet day) +/- SD (solid black line with error bars for the original Tweedie model, and solid red line with error bars for the new delta model) and the corresponding standardized effort (dash line) for anglerfish based on the data from the Norwegian coastal reference fleet in ICES Subarea 2a, from vessels targeting anglerfish with large meshed gillnets.

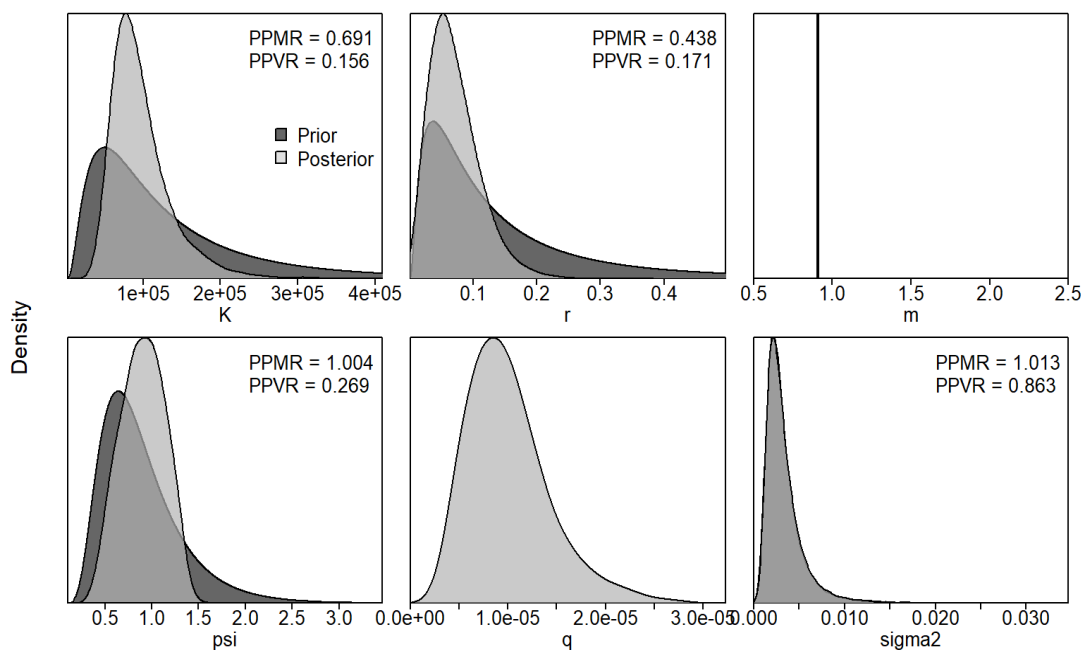


Figure 9.10. Prior and posterior distributions of the JABBA model parameters for the anglerfish assessment.

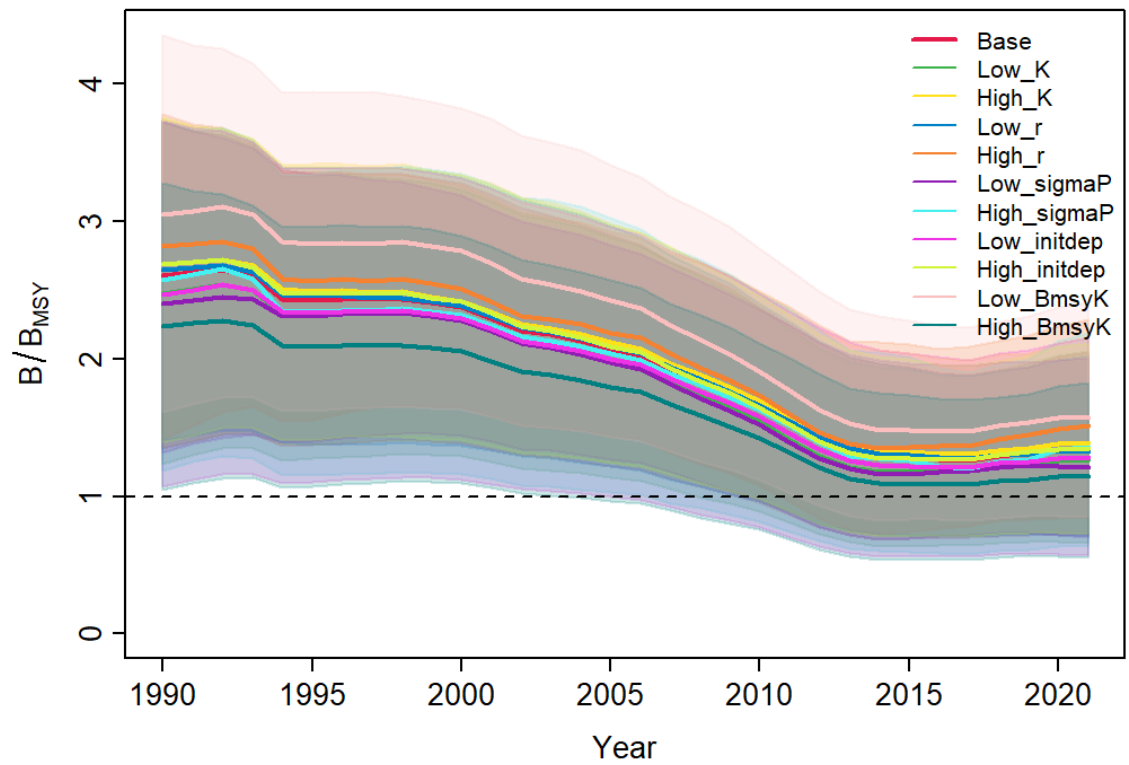


Figure 9.11. Estimated trajectories for  $B/B_{MSY}$  for the ICES subareas 1 and 2 anglerfish based on 11 JABBA scenarios (the name of scenario and the associated colour is indicated in the figure). The lines show the mean trajectory and the shaded areas denote 95% credibility intervals.

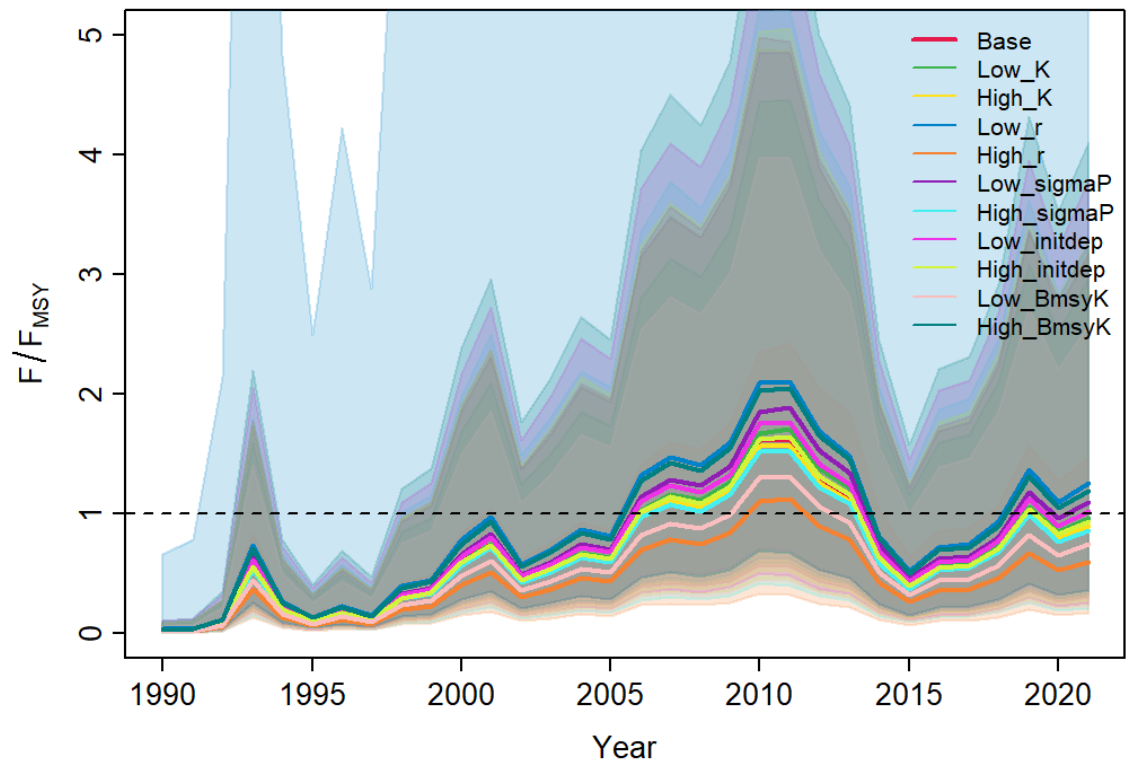
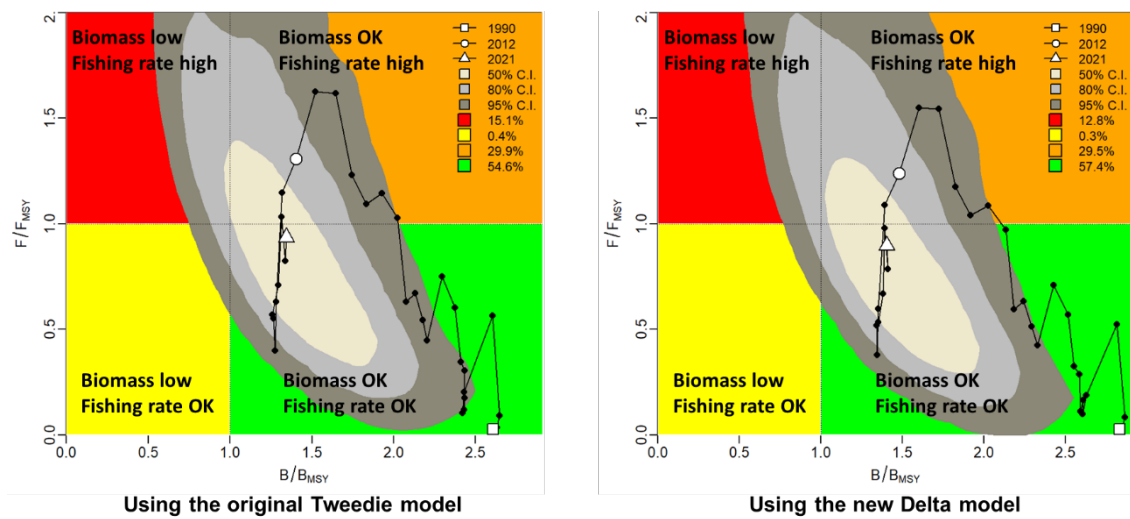


Figure 9.12. Estimated trajectories for  $F/F_{MSY}$  for the ICES subareas 1 and 2 anglerfish based on 11 JABBA scenarios (the name of scenario and the associated colour is indicated in the figure). The lines show the mean trajectory and the shaded areas denote 95% credibility intervals.



9.13. Kobe plot for the JABBA base case scenario showing the estimated joint trajectories (1990–2021) of  $B/B_{MSY}$  and  $F/F_{MSY}$ . Different grey shaded areas denote the 50%, 80%, and 95% credibility interval for the terminal assessment year. The probability of terminal year points falling within each quadrant is indicated in the figure legend. The figure on the left shows the results using the original Tweedie model when calculating the abundance index while the figure on the right uses the index derived from the delta model.

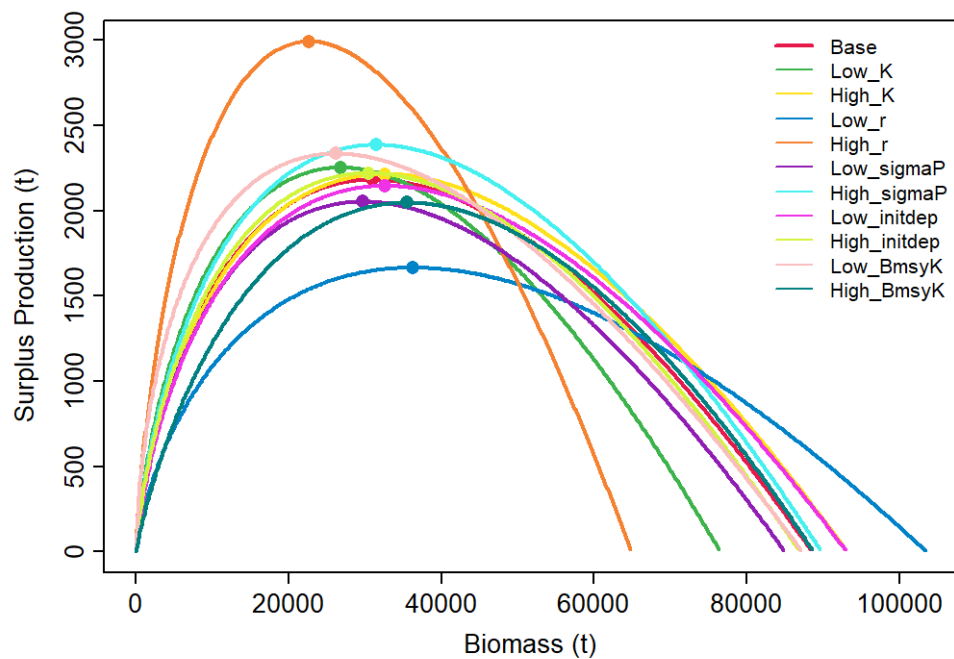


Figure 9.14. Sensitivity analysis for the ICES subareas 1 and 2 anglerfish based on 11 JABBA scenarios (the name of scenario and the associated colour is indicated in the figure). The analysis says that MSY could be around 2000 tonnes, with  $B_{MSY} \sim 30000$  tonnes. Note that the MSY value is quite sensitive to the choice of prior on  $r$  = population growth rate.



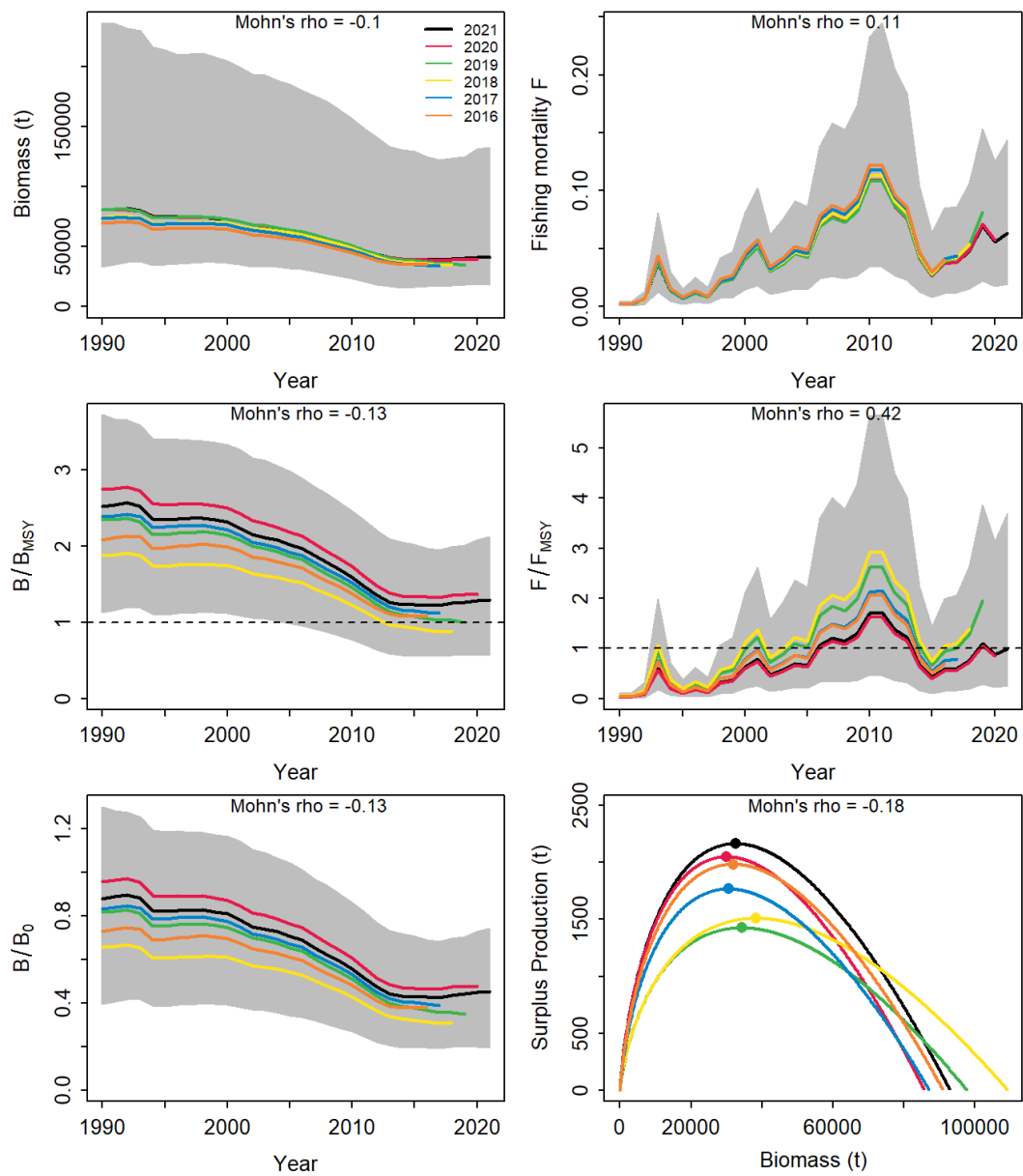


Figure 9.15. Retrospective analysis from the JABBA base case scenario. Different colours illustrate the results from different peels.

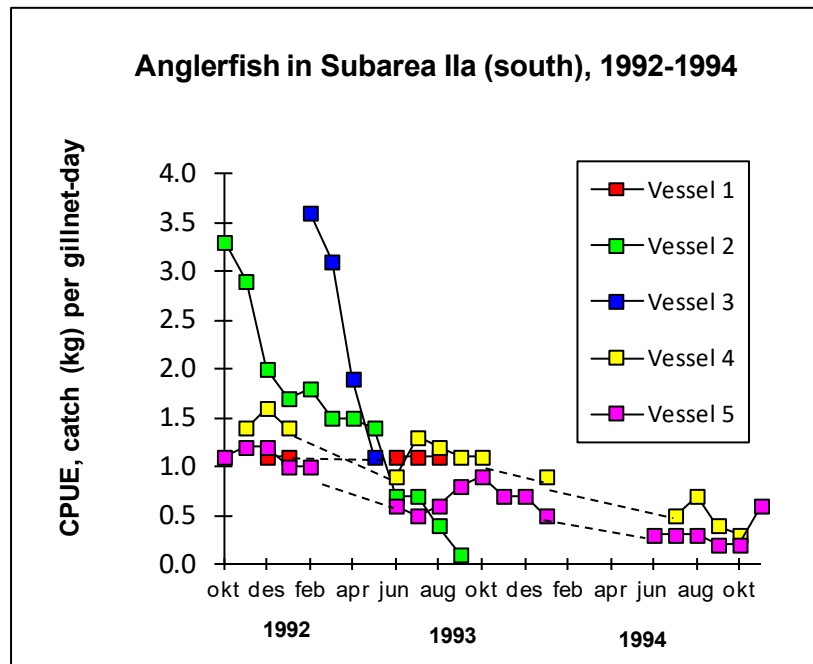
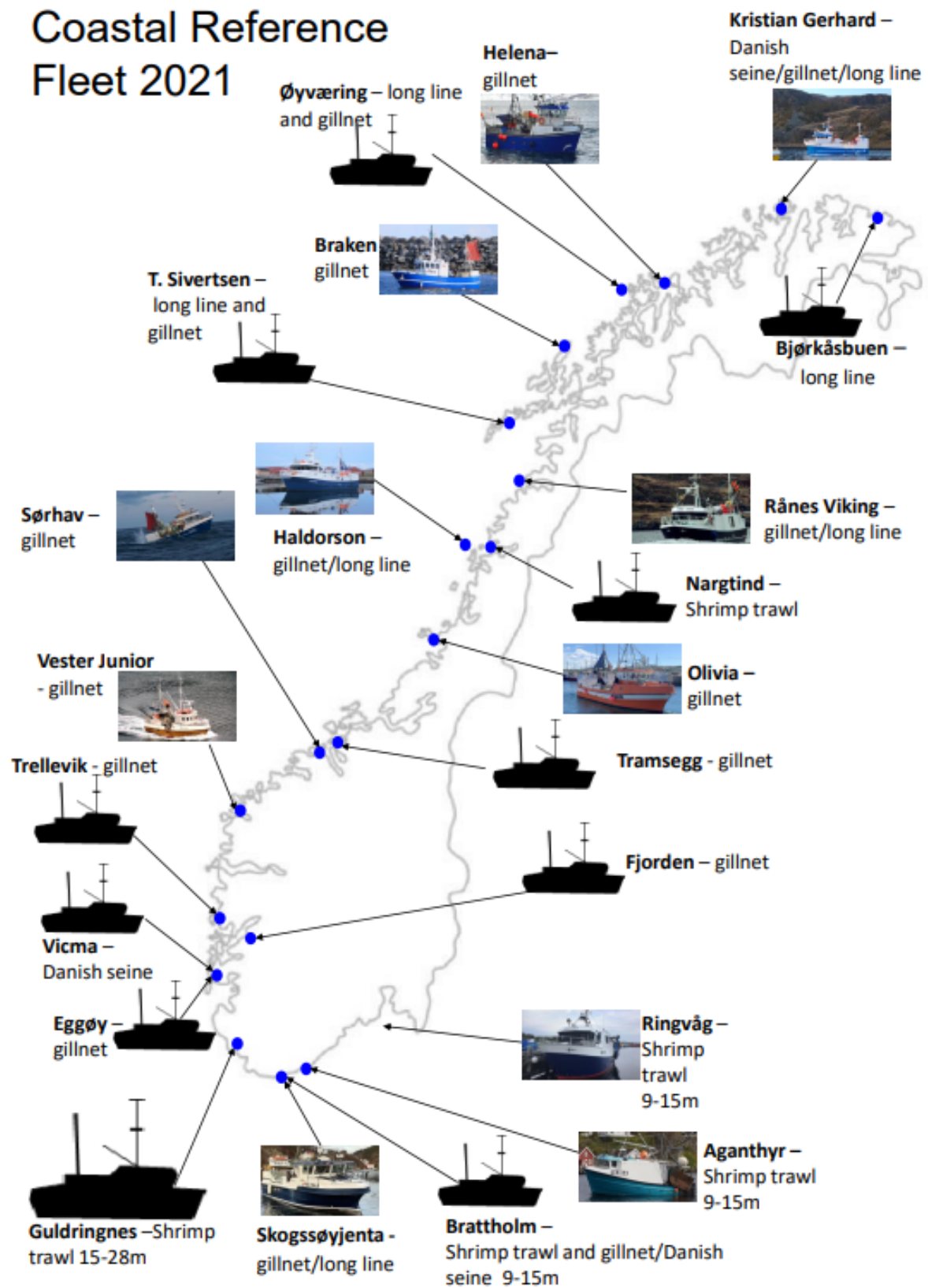


Figure 9.16. Catch per unit effort for five boats in the gillnet fishery for anglerfish in Møre and Romsdal (the same area as vessel A in figure 8 is fishing in) in the period October 1992 to October 1994. Boat 1 > 25m; Boat 2 ca. 20 m; Boat 3 ca. 10 m; Boat 4 and 5 ca. 16 m. Boats 1–4 were fishing with gillnet 360 mm mesh size, boat 5 with 300 mm mesh size.

Appendix figure H1.

## Coastal Reference Fleet 2021

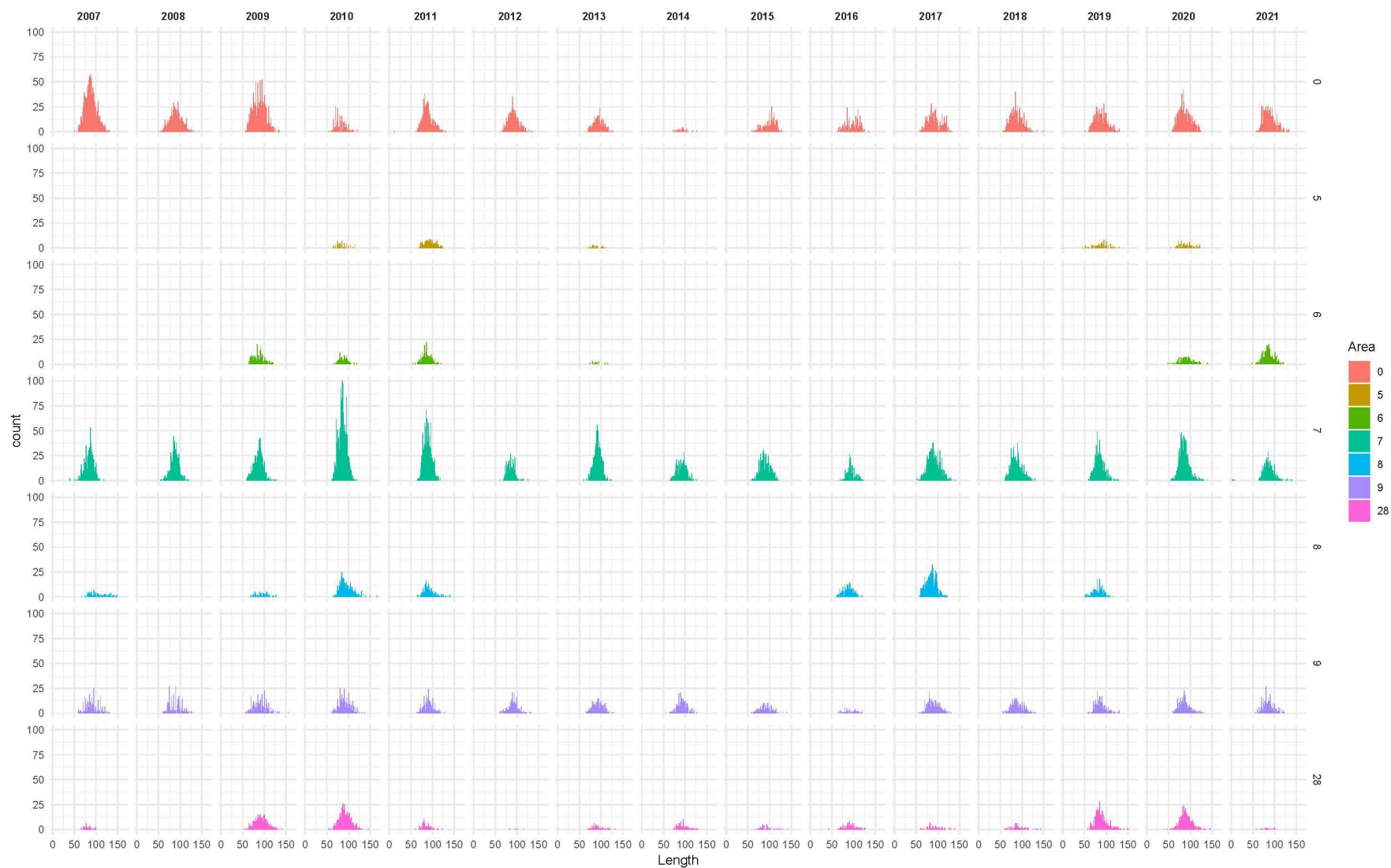


**Appendix table H1. Input data to the JABBA assessment in the form of catch and abundance indices of anglerfish (*L. piscatorius*) in ICES subareas 1 and 2.**

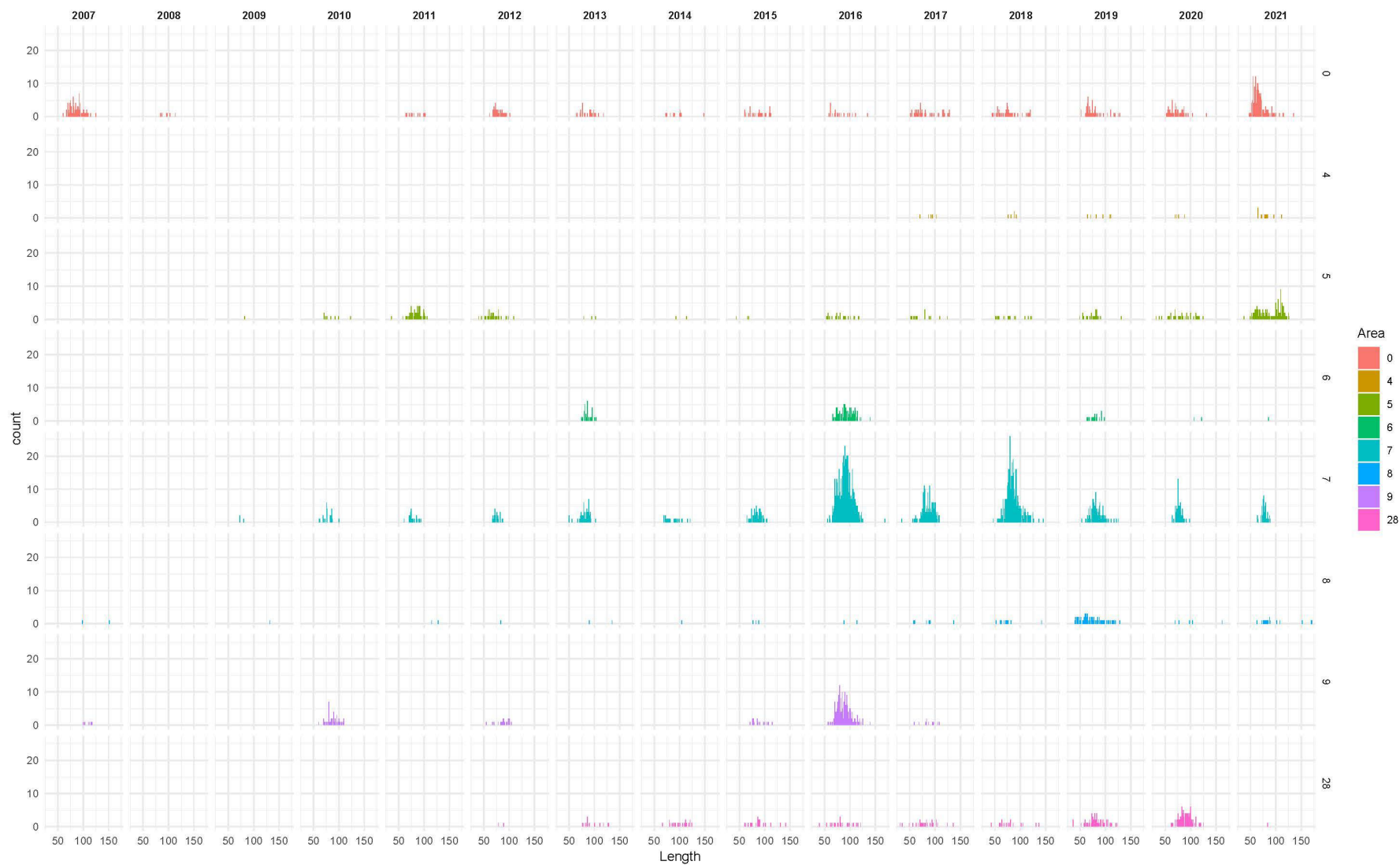
Year	Catch	CPUE (mean)	CPUE (SE)
1990	151		
1991	180		
1992	488	1.5	0.3
1993	3042	1	0.2
1994	1024	0.5	0.1
1995	526		
1996	887		
1997	601		
1998	1549		
1999	1743		
2000	2999		
2001	3624		
2002	2071		
2003	2477		
2004	3001		
2005	2735		
2006	4348		
2007	4591	0.52	0.08
2008	4151	0.56	0.07
2009	4458	0.51	0.06
2010	5515	0.45	0.05
2011	5112	0.47	0.06
2012	3765	0.45	0.06
2013	3103	0.33	0.04
2014	1657	0.41	0.06
2015	1043	0.41	0.07
2016	1435	0.32	0.05
2017	1484	0.29	0.06

Year	Catch	CPUE (mean)	CPUE (SE)
2018	1903	0.36	0.08
2019	2809	0.30	0.05
2020	2280	0.48	0.06
2021	2601	0.42	0.06

**Appendix figure H2. Length distributions of anglerfish (*L. piscatorius*) caught and retained in large-meshed gillnets per year and Norwegian statistical areas. Areas 0, 5, 6 and 7 represent ICES Subarea 2. Note the different scale of the y-axis in App. figs H2-H4.**



**Appendix figure H3. Length distributions of anglerfish (*L. piscatorius*) caught as bycatch and retained in other gillnets per year and Norwegian statistical areas. Note the different scale of the y-axis in App. figs H2-H4.**



**Appendix figure H4. Length distributions of anglerfish (*L. piscatorius*) caught as bycatch and retained in other gears per year and Norwegian statistical areas. Note the different scale of the y-axis in App. figs H2-H4.**





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