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Section contents

9 Anglerfish in subareas 1 and 2 (Northeast Arctic)

Lophius budegassa and Lophius piscatorius – anf.27.1–2

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, WGNSDS, and WGCSE, and more recent catch data collected by the Norwegian Reference Fleet since 2006 (Anon., 2013, Clegg and Williams, 2020). 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 (*L. piscatorius*) and black (or black-bellied) anglerfish (*L. budegassa). Lophius 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 recent years (2014–2020) this ratio has some years been up to 1 out of 200 anglerfish being *L. budegassa* in Norwegian waters, but usually about 1 out of 1000.

9.1.2 Stock description and management units

The WGNSDS (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 has 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, at 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 for *Lophius* at both Iceland (Solmundsson *et al.*, 2007), Faroe Islands (Ofstad, 2013) and Norwegian waters north of 62°N (i.e. subareas 1 and 2) to be 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).

Results from the use of otolith shape analysis in stock identification of anglerfish (*L. piscatorius*) in the Northeast Atlantic (Cañás *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 of 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 this publication, Dr Laurenson reported to www.fishupdate.com about 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 time being.

9.1.3 Biology

Sex ratios in Subarea 2 show that females outnumber males above approximately 75 cm, and above 100 cm all fish were females (Thangstad *et al.*, 2006). This is very similar to 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 influx or migration of juveniles from ICES subareas 4 and 6. Estimation of GSI (gonad-somatic index) for females in Division 2.a, indicates developing ovaries 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 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 of 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 1o 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 exploit 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 Scientific surveys

Anglerfish appears in demersal trawl surveys along the Norwegian shelf but very small numbers. There has been a change in the surveys, going from single species- to multispecies surveys, 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.

9.1.5 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 2010–201here 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 catches of anglerfish often culminate after a couple of years' fishing (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, Norwegian waters. Catches of anglerfish in Division 2.a former EC waters, now UK waters, are taken as a part of the 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 (s) 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 argentines 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.

9.2 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 201o 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, but did the years after also happen from south to north in the ICES Subarea north of 62˚N. And likewise, the decrease seen in 2020 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) provide 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) recommended therefore 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 2020) 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 o vary between 11 and 32 tonnes during 2014–2018 (i.e. 1.5–2.5% of total gillnet catch), but 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 1992–2019, 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 9.3). 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 2020. This indicates recruitment into Subarea 2 during 1997–2001 which has not been observed until 2017–2019 when a new drop in mean length is seen, again indicating some recruitment of smaller sized anglerfish to the area.

Length distributions of retained anglerfish (*L. piscatorius*) caught by the reference fleet as target species during 2007–2020 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 2007–2020.
- 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^2) 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.

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 get 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"[1]. GTG LBSPR is therefore used for all subsequent analyses.

Some of the life-history parameters for the analysis were taken from WKANGLER (2018). 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, L50, L95 (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 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 was not included in the test as it seemed unrealistic for the species). The analysis gave a target reference point of SPR = 0.4 (with F/M~1) and SPR = 0.25 (with F/M~2) and for a steepness value of 0.7 and 0.9, respectively. What we obtained from the stochastic LBSPR runs instead is a relatively stable annual estimates of SPR (between 0.15 and 0.5 (the IQR range)) and F/M (between 1.5 and 2.5; Figure 9.4). This would suggest 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 evaluation 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.

[1] https://github.com/AdrianHordyk/LBSPR

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 o 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 2020) 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.

The data showed some signs of overdispersion based on residual analysis of simple models (e.g. gaussian, poisson) i.e. the presence of greater variability of the dataset than would be expected based on a given statistical model. The Tweedie distribution was selected as the best model (after model selection) to address this problem. Tweedie distribution belongs to the exponential family and its variance term is modelled as a power function of the mean (μ) i.e. φμ p. The power parameter, p, is restricted to the interval $1 < p < 2$. The Tweedie distribution is commonly used for generalized linear models (e.g. Jørgensen 1997).

The best model has the following parameterization (for fixed and random effects):

CPUE = year + subarea + month + (1|vessel) + (1|subarea_year) + (1|month_year) + (1|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.

Further exploration of the residual pattern (more specifically the plot of scaled residual against predictors) indicated some possible issues with the vessel random effect which showed a systematic deviation for some simulated vessel effects (part of the test feature available in DHARMa). These problematic vessels only fished a few times in a single area and time, causing estimation to be less reliable. To address this issue, we filtered the data to keep data from vessels that had more than 5 or 10 observations. Using the 10-minimum-observations criteria greatly improved the residual pattern of the model hence was kept as the final model to produce the standardized annual CPUE index.

The standardized annual CPUE index was created by summing up all predictions based on all possible combinations of the year (2007–2020), subarea (in ICES area 2.a), and month (1–12) after weighting the prediction for each subarea by its surface (in km^2 within the 12 nautical miles as shown in Figure 9.5) relative to the total surface (sum of all subarea surfaces in the ICES area 2.a). 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 a 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 was directly calculated in glmmTMB by modifying the source code ('glmmTMB.cpp' file).

Figure 9.6 shows that anglerfish population in ICES Subarea 2.a might have declined over the last decade (as well as the raw effort) but 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 and Figure 9.10 for the early years 1992–1994. 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 9.7). 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 9.8 shows the trajectory of the population estimates from 1990–2020 based on the 1ested 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 9.9). Figure 9.10 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 2020 estimates of biomass and fishing mortality. The percentage numbers at the top right indicate how much of the 2020 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 23% probability that the 2020 population estimate falls within the red zone, 22% in the orange, 2% in the yellow, and 53% in the green zone. Finally, retrospective analysis indicates that overall, there is little retrospective issue with the anglerfish JABBA base model run with |Mohn's rho| ≤ 0.11 except for F/F_{MSY} (Table 9.7). In general, estimates of final year biomass and F were consistent over the last 4 retrospective peels but the scaling for F (i.e. F/F_{MSY}) was less consistent (i.e. larger relative error; Table 9.7).

The sensitivity analysis says that MSY could be around 2000 tonnes, with a B_{MSY} ~30 000 tonnes (Figure 9.12). 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 9.11) 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 ~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 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 ceased decrease in mean catch size (a sign of reduced recruitment to the fishery) and decreased catch in 2020 compared to 2019 suggest a reduction in fishing effort. The "2-over-3" rule used on the CPUE time-series, including both an uncertainty cap and a precautionary buffer, also suggest a 20% reduction in effort or catch advice for 2022.

The three approaches tested in this report, all very different (except that JABBA also uses the CPUE as abundance indices), offer corroborative evidence suggesting that the anglerfish population has declined over time.

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 seems too high (above F_{MSY}) and should be reduced before the population does fall below the biomass and SPR targets.

The quality of the current exploratory assessment was this year further evaluated by analysing more diagnostics, e.g. the JABBA model sensitivity of priors settings. 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, 1999–2020, as officially reported to ICES.

	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020*
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
D	4	17	65	59	55	70	55	+	+	0	+	82	70	0	-	+	+	+	1	1	50	-
Iceland	-	-	-	-	-	-	-	-	-	-	-	-	7	-	-	-	-	-	-	-	-	-
Norway	1733	2952	3554	2000	2405	2907	2650	4257	4470	4007	4298	5391	5031	3758	2988	1655	933	1355	1473	1884	2750	2258
Portugal	-	-	-	-	-	-	-	-	-	2	6	1	+	-	-	-	-	-	-	-	-	-
UK	6	30	2	11	15	18	19	86	114	138	152	40	3	3	111	2	105	76	5	15	+	16
Others														1	1	-	-	+	-	+	-	-
Total	**1743**	**2999**	**3624**	**2071**	**2477**	**3001**	**2735**	**4348**	**4591**	**4151**	**4458**	**5515**	**5112**	**3765**	**3103**	**1657**	**1043**	**1435**	**1484**	**1903**	**2809**	**2280**

***Preliminary.**

Table 9.2. Anglerfish in ICES subareas 1 and 2. Norwegian landings (tonnes) by fishery in 2008–2020. 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*
Coastal gillnet	3574	3934	4806	4557	3521	2758	1506	829	1231	1320	1727	2502	1939
Offshore gillnet	240	171	391	319	115	158	95	52	62	87	68	153	168
Danish seine	75	68	40	26	16	19	11	12	17	23	28	26	35

Fleet NORWAY	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020*
Demersal trawl	34	36	48	19	11	8	7	3	5	6	10	5	3
Other gears	84	89	106	83	96	45	36	37	40	31	51	64	113
Total	**4007**	**4298**	**5391**	**5031**	**3759**	**2988**	**1655**	**934**	**1355**	**1468**	**1884**	**2750**	**2258**

***Preliminary per 6 April 2021.**

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
ΔMat = L95 - 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_{samp}	1000
CV(M)	0.15
Cor (L_{inf}_K)	0.9
CV(K)	0.3
CV(L_{inf})	0.15
CV(L50)	0.05
CV(ΔMat)	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	102	256

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 2a
2007	93
2008	81
2009	81
2010	71
2011	84
2012	39
2013	55
2014	33
2015	74
2016	57
2017	88
2018	94
2019	68
2020	89

Year	ICES 1 and 2a
2007	2530
2008	1922
2009	2574
2010	2199
2011	2869
2012	1318
2013	1551
2014	836
2015	2054
2016	1339
2017	3604
2018	3233
2019	3223
2020	4129

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

Scenario name	K	r	σ_P	Initial depletion	B_{MSY}/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
Low_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_{MSY}/K value controls for the position of the inflection point of the surplus production curve with respect to K (a value from o 1).**

Table 9.7. Relative error (RE) in parameter estimates between the base run with full dataset (Table 9.6) and the retrospective peels (o 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	F	B/BM_{SY}	F/F_{MSY}	B/B0	MSY
RE_peel1	-0.029	0.030	-0.100	0.496	-0.100	-0.277
RE_peel2	-0.089	0.097	-0.188	0.522	-0.188	-0.206
RE_peel3	-0.060	0.064	-0.114	0.577	-0.114	-0.241
RE_peel4	-0.064	0.068	-0.027	0.050	-0.027	-0.026
RE_peel5	-0.124	0.142	-0.021	-0.108	-0.021	0.175
Mohn's rho	-0.073	0.080	-0.090	0.308	-0.090	-0.115

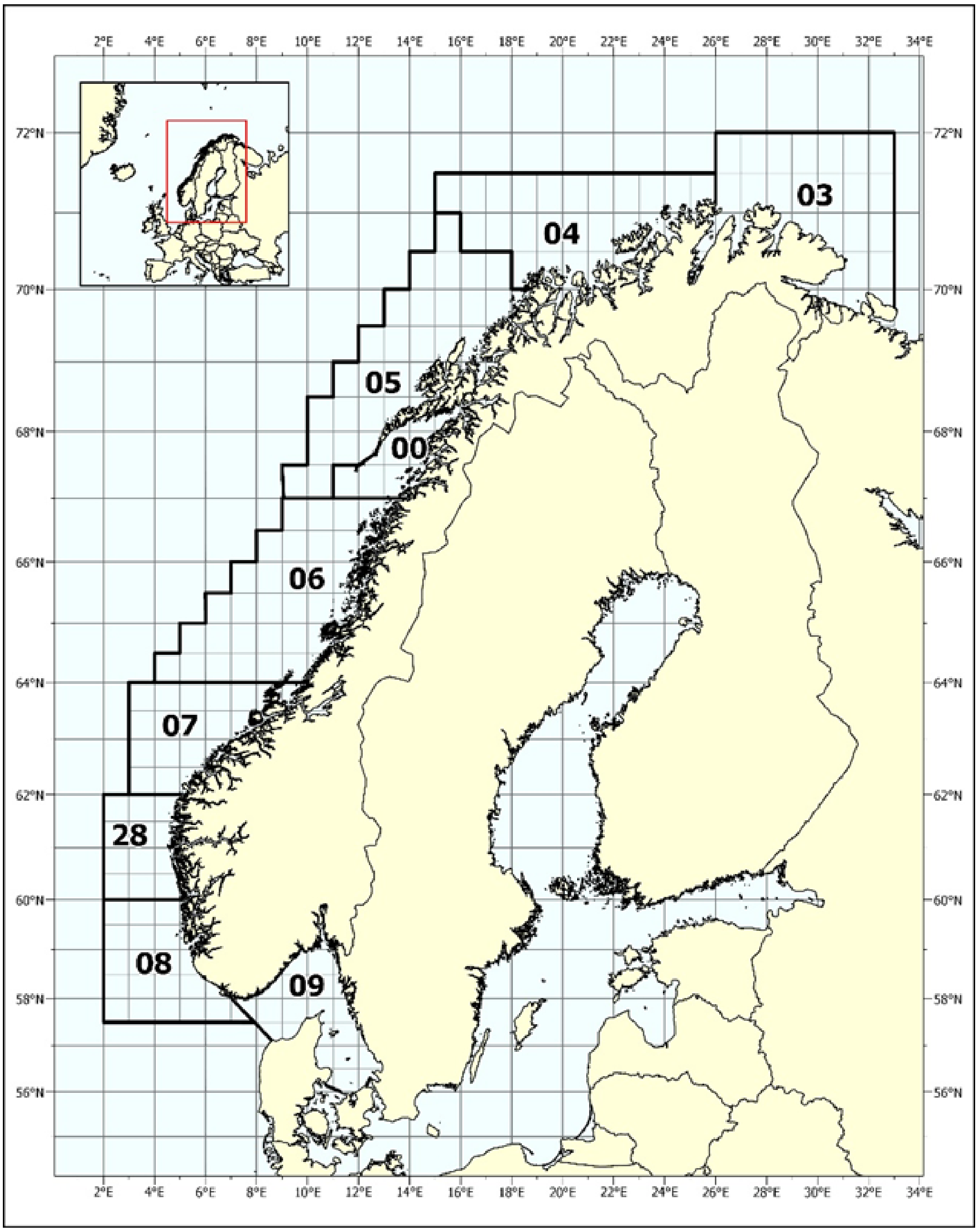


Figure 9.1. Map showing the Norwegian statistical coastal areas. Area 03 is part of ICES Subarea 1; areas 04, 05, 00, 06, and 07 are part of ICES Subarea 2; Areas 28 and 08 are part of ICES Subarea 4, and Area 09 corresponds roughly with ICES Subarea 3.

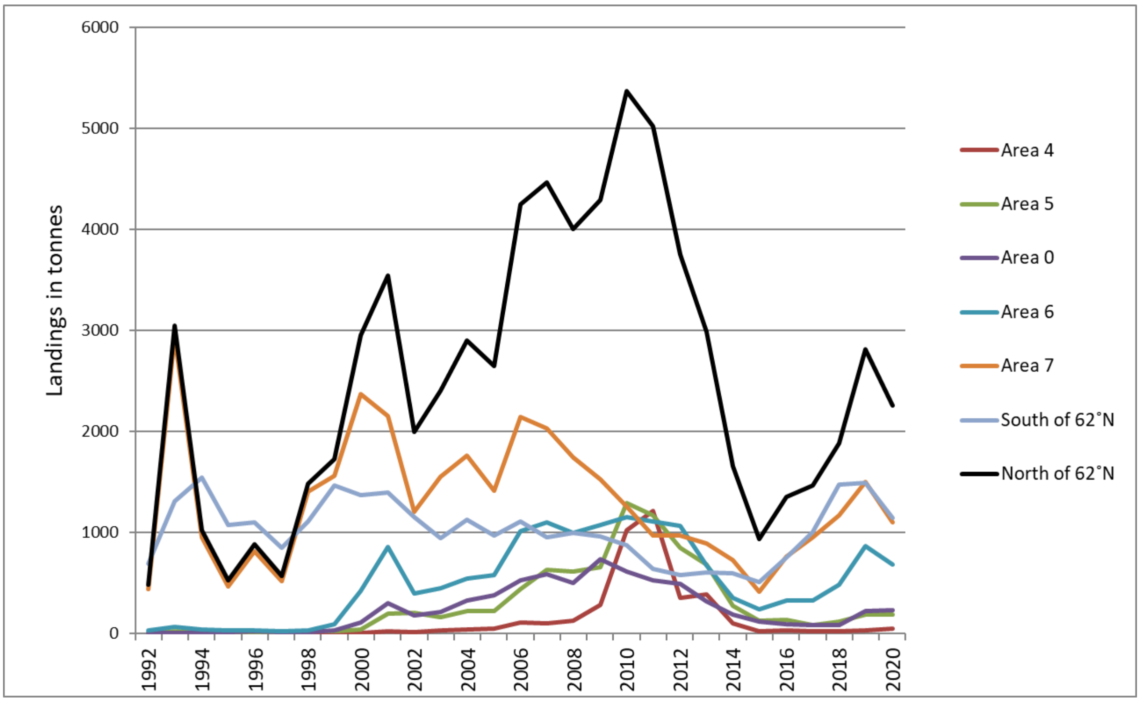


Figure 9.2. Norwegian official landings (in tonnes) of anglerfish (*Lophius piscatorius*) per statistical area (see Figure 9.1) within ICES areas 1 and 2 during 1992–2020. Norwegian landings from the area south of 62°N (ICES 4 and 3) are shown for comparison.

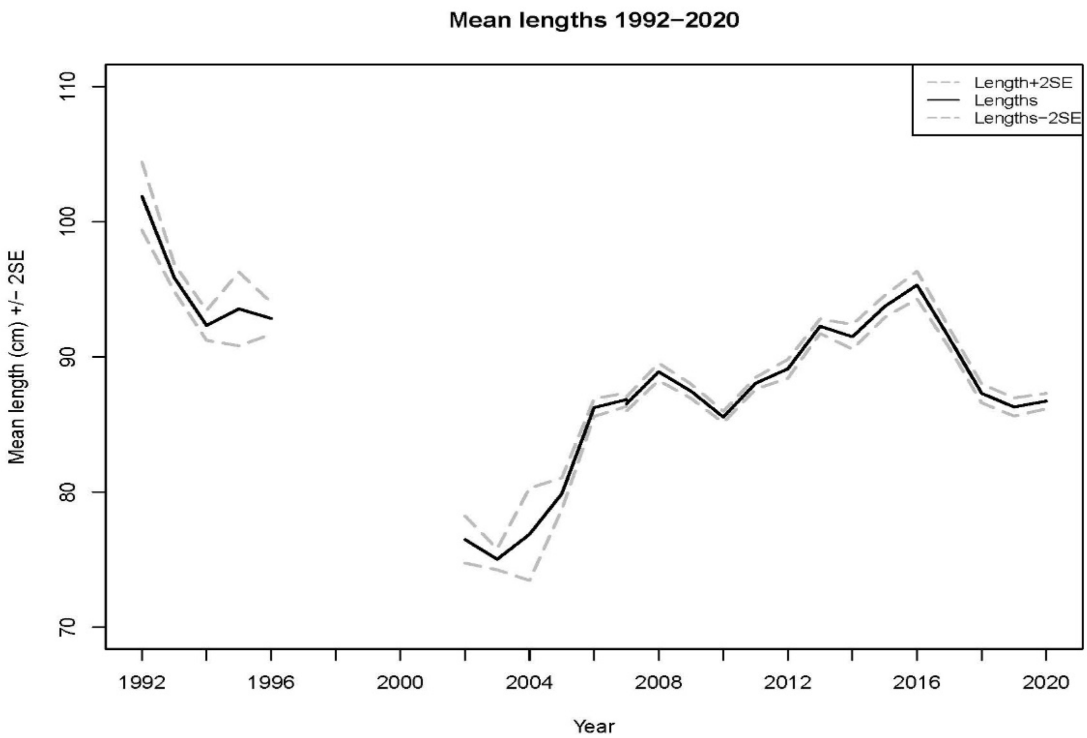


Figure 9.3. Anglerfish (*Lophius piscatorius*) in subareas 1 and 2. Mean lengths for anglerfish caught in the directed coastal gillnetting in Division 2.a during 1992–2020, dotted lines represent ± 2SE of the mean. Note that data are lacking for 1997–2001. This illustrates pulses of new recruitment entering Division 2.a from subareas 4/; last time during 2002–2003, and to a lesser extent in 2017–2019.

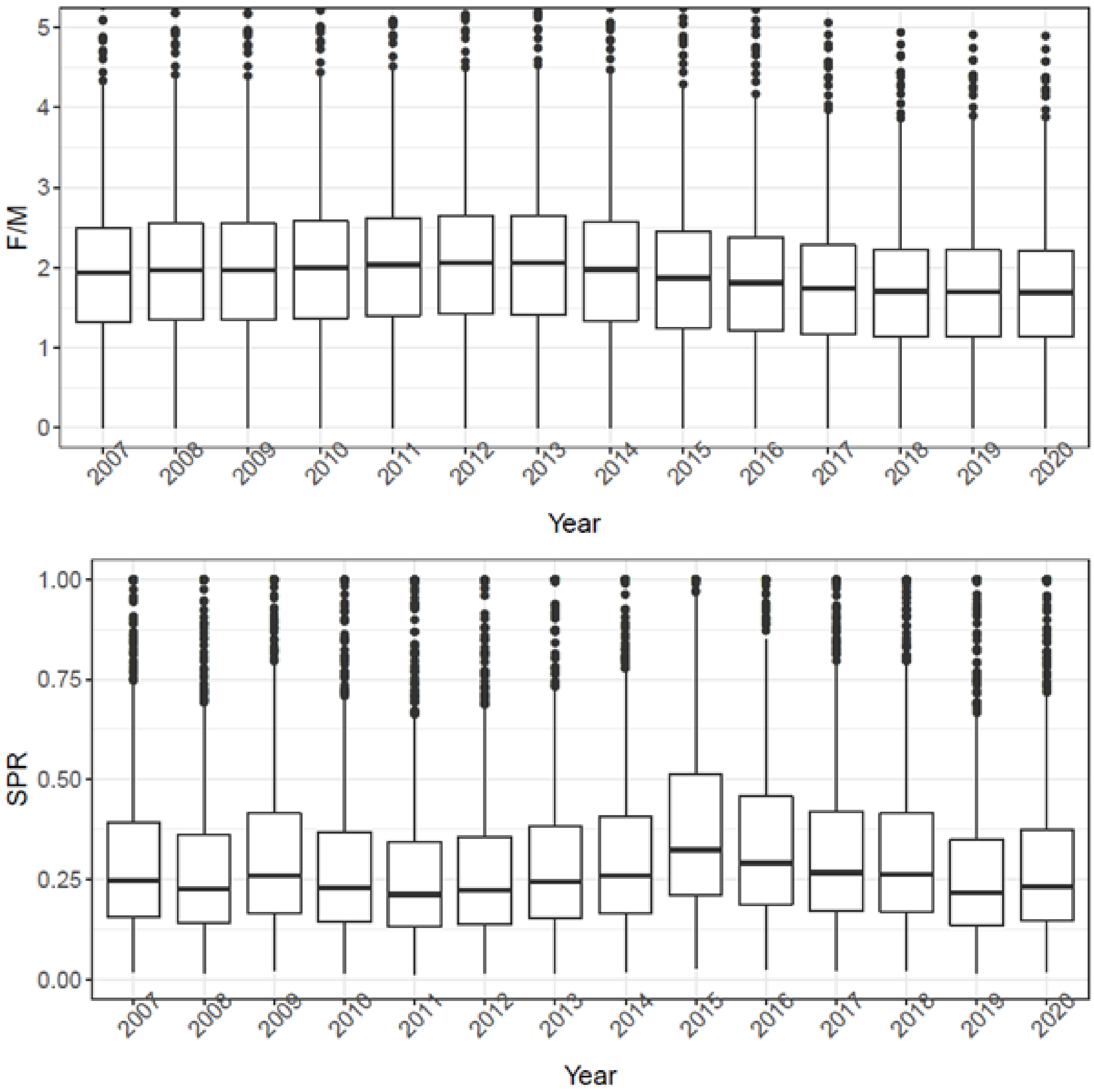


Figure 9.4. Annual estimates of F/M (above) and SPR (below) from the stochastic LBSPR approach using the length composition data from 200o 2020.

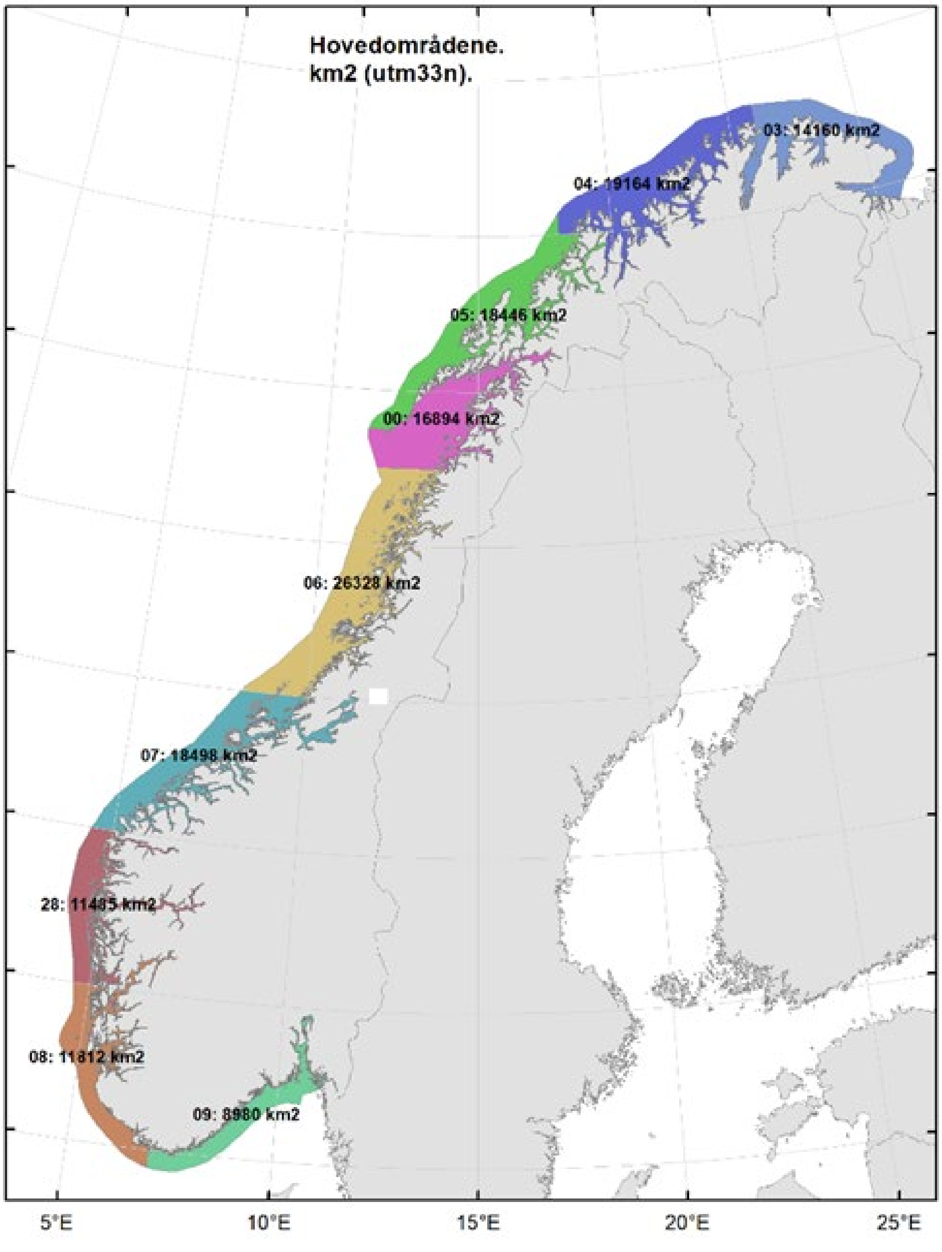


Figure 9.5. Map showing the area (km²) of each Norwegian statistical subarea inside 12 nautical miles. The subareas 4, 5, 0, 6, and 7 belong to the ICES Division 2.a.

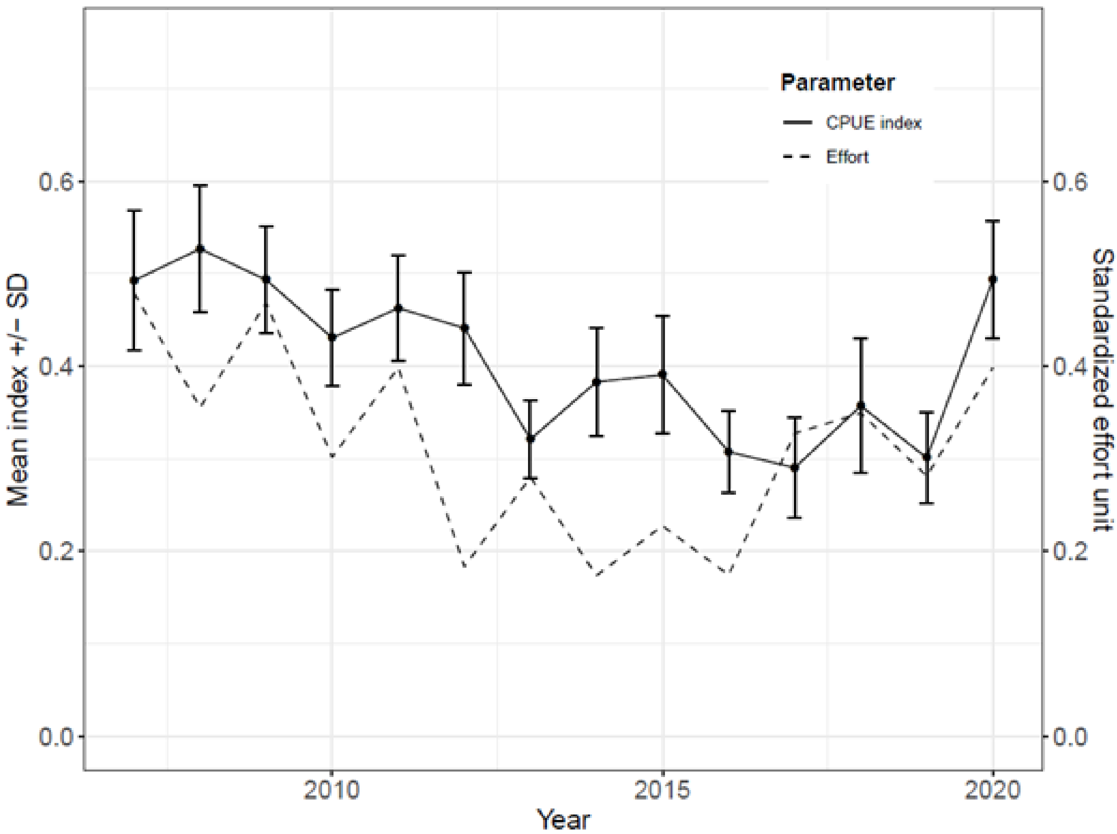


Figure 9.6. Standardized CPUE (kg per gillnet day) +/- SD (solid black line with error bars) and the corresponding standardized effort (dash line) for anglerfish based on the data from the Norwegian coastal reference fleet in ICES Subarea 2.a, from vessels targeting anglerfish with large meshed gillnets.

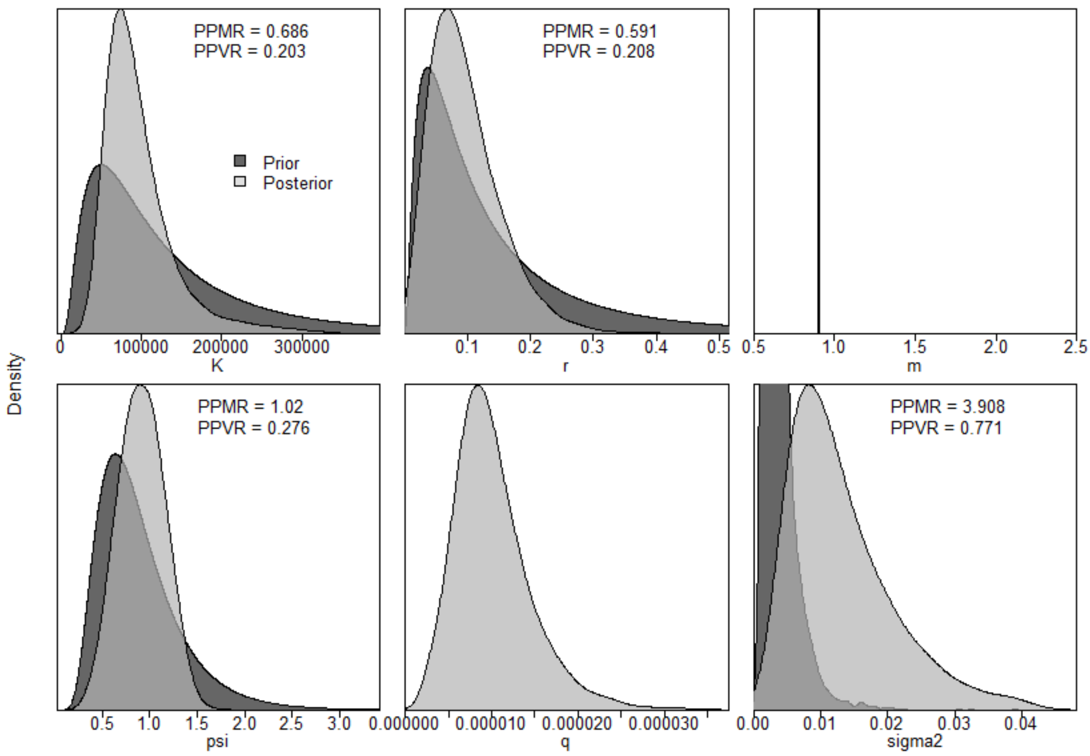


Figure 9.7. Prior and posterior distribution of the model parameters for the anglerfish assessment.

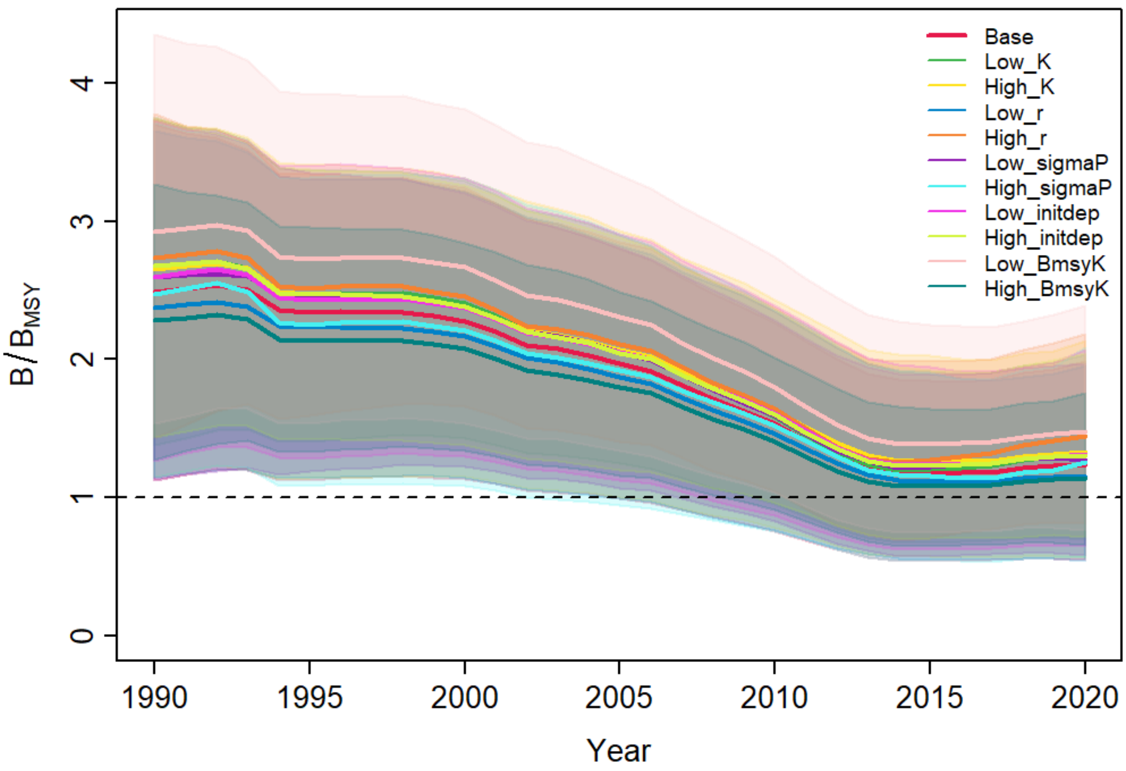


Figure 9.8. Estimated trajectories for B/B_{MSY} for the ICES subareas 1 and 2 anglerfish based on 11 JABBA scenarios (the name of scenario and the associated colour is indicated in the figure). The lines show the mean trajectory and the shaded areas denote 95% credibility intervals.

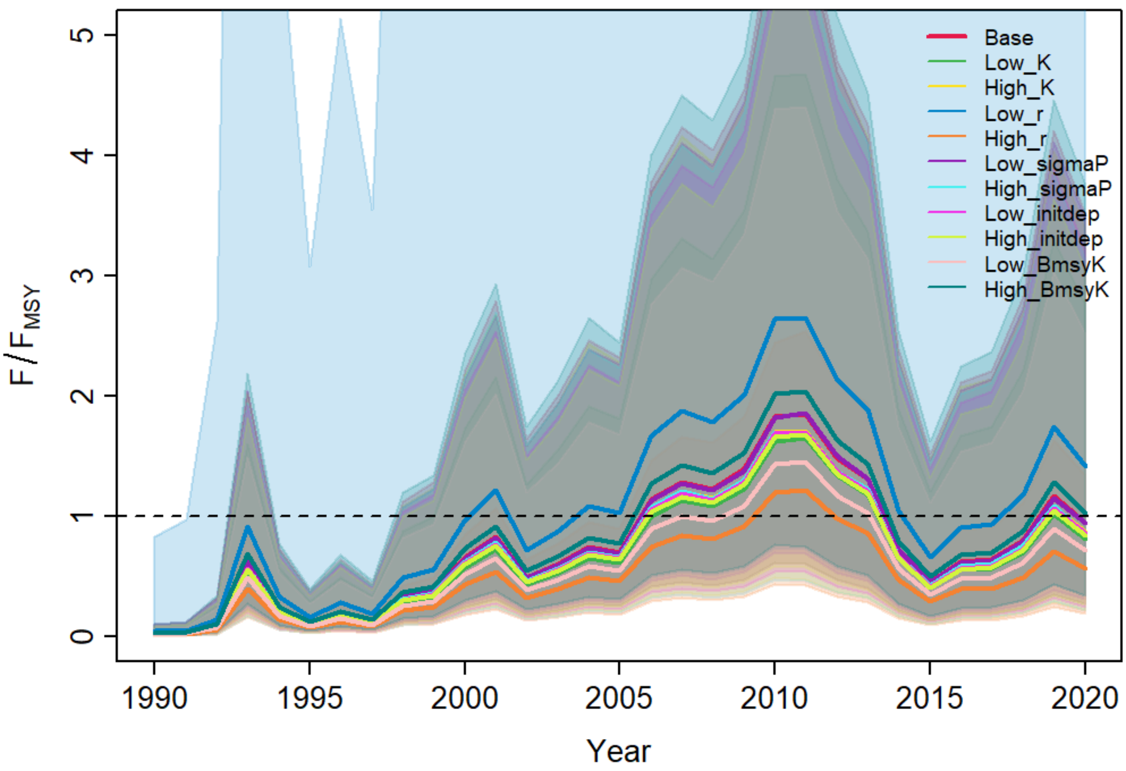


Figure 9.9. Estimated trajectories for F/F_{MSY} for the ICES subareas 1 and 2 anglerfish based on 11 JABBA scenarios (the name of scenario and the associated colour is indicated in the figure). The lines show the mean trajectory and the shaded-areas denote 95% credibility intervals.

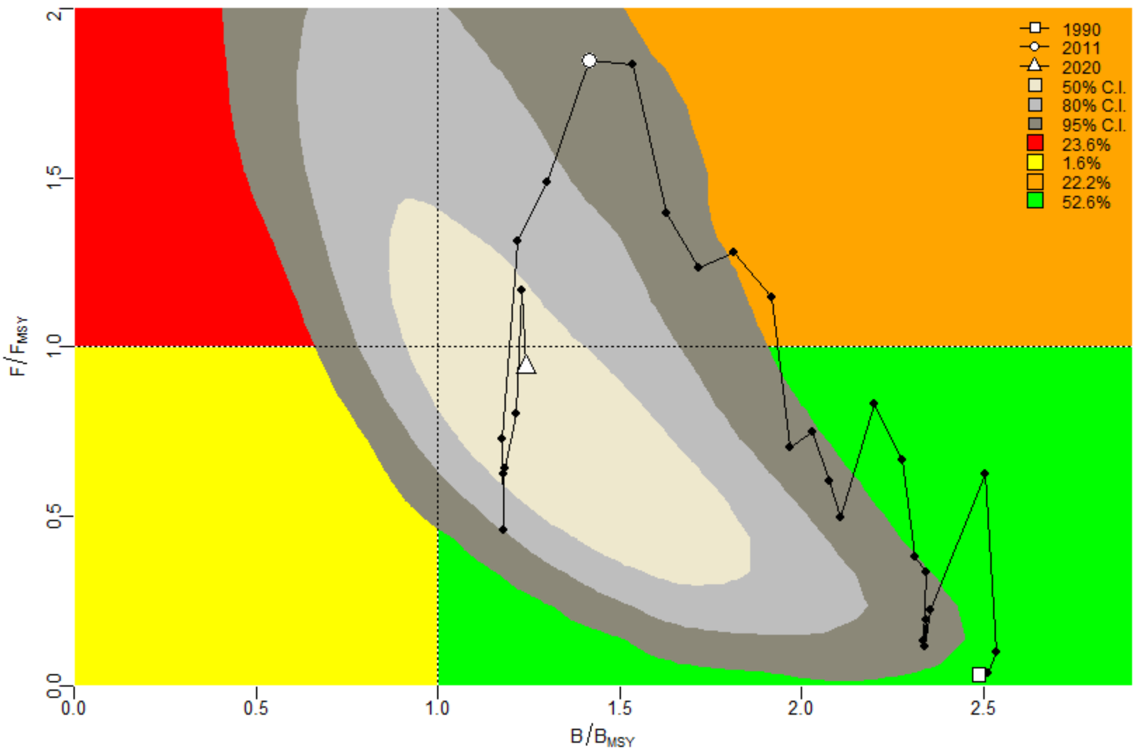


Figure 9.10. Kobe plot for the JABBA scenario showing the estimated trajectories (1990–2020) of B/B_{Msy} and F/F_{MSY}. Different grey shaded areas denote the 50%, 80%, and 95% credibility interval for the terminal assessment year. The probability of terminal year points falling within each quadrant is indicated in the figure legend.

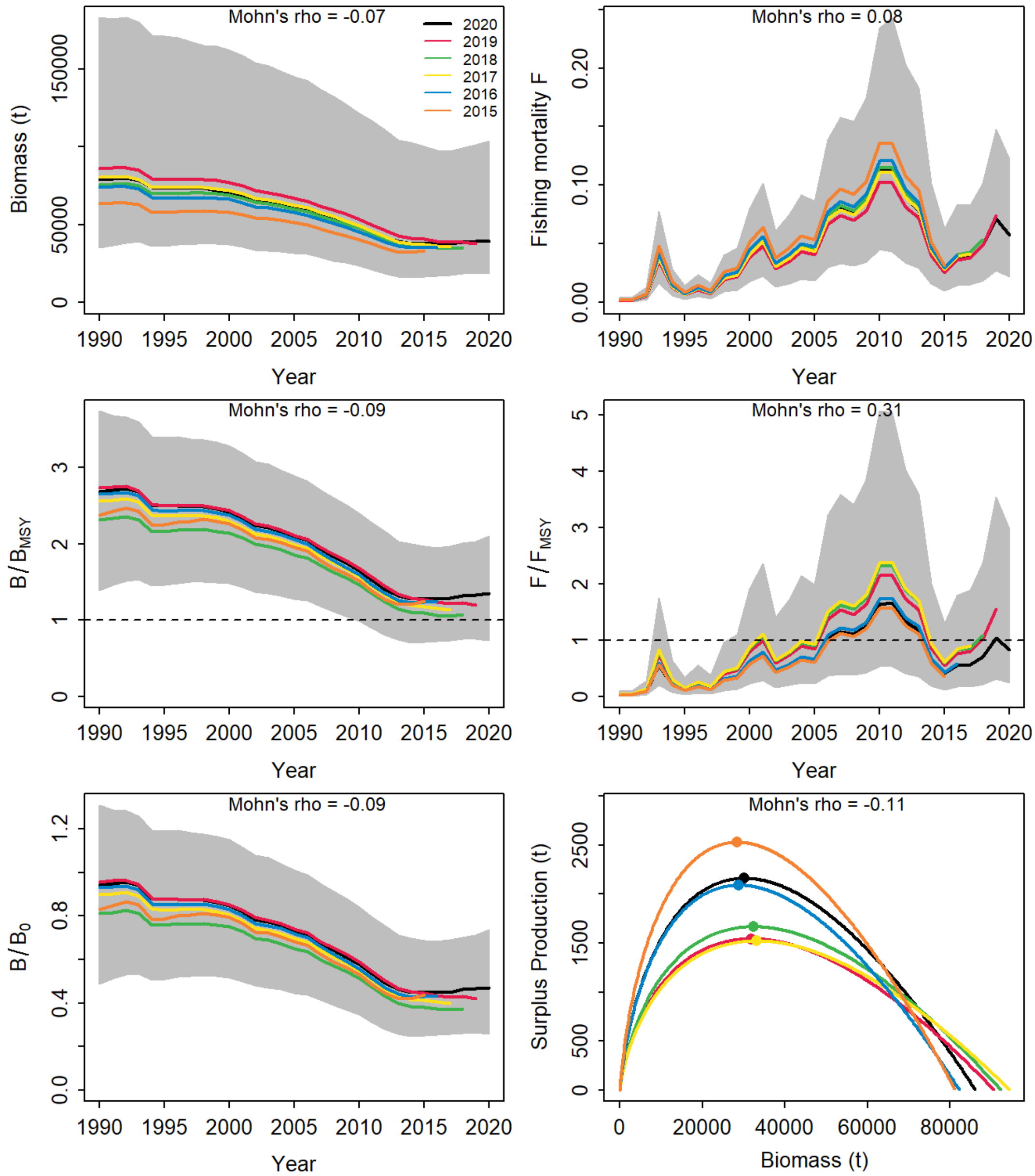


Figure 9.11. Retrospective analysis from the JABBA base case scenario. Different colours illustrate the results from different peels.

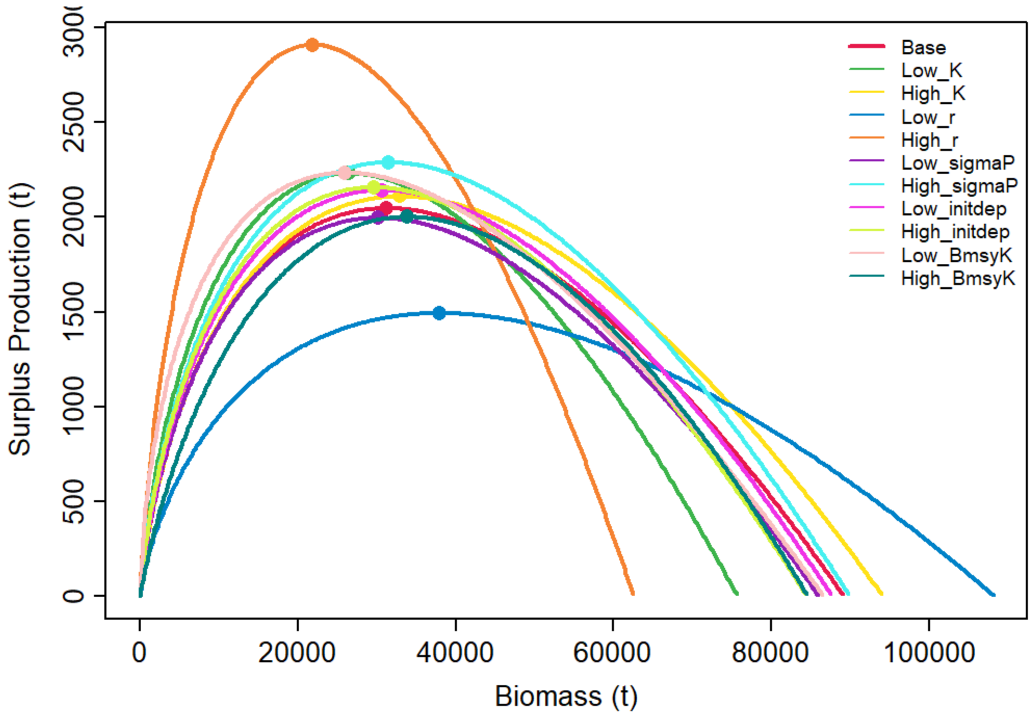


Figure 9.12. Sensitivity analysis for the ICES subareas 1 and 2 anglerfish based on 11 JABBA scenarios (the name of scenario and the associated colour is indicated in the figure). The analysis says that MSY could be around 2000 tonnes, with a B_{MSY} ~30000 tonnes. Note that the MSY value is quite sensitive to the choice of prior on r = population growth rate.

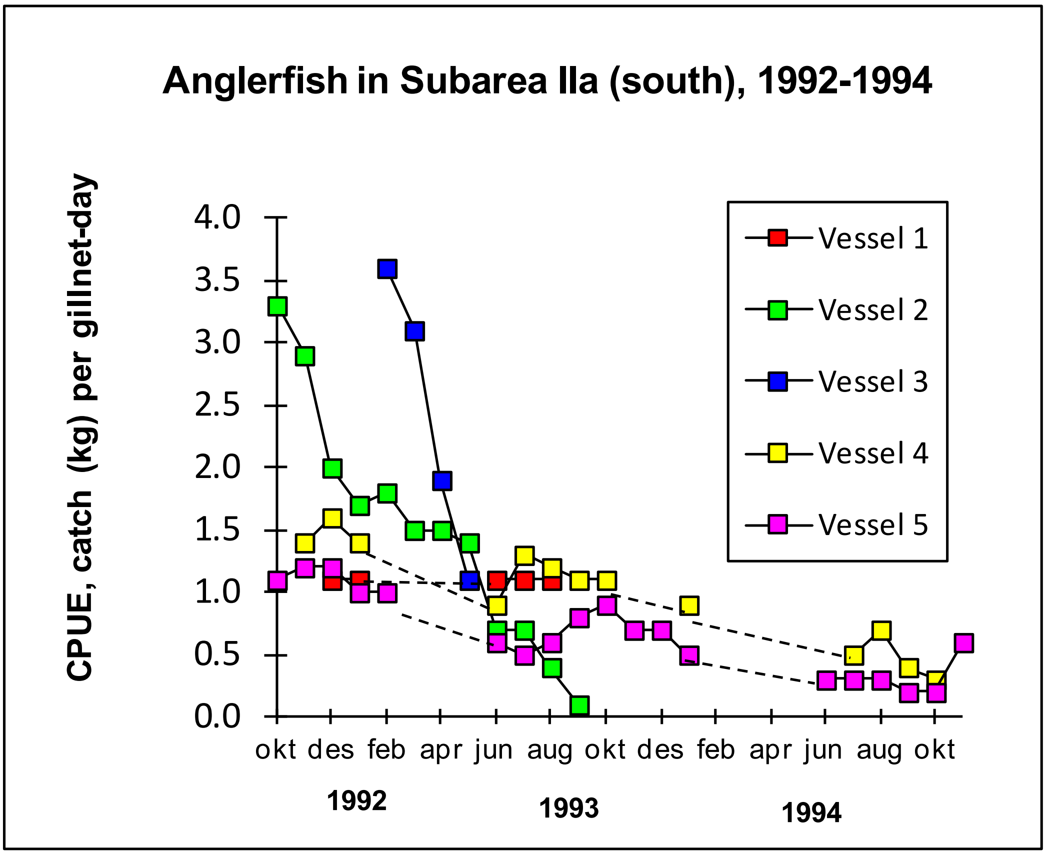
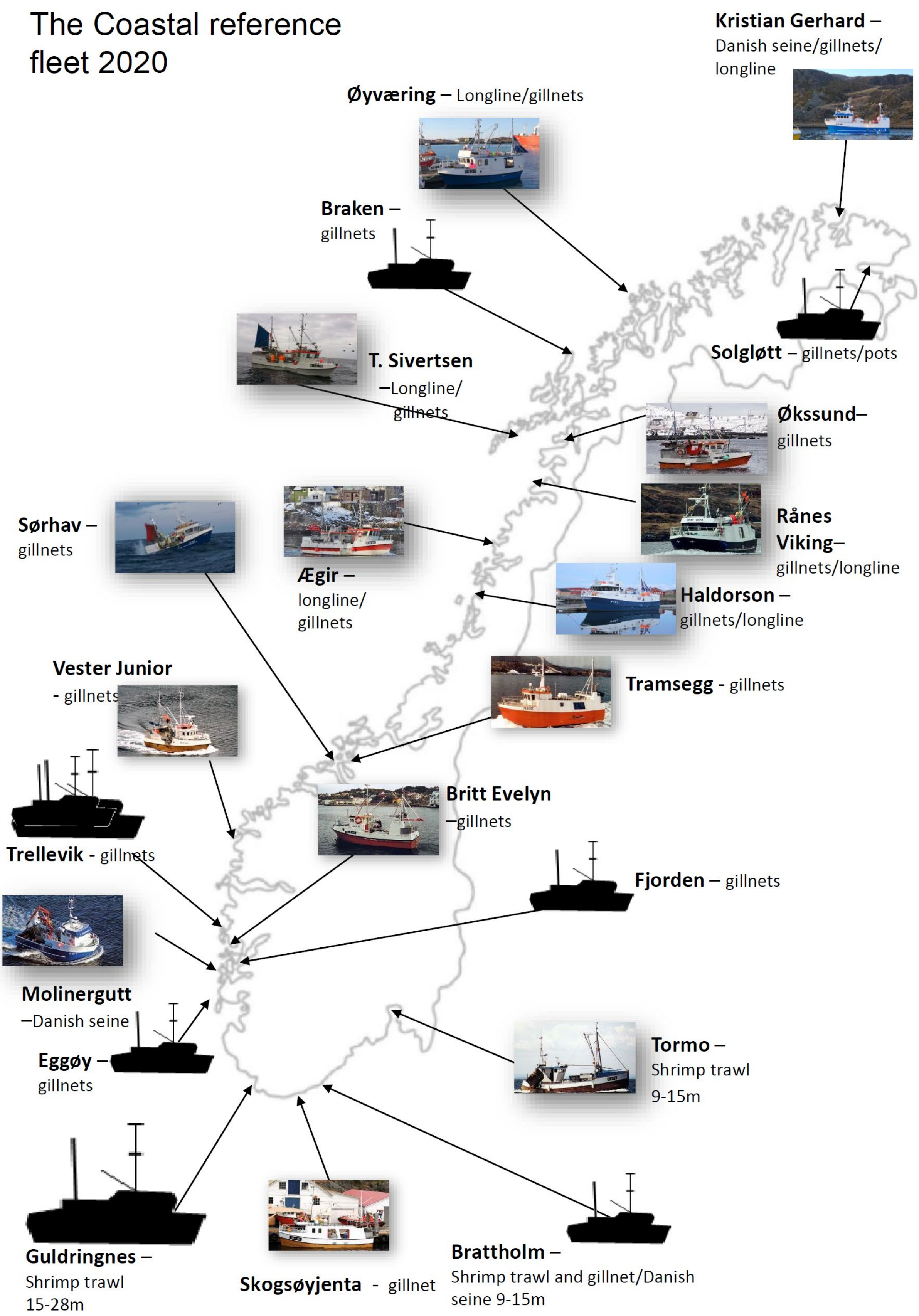


Figure 9.13. Catch per unit effort for five boats in the gillnet fishery for anglerfish in Møre and Romsdal (the same area as vessel A in figure 8 is fishing in) in the period October 199o October 1994. Boat 1 > 25m; Boat 2 ca. 20 m; Boat 3 ca. 10 m; Boat 4 and 5 ca. 16 m. Boats 1–4 were fishing with gillnet 360 mm nesh size, boat 5 with 300 mm mesh size.

Appendix figure H1.

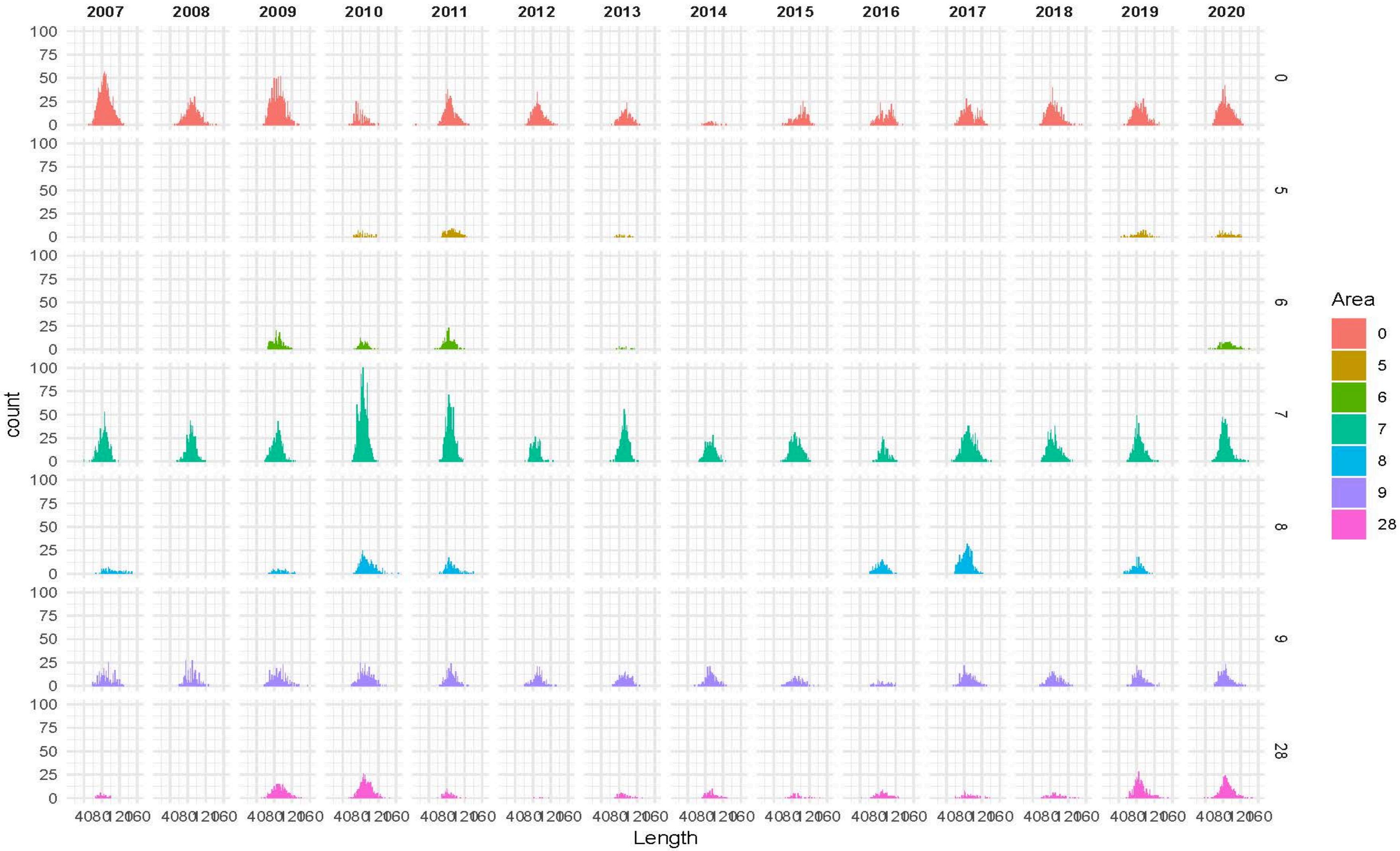


Appendix table H1. Input data to the JABBA assessment in the form of catch and abundance indices of anglerfish (*L. piscatorius*) in ICES Subareas 1 and 2.

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	0.49	0.07
2008	4151	0.53	0.06
2009	4458	0.49	0.07
2010	5515	0.43	0.08
2011	5112	0.46	0.06
2012	3765	0.44	0.06
2013	3103	0.32	0.04
2014	1657	0.38	0.05
2015	1043	0.39	0.06
2016	1435	0.31	0.04
2017	1484	0.29	0.04

Year	Catch	CPUE (mean)	CPUE (SE)
2018	1903	0.36	0.08
2019	2809	0.30	0.05
2020	2280	0.49	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.