Stock Annex: Spurdog (*Squalus acanthia*) in subareas 1-10, 12 and 14 (the Northeast Atlantic and adjacent waters)

Stock specific documentation of standard assessment procedures used by ICES.

Stock: Spurdog

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General

Stock distribution

Spurdog, *Squalus acanthias*, has a worldwide distribution in temperate and boreal waters, and occurs mainly in depths of 10–200 m. In the NE Atlantic this species is found from Iceland and the Barents Sea southwards to the coast of Northwest Africa (McEachran and Branstetter, 1984).

WGEF considers that there is a single NE Atlantic stock ranging from the Barents Sea (Subarea 1) to the Bay of Biscay (Subarea 8), and that this is the most appropriate unit for assessment and management within ICES.

Spurdog in Subarea 9 may be part of the NE Atlantic stock, but catches from this area are likely to consist of a mixture of *Squalus* species, with increasing numbers of *Squalus blainville* further south. The relationships between the main NE Atlantic stock and populations in the Mediterranean are unclear.

In the ICES area, this species exhibits a complex migratory pattern. Norwegian and British tagging programmes conducted in the 1950s and 1960s focused on individuals captured in the northern North Sea. These were regularly recaptured off the coast of Norway, indicating a winter migration from Scotland, returning in summer (Aasen, 1960; 1962). Other tagging studies in the English Channel indicated summer movement into the southern North Sea (Holden, 1965). Few individuals tagged in this more southerly region were recaptured in the north and vice-versa and therefore at this time, distinct Scottish-Norwegian and Channel stocks were believed to exist. A tagging study initiated in the Irish and Celtic Seas in 1966 yielded recaptures over 20 years from all round the British Isles and suggests that a single NE Atlantic stock is more likely (Vince, 1991). Transatlantic migrations have occurred (e.g. Templeman, 1976), but only occasionally, and therefore it is assumed that there are two separate North Atlantic stocks.

No studies have been conducted using parasitic markers and only preliminary studies on population genetics, to identify spurdog stocks. Data on morphometrics/meristics are inadequate for stock identification. The conclusions drawn about stock identity are therefore based solely on the tagging studies described above.

The fishery

Historically, spurdog was a low-value species and in the 1800s was considered as a nuisance to pelagic herring fisheries, both as a predator and through damage to fishing nets. However, during the first half of the 20th century, this small shark became highly valued, both for liver oil and for human consumption, and NE Atlantic spurdog was increasingly targeted. By the 1950s, targeted spurdog fisheries were operating in the Norwegian Sea, North Sea and Celtic Seas. Landings peaked at a total of over 60 000 tonnes in the 1960s (See Figure 2.1; Table 2.1 in 2010 Report) and since then have declined, except for a brief period during the 1980s when targeted gillnet and longline fisheries along the west coasts of Ireland and in the Irish Sea developed.

In more recent years, an increasing proportion of the total spurdog landings are taken as bycatch in mixed demersal trawl fisheries. The larger, offshore longline vessels that targeted spurdog around the coasts of the British Isles have stopped, although there are landings from gillnet and longline fisheries, which are often undertaken in seasonal, inshore fisheries.

The main exploiters of spurdog have historically been France, Ireland, Norway and the UK (see Figure 2.2 and Table 2.21 in 2010 Report). The main fishing grounds for the NE Atlantic stock of spurdog are the North Sea (4), West of Scotland (6.a) and the Celtic Seas (7) and, during the decade spanning the late 1980s to 1990s, the Norwegian Sea (2) (see Figure 2.3 and Table 2.3 in 2010 Report). Outside these areas, landings have generally been low.

In the UK (E&W), more than 70% of spurdog landings were taken in line and gillnet fisheries in 2005, with most landings coming from Subarea 7 and in particular the Irish Sea. Such fisheries are likely to be closer inshore and may be targeting aggregations of mature female spurdog. The introduction of a bycatch quota deterred such target fisheries in both Subareas 4 and 7 in 2008 and 2009.

Scottish landings of spurdog in 2009 mainly came from the mixed demersal trawl and seine fisheries in the North Sea and to the West of Scotland. Less than 1% of landings were taken by other gears, compared with more than 20% taken by longliners in 2007. It seems likely that this reduction has been due to the extension of the 5% bycatch regulation to the West of Scotland region in 2008 and potentially due to the implementation of limits on the maximum landings size (100 cm) in 2009 to deter target fisheries.

The Irish fishery for spurdog consists mainly of bottom otter trawlers, and less than 30% of landings coming from longline and gillnet fisheries. Most landings are reported from Division 6.a and Division 7.g. From April 2008 there has been no directed spurdog fishery in Irish waters.

Over 70% of Norwegian spurdog landings in 2009 were taken in gillnet fisheries operating in Subareas 2.a, 3.a and 4.a. In Subarea 3.a, a significant component of the landings (> 40%) was taken as bycatch by shrimp trawlers. The remainder of the landings are taken in line fisheries and to a lesser extent, other trawl fisheries.

Management applied to spurdog in the NE Atlantic

The management that has been applied to NE Atlantic spurdog has evolved in recent times. This is summarised below, to aid in the interpretation of available data.

Within EU waters, there was no TAC management for spurdog until 2000, when a TAC was first introduced for the North Sea area. Other TAC management units were introduced over the years 2007–2009. Footnotes in the EU fishing opportunities, in force during 2007–2010, were also used to prevent target fisheries, including stipulating bycatch ratios and a maximum landing length (100 cm).

The TACs were subject to annual reductions before being reduced to zero in 2010 (albeit with a 10% allowance of the previous year). The TAC was then specified as zero for 2011–2016 (in part). An in-year amendment to the quota regulations in 2016 allowed for limited dead bycatch to be landed from 'bycatch avoidance fisheries' in western waters (DGS/15X14). This caveat aside, the species has been listed as a prohibited species from 2017.

The WGEF had compiled estimates of total landings of NE Atlantic spurdog from 1905. Obviously, discards information for such a long time-series are unavailable. Consequently, the model required the assumption that landings equated with catch (i.e. that quantities of dead discards were negligible).

Given the lack of management for the main part of the longer time-series, there is no clear indication that there would have been regulatory discarding for most nations. However, it is noted that Norway has had a minimum landing size of 70 cm since 1964 (Pawson *et al.*, 2009). Furthermore, management measures for spurdog have become increasingly restrictive since the late 2000s and, whilst preventing target fisheries, will also have increased regulatory discards.

Consequently, the 2020 Data Call (in preparation for the 2021 benchmark; ICES, 2021a) requested that additional commercial data be provided, including estimates of discards for the main nations whose fleets interact with the stock, length-composition data from national observer and port sampling programmes, and effort data. Catch data for spurdog, as with all elasmobranchs, have been reviewed as part of a series of WKSHARK meetings (ICES, 2016, 2017, 2020a), and ICES estimates of landings and discards made available. Discard estimates are now included in the assessment from 2005 onwards, along with revised landings estimates for the same period.

Catch data

Landings

Total annual landings (over a 60 year time period), as estimated by the WG for the NE Atlantic stock of spurdog are given in the WGEF Report 2010.

A number of generic categories are used in the logbooks which may include some spurdog. The estimates of total landings made by the WG (and used in the Stock Assessment) are therefore based on expert judgement and the process for obtaining these estimates is described below:

1903–1960: Landings data from the *Bulletin Statistique* for the category "Dogfish, etc." have been assumed to be comprised entirely of spurdog. Landings of other dogfishes (e.g. tope and smooth hound) are assumed to be a negligible component of these catches, as these species are typically discarded in the stock area.

1961–1972: Landings data from the *Bulletin Statistique* for the categories "Picked dogfish" and "Dogfishes and hounds" have been used, and assumed to be comprised almost entirely of spurdog. Landings of other dogfishes (e.g. tope and smooth hound) are assumed to be a negligible component of these catches, as these species are typically discarded in the stock area. No country consistently reported both of these dogfish categories in proportions that would be consistent with the nature of the fisheries. Fisheries for deep-water sharks were not well established in the stock area in this period.

1973–present: Landings data from the ICES database were used, and these data included species-specific data for spurdog and some of the data from the appropriate generic categories (i.e. *Squalus* spp, Squalidae, Dogfishes and hounds, and Squalidae and Scyliorhinidae). National species-specific data for Iceland (1980–2002), Germany (1995–2002) and Ireland (1995–2002) were used to update data from the ICES database (ICES, 2003). The following assumptions were made regarding generic categories, based on the judgement of WG members.

Belgian landings of *Squalus* spp. were assumed to be spurdog.

Landings of Squalidae from ICES Subareas 1–5 and 7 (except French landings) were assumed to be spurdog on the basis that fisheries for other squaloids (i.e. deep-water species) were not well developed in these areas over the period of reported landings. Landings of Squalidae from ICES Subarea 6 were assumed to be spurdog for early period and for nations landings low quantities. The increase in French and German landings of Squalidae in this area after 1991 and 1995 respectively were assumed to be comprised of deep-water squaloid sharks. Similarly, French landings from ICES Divisions 7.b–c (all years), 7.g–k (1991 onwards) and 8 (all years) were assumed to be deep-water sharks. Landings of Squalidae from areas further south were excluded as they were out of the stock area and were likely comprised of deep-water species.

Landings of "dogfishes and hounds" from Areas 7.a and 8 were assumed to be spurdog. Landings of this category from other areas were generally low and excluded, with the assumption that spurdog contained in this category would be negligible.

French data were lacking from the ICES database and Bulletin Statistique for the years (1966–1967 and 1969–1977 inclusive), and these data were estimated from "Statistique des Peches Maritimes". As only aggregated shark landings were available for these years, spurdog landings were assumed to comprise 53% of the total shark landings, as spurdog comprised 50–57% of shark landings in subsequent years.

The landings data from 1905–2004 used in the original benchmarked assessment (ICES, 2011) were retained for the assessment. More contemporary landings data collated by ICES (e.g. ICES, 2016, 2017) and updated by WGEF (ICES, 2020b, 2022) were used for the years 2005–present from 12 countries, and missing data was added from the data provided to the Data Call, as detailed in the WD5 of the 2021 benchmark (ICES, 2021a) and subsequent WGEF meetings (e.g. ICES, 2022).

Discards

Estimates of total amount of spurdog discarded are not routinely provided although some discard sampling does take place.

Some preliminary elasmobranch discard estimates from the Basque fleets operating in Subareas 6, 7 and 8 were presented in Diez *et al*., (2006, WD). Initial studies found no discarding of spurdog by the Baka trawler fleets.

A recent study on the estimated short-term discard mortality of otter trawl captured spurdog in the NW Atlantic demonstrated that mortality 72 h after capture was in some cases well below the currently estimated 50% for trawling (Mandelman and Farrington, 2006). When catch-weights exceeded 200 kg, there were increases in 72 h mortality that more closely approached prior estimates, indicating that as tows become more heavily packed, there was a greater potential for fatal damage to be inflicted. It should be noted that tow duration in this study was only 45–60 minutes, and additional studies on the discard survivorship in various commercial gears are required, under various deployment times.

Discard survival from liners is unknown, and may depend on hook type, where the fish is hooked and also whether there is a bait stripper. Spurdog with broken jaws (i.e. possibly have gone through a bait stripper) have been observed (Ellis, pers. obs.) with healed wounds, although quantitative data are lacking.

The assessment now includes discard data from 2005 onwards, and were supplied by nine countries, submitted to the 2021 benchmark Data Call and subsequent WGEF data Data Calls. The estimation of discards is detailed in the WD5 of the 2021 benchmark (ICES, 2021a) and subsequent WGEF meetings (e.g. ICES, 2022). Some in-filling of missing discard data was needed (e.g. for the UK England & Wales gillnet and trammel net fisheries), and is detailed in ICES (2022).

Quality of catch data

In addition to the problems associated with obtaining estimates of the historical total landings of spurdog due to the use of generic dogfish landings categories, anecdotal information suggests that widespread misreporting by species may have contributed significantly to the uncertainties in the overall level of spurdog landings.

Under-reporting may have occurred in certain ICES areas when vessels were trying to build up a track record of other species, for example deep-water species. It has also been suggested that over-reporting may have occurred where stocks with highly restrictive quotas have been recorded as spurdog. However, it is not possible to quantify the amount of under and over-reporting that has occurred. The introduction of UK and Irish legislation requiring registration of all fish buyers and sellers may mean that these misreporting problems have greatly declined since 2006.

It is not known whether the 5% bycatch ratio has led to any misreporting or reporting under generic landings categories, although the buyers and sellers legislation should deter this and so the bycatch ratio may have resulted in more discarding.

There remain gaps in discard data (missing discards for some nations, métiers and years), and some infilling has been used to estimate missing discards for métiers where more substantial discard occurs (e.g. for the UK England & Wales gillnet and trammel net fisheries; see ICES, 2022, for more details).

Commercial catch composition

Length compositions

Sex disaggregated length frequency samples are available from UK (E&W) for the years 1983–2001 and UK (Scotland) for 1991–2004 for all gears combined. Scottish data are available for the North Sea and West of Scotland separately while the English data are all areas combined. The two sets of Scottish length frequency distributions (4 and 6.a) are very similar and these have therefore been combined to give a ‘total’ Scottish length frequency distribution. Typically these appear to be quite different from the length frequency distributions obtained from the UK (E&W) landings, with a much larger proportion of small females being landed by the Scottish fleets. The length distributions of the male landings appear to be relatively similar. Figure 1 shows landings length frequency distributions averaged over five year intervals. The Scottish data have been raised to total Scottish reported landings of spurdog while the UK

(E&W) data have only been raised to the landings from the sampled boats.

Discard length frequencies have previously (prior to the 2021 benchmark) been provided by UK (E & W) for fisheries operating in the Celtic Seas (Subareas 6–7) and North Sea (Subarea 4), as observed for the years 1999–2006 (Figure 2). The data for beam trawl, demersal trawl and drift/fixed net fisheries indicate that most spurdog are retained, although juveniles (e.g. individuals <45–50 cm) tend to be discarded, which agrees with data from market sampling. Data were limited for seine and longline fisheries.

More recent commercial catch length composition data for 2007–2019 were compiled for spurdog, using the collated length frequencies reported in the WD3 of the 2021 benchmark (ICES, 2021a). The length composition data prior to 2005 representing targeted (England and Wales) and non-targeted (Scotland) fishing up to 2004 continued to be used as in the original benchmarked assessment (described above; ICES, 2011).

For the period from 2005 onwards, two gear groupings were selected as representing the two main types of fishing activity, namely "trawls & other" and "nets & hooks". The length frequencies which formed the basis of the "trawls & other" fleet are shown in Figure 3; these length frequencies were combined by first expressing them as proportions by length category (according to the established life-stage-based length bins used for spurdog), and then combining them by using weighted averaging using the relative contribution by nation to the fleet (Table 2 gives an example of these weights from ICES, 2022). For the "nets & hooks" fleet, length frequencies from gillnet and trammel nets were combined with equal weighting (Figure 4)

Quality of data

Length frequency samples prior to 2005 are only available for UK landings and these are aggregated into broader length categories and have been used in the previously presented assessments. Prior to 2005, no data were available from Norway, France or Ireland who are the other main exploiters of this stock. The availability of length data from 2005 onwards has improved following the Data Call associated with the 2021 benchmark.

Commercial catch-effort data

No studies of commercial cpue data have been undertaken.

Fishery-independent information

Cpue

The overall trends in the various surveys examined in previous meetings have indicated a trend of decreasing occurrence and decreasing frequency of large catches (Figures 5 and 6), with catch rates also decreasing, although catch rates are highly variable (ICES, 2006).

Survey Indices

Prior to 2021, a single biomass index derived using a delta-lognormal model GLM fitted to Scottish survey data (see above) covering Divisions 6a and 4a was used in the assessment. During the WKNSEA data compilation meeting it was agreed to explore the development of three separate indices based on survey data collected on a number of different surveys from quarters 1, 3 and 4 separately and covering areas from as far south as the Celtic Sea to Division 3.a.

The survey series included in the construction of the indices, their coverage and source of data are given below:

Quarter	Survey	Acronym	Gear	Spatial coverage	Years	Source
Quarter 1	North Sea International Bottom Trawl Survey	NS-IBTS-Q1	GOV	4.a, 4.b, 3.a	1985-present	DATRAS
	Scottish West Coast Groundfish Survey	SWC-IBTS	GOV	6.a, 4.a (limited)	1985-2010	DATRAS
		SCOWCGFS	GOV	6.a	2011-present	DATRAS
	Norwegian Shrimp Survey	NO-SH	GOV	3.a, 4.a	2006-present	WKNSEA data call
Quarter 3	North Sea International Bottom Trawl Survey – Q3	NS-IBTS-Q3	Mainly GOV Some ABD	4, 3.a	1992-present	DATRAS
Quarter 4	Scottish West Coast Groundfish Survey	SWC-IBTS	GOV	6.a, 7.a (limited) & 7.b (limited)	2003-2009	DATRAS
		SCOWCGFS	GOV	6.a, 7.b (limited)	2011-present	DATRAS
	Irish Groundfish Survey	IE-IGFS	GOV	6.a (South), 7.a, 7.b, 7.g, 7.j	2003-present	DATRAS
	French EVHOE Survey	EVHOE	GOV	7.g, 7.h, 7.j	2003-present (excl 2017)	DATRAS
	Northern Irish Groundfish	NIGFS	ROT	7.a	2003-present	WKNSEA data call

Survey

For each quarter, the survey dataset consists of numbers at length (mostly by sex) at each trawl station (‘HL’ records in Datras) and in addition, a subsample of individuals for which biological data such as weight are recorded (‘CA’ records). Catch weight per haul is derived from the length composition (by sex) and a sex specific weight length relationship derived from the sampled individuals. On some hauls/surveys, individuals are recorded without sex and in such cases the weight caught is derived using a combined sex length weight relationship. Total weight per haul in grammes is then the sum over male/female and unsexed individuals.

Statistical modelling is carried out using the ‘surveyIndex’ R package (Berg, et al. 2014) using the delta-lognormal approach with the full model (for both the presence-absence and positive parts of the model) defined as follows:

$$g(\mu_i) = Year_i + Gear_i + U(Ship_i) + s_1(\text{lon}_i, \text{lat}_i) + s_2(\text{depth}_i) + s_3(\text{timeofday}_i) + \log(\text{HaulDur}_i)$$

where g is the logit link function for the binomial model (1/0 response), and the lognormal for the positive observations (implemented by log-transforming the response variable and using a normal distribution with identity link function). The model includes an offset to account for the effects of haul duration.

The full model includes both a depth and time of day effect in addition to spatial (lat-lon), Year and Ship effects. The spatial effect is modelled as a 2-dimensional thin plate regression spline (function s_1) without year interaction, depth as a 1-d thin plate spline (s_2) and a cyclic cubic regression spline used for time of day (s_3). A ship effect was included as a random effect and in addition, a gear effect was also considered where relevant. No consideration was given to a time varying spatial effect.

A selection of models including different subsets of explanatory variables were fitted and compared, using AIC to evaluate which model gave the best fit to the data. The two components of the model were assumed to include the same covariates. The final models chosen for each quarter included the following covariates:

Covariates	Year	s_1(lat,lon)	U(Ship)	s_2(depth)	s_3(time)	Gear
Quarter 1	x	x	x	x	x	-
Quarter 2	x	x	x	x	-	x
Quarter 3	x	x	x	-	-	x

In order to calculate the final indices, a spatial grid covering the survey area is chosen. The biomass is predicted within each grid cell at the haul nearest to the centroid of the cell (cells with no hauls are excluded) giving a spatial distribution map. Other effects such as gear and ship are fixed at each prediction i.e the prediction is made for a standard gear/ship. Summing over the grid points then provides the biomass index. The predictions which provided by the ‘surveyIndex’ package are made for 30 min towing time and therefore, index values are be divided by the number of grid cells and multiplied by two in order to derive an index in g hr^{-1}.

The associated CVs are approximated from the confidence intervals according to:

$$CV_y = \frac{\left(log\left(CI_y^{up}\right) - log\left(CI_y^{lo}\right)\right)}{4}$$

The spatial distribution of raw survey catch rates in weight by quarter are shown in Figures 7-9 for all years combined (note that scales are not comparable between plots). The quarter 1 surveys show catches to be highest to the north and west of Scotland (Figure 7), and a preponderance of zero hauls in the central/eastern North Sea. In quarter 3, there are fewer positive hauls, with relatively higher catches apparent in the northwestern and southern/central North Sea and along the Swedish coast (Figure 8). Spurdog appear to be relatively widely distributed across the area to the west of the British Isles in quarter 4 (Figure 9). Some extremely high catch rates are apparent in the western Irish Sea while there are also areas of relatively high concentration to the south and west of Ireland and around the Outer Hebrides. The blank area with no hauls to the west of the Outer Hebrides is an area of rocky ground in which no trawling can take place.

Further details of the analysis and sensitivity testing can be found in WD1 to WKNSEA (ICES, 2021a).

Length distributions

Length distributions were analysed from survey data made available to the group in 2009. The UK (E&W) Q4 SWIBTS exhibits annual differences in length frequency distributions of spurdog caught. In 2005 the mean length frequency of females and males was higher than previous and preceding years. In 2008 relatively larger numbers of juveniles <55 cm were caught in the survey (Figure 10).

The length frequency distributions obtained from the UK(NI) Q4 GFS survey demonstrate a large proportion of larger fish (>85 cm) which are likely to be mature females (males are smaller) (Figure 11), although sex disaggregated data are only available since 2006 (Figure 12–13). A large haul of predominantly large females was caught in 2008 which has influenced the pattern of the length frequencies from this survey (Figure 13).

Length frequencies generated from the Irish Q3 GFS survey suggest spatial as well as temporal variation in the size distributions (Figure 14). Catches in the southern region of the survey area (7.g) tended to consist of smaller individuals, while larger individuals were the dominant component in the remaining areas.

Length distributions from surveys included in the assessment, given as proportions by length category, can be found in the 2021 benchmark report (ICES, 2021a) and in subsequent WGEF reports.

Presence of Pups

Pups of spurdog (individuals ≤25 cm) are caught in many of the surveys, although generally in very small numbers. Although catches of pups tend to be low and may not be accurate indicators of recruitment, the location of catches may indicate possible pupping grounds or nursery areas. The location of survey hauls were spurdog pups (individuals ≤25 cm) were present was plotted for data from the North Sea (Figure 15).

Seasonal distributions of spurdog catches in 7.a(N) and 6.a(S) by biomass and numbers have been plotted from survey data in the area (Figure 16).

Biological parameters

Length–weight

Although there have been several studies in the North Atlantic and elsewhere describing the age and growth of spurdog (Holden and Meadows, 1962; Sosinski, 1977; Hendersen *et al*., 2002; Albert *et al*., 2019), routine ageing of individual from commercial catches or surveys is not carried out.

WGEF assumes the following sex-specific parameters in the length–weight relationship ($W=aL^b$) for NE Atlantic spurdog (Bedford *et al*., 1986; Coull *et al*., 1989):

	A	B
Female	0.00108	3.301
Male	0.00576	2.89

where length is measured in cm and weight in grammes.

Proportion mature-at-length

The proportion mature-at-length was assumed to follow a logistic ogive with 50% maturity at 80 cm for females and 64 cm for males. Values of female length at 50% maturity from the literature include 74 cm (Fahy, 1989), 81cm (Jones and Ugland, 2001) and 83 cm (Gauld, 1979). No updates to the length-at-maturity for male and female spurdog were introduced during the 2021 benchmark, with the length at first (smallest mature), 50% and 95% maturity of female spurdog being 70, 80 and 87 cm, respectively (De Oliveira et al., 2013; ICES, 2021a).

Fecundity-at-length

A linear relationship between fecundity (F) and total length (L) is described as follows:

F = 0.344.L–23.876 (Gauld, 1979).

More recent information on the fecundity length relationship of spurdog caught in the Irish Sea indicates:

F = 0.428.L–31.87 (n=179; Ellis and Keable, 2008).

The parameters for this relationship are derived in the assessment model by likelihood profiling and fitting to fecundity-at-length data (see details in the model description below).

New data on fecundity-at-length were included during the 2021 benchmark (ICES, 2021a). These data comprised contemporary data collected during Norwegian (Albert et al., 2019) and UK (WD6 in ICES, 2021a) studies, as well as additional historical data on fecundity-at-length from published sources (Ford, 1921; Gauld, 1979; Fahy, 1988; Walenkamp, 1988; Jones & Ugland, 2001; Henderson *et al*., 2002; Stenberg, 2005). The available fecundity-at-length data now covers the years 1921, 1960, 1978, 1987, 1988, 1997, 2005, 2010, 2014, and 2016–2020). Some of these studies provided fecundity by length group, and in such instances the fecundity was assumed to occur at the mid-point of the length group.

Fecundity data used in the assessment were generally limited to uterine fecundity (i.e. the number of embryos or pups in the uteri), as most published studies would provide ovarian and uterine fecundity for the same samples of fish. Given the limited fecundity data for the earliest years (Ford, 1921), and that the underlying data in this study appeared to be from different samples, both uterine and ovarian fecundity were used from this study. All other data sources were limited to uterine fecundity.

Most studies provided data for total uterine fecundity (i.e. the total number of pups or embryos for both uteri combined), whilst some of the more contemporary data collection reported data for each uterus. Following Ellis & Keable (2008), any specimens for which the difference in the number of embryos (or pups) between the two uteri was ≥4 were assumed to have aborted some young and were excluded from further analysis. Where only total fecundity data were available (i.e. the number of embryos in the individual fish, combining both left and right uteri), then no such data filtering was possible.

More details on reproductive parameters can be found in the 2021 benchmark report (ICES, 2021a, including WD6 in that report).

Natural mortality

Not known, though estimates ranging from 0.1–0.3 have been described in the scientific literature (Aasen, 1964; Holden, 1968). WGEF has assumed a length dependent natural mortality with a value of 0.1 for a large range of ages, but higher values for both very small (young) and large (old) fish.

Recruitment

Ellis and Keable, 2008, reported a maximum uterine fecundity of 21 pups, which was greater than previously reported for NE Atlantic spurdog. It is unclear as to whether this increase is a density-dependent effect or sampling artefact.

Exploratory assessment models

Previous studies

Exploratory assessments undertaken in 2006 included the use of a delta-lognormal GLM-standardized index of abundance and a population dynamic model. This has been updated at subsequent meetings. The results from these assessments indicate that spurdog abundance has declined, and that the decline is driven by high exploitation levels in the past, coupled with biological characteristics that make this species particularly vulnerable to such intense exploitation (ICES, 2006). More recent assessments have indicated a recovery of the stock.

Earlier demographic studies on elasmobranchs indicate that low fishing mortality on mature females may be beneficial to population growth rates (Cortés, 1999; Simpfendorfer, 1999). Hence, measures that afford protection to mature females may be an important element of a management plan for the species. As with many elasmobranchs, female spurdog attain a larger size than males, and larger females are more fecund.

Preliminary simulation studies of various Maximum Landing Length (MLL) scenarios were undertaken by ICES, 2006 and suggested that there are strong potential benefits to the stock by protecting mature females. However, improved estimates of discard survivorship from various commercial gears are required to better examine the efficacy of such measures.

Stock assessment

Initial development of the spurdog assessment model

The exploratory assessment for spurdog presented in 2006 (ICES, 2006) was extended to account for further years of landings data, updated statistical analyses of survey data, a split of the largest length category into two to avoid too many animals being recorded in this category, and fecundity data sets from two periods (1960 and 2005). The statistical analysis of survey data provided a delta-lognormal GLM-standardised index of abundance (with associated CVs), based on Scottish groundfish surveys. The exploratory assessment assumed two "fleets", with landings data split to reflect a fleet with Scottish selectivity (non-target), and one with England & Wales selectivity (target). The non-target and target selectivities were estimated by fitting to proportions-by-length-category data derived from Scottish and England & Wales commercial landings data bases.

The assessment is based on an approach developed by Punt and Walker (1998) for school shark (*Galeorhinus galeus*) off southern Australia (De Oliveira et al., 2013). The approach is essentially age- and sex-structured, but is based on processes that are length-based, such as maturity, pup-production, growth (in terms of weight) and gear selectivity, with a length–age relationship to define the conversion from length to age. Pup-production (recruitment) is closely linked to the numbers of mature females, but the model allows deviations from this relationship to be estimated (subject to a constraint on the amount of deviation).

The implementation for spurdog was coded in AD Model Builder (Otter Research). The approach is similar to Punt and Walker (1998), but used fecundity data from two periods (1960 and 2005) in an attempt to estimate the extent of density-dependence in pup-production (a new feature compared to ICES, 2006) and was fitted to the Scottish groundfish surveys index of abundance, and proportion-by-length-category data from both the survey and commercial catches (aggregated across gears) (De Oliveira et al., 2013). Five categories were considered for the survey proportion-by-length-category data, namely length-groups 16–31 cm (pups); 32–54 cm (juveniles); 55–69 cm (sub-adults); and 70–84 cm (maturing fish) and 85+ cm (mature fish). The first two categories were combined for the commercial catch data to avoid zero values.

A closer inspection of the survey proportions-by-length-category data showed a greater proportion of males than females in the largest two length categories. This could indicate a lower degree of overlap between the distribution of females and the survey area compared to males, and requires both a separate selectivity parameter to be fitted for the largest two length categories, and the survey proportion-by-length-category data to be fitted separately for females and males. However, the low numbers of animals in the largest length category (85+) resulted in the occurrence of zeros in this length category, so the approach since 2011 has been to combine the two largest length categories (resulting in a total of four length categories: 16–31 cm, 32–54 cm, 55–69 cm, and 70+) when fitting to survey proportions-by-length-category data for females and males separately.

The only estimable parameters considered in the initial development were the total number of pregnant females in the virgin population ($N_0^{f,preg}$), Scottish survey selectivity-by-length-category (4 parameters), commercial selectivity-by-length-category for the two fleets (6 parameters, three reflecting non-target selectivity, and three target selectivity), extent of density-dependence in pup production (Q_{fec}), and constrained recruitment deviations (1960–2009). Although two fecundity parameters could in principle be estimated from the fit to the fecundity data, these were found to be confounded with Q_{fec}, making estimation difficult, so instead of estimating them, values were selected on the basis of a scan over the likelihood surface. The model also assumed two commercial catch exploitation patterns that have remained constant since 1905, which is an oversimplification given the number of gears taking spurdog, and the change in the relative contribution of these gears in directed and mixed fisheries over time, but sensitivity tests were included to show the sensitivity to this assumption. Growth is considered invariant, as in the Punt and Walker (1998) approach, but growth variation could be included (Punt *et al*., 2001).

Changes in the assessment in 2011 compared to previous assessments were an attempt to address some of the concerns of the reviewers following the benchmark review of spurdog in early 2011 (see Appendix to this Stock Annex; reproduced from ICES, 2011). These changes are summarised as follows:

- To address the concern about appropriate raising procedures for the England and Wales length–frequency data, and the concern that these data are likely heavily biased towards targeted fisheries, the estimated Scottish selectivity is treated as "non-target", and England and Wales selectivity as "target", and alternative scenarios for allocating landings data to non-target and target fisheries were explored. Further details are provided in the Appendix (response R1.2).
- To address the concern that Scottish survey proportion-by-length-category data are dominated by the occasional large tow of spurdog when these occur, these data were recalculated by using the same spatial stratification that forms the basis of the delta-lognormal GLM standardisation of the survey abundance indices. Further details are provided in the Appendix (response R1.5).
- To account for the lack of large females in the Scottish surveys, likely resulting from lack of availability to the survey, the two largest length categories have been combined to form a 70+ category, and separate selectivity parameters defined for males and females in this length category. Furthermore, the survey proportion-by-length-category data are fitted separately for females and males.
- To account for the presumed lack of targeting as a result of management restrictions throughout the distribution area from 2008 onwards, landings data are assumed to come entirely from non-target fisheries from 2008 onwards.

Further extensions implemented during the benchmark in 2021

Survey indices included in the assessment prior to the benchmark in 2021 only covered a relatively small part (primarily divisions 6.a and 4.a) of the entire stock distribution area. Therefore, one of the main aims of the 2021 benchmark was to improve spatial coverage by including a number of eligible surveys in the assessment. The benchmark also considered improved landings data together with newly-compiled discards data from 2005 onwards, and a number of new fecundity data sets.

Based on the discussion on spatial and temporal coverage of the various surveys in DATRAS and those made available as part of the data call, the 2021 benchmark agreed to derive three separate biomass indices, one per quarter (Q1, Q3, Q4). Data extraction and manipulation made use of the 'DATRAS' R package while statistical modelling was carried out using the 'surveyIndex' R package (Berg et al., 2014). It implements a GAM modelling framework allowing for a variety of different model assumptions including 'delta' models with lognormal and gamma distributions for positive observations. In addition to the survey indices (and estimated CVs), the number of individuals by sex (sample size) and proportion by length category and year (and sex) were calculated for use in the stock assessment. This results in the following indices to be used in the assessment:

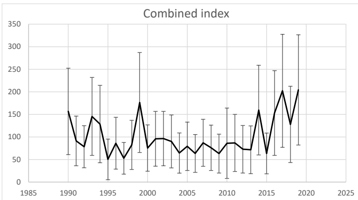
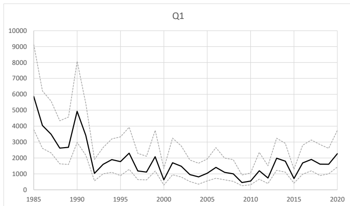
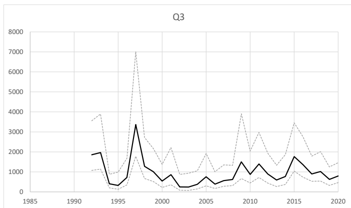
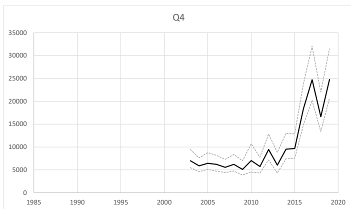
- A modelled Q1 index by sex, based on four survey time-series: NO-SH, NS-IBTS, SWC-IBTS, SCOWCGFS [1985–present].
- Q3 index by sex, based on a single survey: NS-IBTS [1992–present]
- A modelled Q4 index by sex, based on five survey time-series: SWC-IBTS, SCOWCGFS, NIGFS, IE-IGFS, EVHOE [2003–present].

Commercial catch length data were requested as part of the datacall for the benchmark, and this resulted in the definition of two commercial fleet types from 2005 onwards (“nets & hooks” and “trawls & other”), with commercial proportions by length category data compiled from 2007 onwards and used to estimate the selectivity for these two fleet types. The commercial fleet types prior to 2005 were kept as before (“target” and “non-target”), with associated data (as before) to estimate selectivities for these. The model has therefore been extended to reflect four commercial selectivity types, as described above.

Fecundity data used to inform the model were improved from having two data years (1960, 2005) to include 14 data years covering the time-period 1921–2020.

In addition to the substantial improvement in input data for the 2021 benchmark, the only other change to the configuration of the assessment model was to change the current assessment setting of estimating recruitment deviates from 1960 to 1975, based on model-fitting criteria (ICES, 2021a). The estimable parameters of the model are therefore the total number of pregnant females in the virgin population ($N_0^{f,preg}$), Q1, Q3 and Q4 survey selectivity-by-length-category (12 parameters in total), commercial selectivity-by-length-category for the four fleets (12 parameters in total), extent of density-dependence in pup production (Q_{fec}), and constrained recruitment deviations (1975–present).

A comparison between the current assessment (used until 2020) and final WKNSEA 2021 benchmark assessment (ICES, 2021a), with some adjustments, reflecting data updates during WGEF 2022 (including consistency with outputs from the WKSHARK series of meetings):

CATEGORY	CURRENT ASSESS (USED UNTIL 2020)	FINAL WKNSEA 2021 BENCHMARK ASSESSMENT, WITH SOME ADJUSTMENTS
Data		
Catches	1905-2009: International landings assumed to represent catches 2010-present: average of landings in 2007-2009, assumed to represent catches	1905-2004: International landings assumed to represent catches (discards considered negligible) 2005-present: estimates of landings and discards, as submitted following a data call for WKNSEA 2021, and the work of the WKSHARK series of meetings
Commercial length composition	Two Commercial fleet selectivities: Non-targeted (Scottish: 1991-2004 Targeted (Eng & Wales: 1983-2001) [Targeted and non-targeted selection assumed for 1905-2007] [Non-targeted selection only assumed from 2008 onwards]	Four Commercial fleet selectivities: Non-targeted (Scottish: 1991-2004) Targeted (Eng & Wales: 1983-2001) [Targeted and non-targeted selection assumed for 1905-2004] Trawls & other (2005-present) Nets & hooks (2005-present)
Surveys	 Combined index, based on 4 survey time series: ScoGFS-WIBTS-Q1, ScoGFS-WIBTS-Q4, Sco-IBTS-Q1, Sco-IBTS-Q3 [1990-present]	 Q1 index, based on 4 survey time series: NO-SH, NS-IBTS, SWC-IBTS, SCOWCGFS [1985-present]  Q3 index, based on NS-IBTS [1992-present]  Q4 index, based on 5 survey time series: SWC-IBTS, SCOWCGFS, NIGFS, IE-IGFS, EVHOE [2003-present]

Survey length compositions	Combined index by sex: 1990-present	Q1 index by sex: 1985-present Q3 index by sex: 1992-1994, 2008-present Q4 index by sex: 2003-present
Fecundity data	1960: 783 samples 2005: 179 samples	1921: 81 samples 1960: 783 samples 1978: 58 samples 1987: 126 samples 1988: 25 samples 1997: 111 samples 2005: 179 samples 2010: 1 sample 2014: 109 samples 2016: 92 samples 2017: 297 samples 2018: 43 samples 2019: 25 samples 2020: 26 samples
Model settings		
Start year for recruitment deviates	1960	1975

Population dynamics model

The model is presented in De Oliveira et al. (2013), and is largely based on Punt and Walker (1998) and Punt *et al*. (2001).

Basic Dynamics

The population dynamics for spurdog are assumed to be governed by:

$$N^s_{y+1,a} = \begin{cases} \Phi^s R_{y+1} & a=0 \\ (N^s_{y,a-1}e^{-M_{a-1}/2} - \sum_j C^s_{j,y,a-1})e^{-M_{a-1}/2} & 0<a\le A-1 \\ (N^s_{y,A-1}e^{-M_{A-1}/2} - \sum_j C^s_{j,y,A-1})e^{-M_{A-1}/2} + (N^s_{y,A}e^{-M_A/2} - \sum_j C^s_{j,y,A})e^{-M_A/2} & a=A \end{cases} \quad \text{1a}$$

where s=f or m, Φ^s is the sex ratio (assumed to be 0.5), R_y the recruitment of pups to the population, $N^s_{y,a}$ the number of animals of sex s and age a at the start of year y, M_a the instantaneous rate of natural mortality-at-age a, $C^s_{j,y,a}$ the number of animals caught of sex s and age a in year y by fleet j, and A the plus group (60). Total biomass is then calculated as:

$$B_y = \sum_s \sum_a w_a^s N_{y,a}^s \qquad \text{1b}$$

where w_a^s is the begin-year mean weight of animals of sex s and age a.

Recruitment

The number of pups born each year depends on the number of pregnant females in the population as follows:

$$N_{pup,y} = \sum_{a=1}^{A} P'_a P''_a N_{y,a}^f \qquad \text{2a}$$

where P'_a is the number of pups per pregnant female of age a, and P''_a the proportion females of age a that become pregnant each year. Q_y, the density-dependence factor that multiplies the number of births in year y, is calculated as follows:

$$Q_y = 1 + (Q_{fec} - 1)(1 - N_{pup,y} / R_0) \qquad \text{2b}$$

where Q_{fec} is the parameter that determines the extent of density dependence, and R_0 the virgin recruitment level (see "Initial conditions" below). Recruitment in year y is the product of these two equations, and in order to allow for interannual variation in pup survival rate, "process error" is introduced to give the following:

$$R_y = Q_y N_{pup,y}\, e^{\varepsilon_{r,y}} \qquad \text{2c}$$

where the recruitment residuals $\varepsilon_{r,y}$ are estimated (see equation 9a below).

Fecundity

Fecundity, expressed as number of pups per pregnant female of age a, is modelled as follows:

$$P'_a = \begin{cases} 0 & l_a^f < l_{mat00}^f \\ b_{fec}\left(l_a^f + \sqrt{(l_a^f + a_{fec}/b_{fec})^2 + \gamma^2} - \sqrt{(a_{fec}/b_{fec})^2 + \gamma^2}\right)/2 & l_a^f \ge l_{mat00}^f \end{cases} \qquad \text{3}$$

where l_{mat00}^f is the female length-at-first maturity (Table 1), and γ is set at 0.001. The bent hyperbola formulation (Mesnil and Rochet, 2010) given in the bottom line of equation 3, is to ensure that if parameters a_{fec} and b_{fec} are estimated, P'_a remains non-negative and the function is differentiable for $l_a^f \ge l_{mat00}^f$.

Estimated fishing proportion and catch-at-age

Catches are assumed to be taken in a pulse in the middle of the year, with the fully selected fishing proportion $F_{j,y}$ being estimated from the observed annual catch (in weight) by fleet $C_{j,y}$ as follows:

$$F_{j,y} = \frac{C_{j,y}}{\sum_a e^{-M_a/2} \sum_s w^s_{a+\frac{1}{2}} S^s_{com,j,a} N^s_{y,a}} \quad (4a)$$

where $w^s_{a+\frac{1}{2}}$ is the mid-year mean weight of animals of sex *s* and age *a*, and $S^s_{com,j,a}$ the selectivity-at-age of animals of sex *s* and age *a* caught by fleet *j*. For the purposes of estimating a mean fishing proportion trajectory, the mean effective fishing proportion over ages 5–30 is calculated as follows:

$$F_{prop5-30,y} = \sum_j \frac{1}{26} \sum_{a=5}^{30} \left[\frac{\sum_s S^s_{com,j,a} N^s_{y,a} (F_{j,y} S^s_{com,j,a})}{\sum_s S^s_{com,j,a} N^s_{y,a}} \right] \quad (4b)$$

Catch-at-age (in numbers) is estimated as follows:

$$C^s_{j,y,a} = F_{j,y} S^s_{com,j,a} N^s_{y,a} e^{-M_a/2} \quad (4c)$$

Commercial selectivity

Commercial selectivity-at-age is calculated from commercial selectivity-by-length category parameters as follows:

$$S^{s*}_{com,j,a} = \begin{cases} S_{c2,j} & 16 \le l^s_a < 55 \\ S_{c3,j} & 55 \le l^s_a < 70 \\ S_{c4,j} & 70 \le l^s_a < 85 \\ 1 & l^s_a \ge 85 \end{cases} \quad (5a)$$

so that:

$$S^s_{com,j,a} = S^{s*}_{com,j,a} / \max_j (S^{s*}_{com,j,a}) \quad (5b)$$

where l^s_a is the length-at-age for animals of sex *s*. Selectivity-by-length category parameters $S_{c2,j}$, $S_{c3,j}$ and $S_{c4,j}$ (*j=non-tgt* or *tgt* prior to 2005, and *j=nets & hooks* or *trawls & other* from 2005 onwards) are estimated in the model.

Survey selectivity

Survey selectivity-at-age $S^s_{sur,k,a}$ for animals of sex *s* is calculated in the same manner as commercial selectivity, except that there is only one survey abundance-series (the index *j* is replaced by *k* in the above equations, representing survey index Q1, Q2 or Q3) and different length categories (the 16–54 cm category is split into 16–31 and 32–54, and the 70-84 and 85+ categories are combined into a single 70+ category), leading to four selectivity parameters per survey index to be estimated ($S_{s1,k}$, $S_{s2,k}$, $S_{s3,k}$ and $S_{s4,k}$), the first three applying to the smallest length categories (16-31, 32-54 and 55-69), regardless of sex, and the fourth ($S_{s4,k}$) to the 70+ category for females only (assuming 1 for males in this length category).

Initial conditions

The model assumes virgin conditions in 1905, the earliest year for which continuous landings data are available, with the total number of pregnant females in the virgin population, $N_0^{f,preg}$, treated as an estimable parameter in the model. Taking the model back to 1905 ensures that the assumption of virgin conditions is more appropriate, although it also implies that exploitation patterns estimated for the most recent period (1980+) are taken back to the early 1900s. Taking the model back also allows early fecundity data to be fitted. Virgin conditions are estimated by assuming constant recruitment and taking the basic dynamics equations forward under the assumption of no commercial exploitation. Virgin recruitment (R_0) is then calculated as follows [note: $\sum_{i=0}^{-1}()$ is defined as 0]:

$$R_0 = \frac{N_0^{f,preg}}{\Phi^f \left[\sum_{a=0}^{A-1} P''_a e^{-\sum_{i=0}^{a-1} M_i} + P''_A \frac{e^{-\sum_{i=0}^{A-1} M_i}}{1-e^{-M_A}} \right]} \qquad 6$$

Natural mortality for pups (M_{pup})

With the possibility of estimating the fecundity parameters a_{fec} and b_{fec} (equation 3), the natural mortality parameter M_{pup} (Table 1) needs to be calculated so that, in the absence of harvesting, the following balance equation is satisfied:

$$\frac{1}{\Phi^f} = \sum_{a=0}^{A-1} P'_a P''_a e^{-\sum_{i=0}^{a-1} M_i} + P'_A P''_A \frac{e^{-\sum_{i=0}^{A-1} M_i}}{1-e^{-M_A}} \qquad 7$$

Estimating MSY parameters

Two approaches were used to derive MSY parameters. In order to derive MSYR, the ratio of maximum sustainable yield, MSY, to the mature biomass (assumed to be the biomass of all animals $\geq l_{mat00}^f$) at which MSY is achieved (MSY/B_{MSY}) is calculated. This follows the same procedure for calculating MSYR as Punt and Walker (1998), and ensures that MSYR is comparable among different stocks/species, which would then allow MSYR estimates for other stocks/species to be used to inform on the likely range for spurdog. The selectivity for this first approach is therefore simply:

$$S_{MSY,a}^{s,mat} = \begin{cases} 0 & l_a^s < l_{mat00}^f \\ 1 & l_a^s \geq l_{mat00}^f \end{cases} \qquad 8a$$

However, an estimate of $F_{prop,MSY}$ is needed from the assessment, which should correspond to the selection patterns of the fleets currently exploiting spurdog. The second approach was therefore to use selection patterns estimated for the non-target and target fleets (average over most recent five years; equations 4a-b) to estimate $F_{prop,MSY}$. The selectivity for the second approach is therefore calculated as follows:

$$S_{MSY,j,a}^{s,cur} = \bar{f}_{rat,j} \, S_{com,j,a}^{s} \qquad 8b$$

where $S_{com,j,a}^{s}$ is from equation 5b, and $\bar{f}_{rat,j}$ is a five-year average as follows:

$$\bar{f}_{rat,j} = \frac{1}{5} \sum_{y=yend-4}^{yend} \frac{F_{j,y}}{\sum_j F_{j,y}} \qquad \text{8c}$$

where $F_{j,y}$ is from equation 4a, and *yend* is the most recent year of data used in the assessment. In order to calculate MSY parameters, the first step is to express population dynamics on a per-recruit basis. Therefore, taking equations 1a and 4c, the equivalent per-recruit equations (dropping the *y* subscript) are given as:

$$N^s_{pr,a} = \begin{cases} \Phi^s & a = 0 \\ \Phi^s \prod_{i=0}^{a-1} \left(1 - \sum_j F_{mult} S^s_{MSY,j,i}\right) e^{-M_i} & 0 < a \le A-1 \\ \Phi^s \dfrac{\prod_{i=0}^{A-1} \left(1 - \sum_j F_{mult} S^s_{MSY,j,i}\right) e^{-M_i}}{\left(1 - \sum_j F_{mult} S^s_{MSY,j,A}\right)(1 - e^{-M_A})} & a = A \end{cases} \qquad \text{8d}$$

where *s* represents sex, F_{mult} replaces $F_{j,y}$ as the multiplier that is used to search for MSY, and the selection pattern $S^s_{MSY,j,a}$ reflects either the first approach (equation 8a, defined in terms of animals all animals $\ge l^f_{mat00}$ only, so subscript *j* and the summation over *j* is dropped) or the second approach (equation 8b, reflecting exploitation by current fleets, so subscript *j* and the summation over *j* is kept). Equation 2a therefore becomes:

$$N_{pup,pr} = \sum_{a=1}^{A} P'_a P''_a N^f_{pr,a} \qquad \text{8e}$$

Recruitment can be expressed in terms of $N_{pup,pr}$ by re-arranging equations 2b–c (omitting the process error term) as follows:

$$R = \frac{R_0}{N_{pup,pr}} \left[1 - \frac{(1/N_{pup,pr} - 1)}{Q_{fec} - 1} \right] \qquad \text{8f}$$

Yield can then be calculated as follows for the first (Y^{mat}) and second (Y^{cur}) approaches:

$$Y^{mat} = R \sum_s \sum_{a=0}^{A} \left(F_{mult} S^{s,mat}_{MSY,a} w^s_a N^s_{pr,a} \right) \qquad \text{8g}$$

and

$$Y^{cur} = R \sum_s \sum_{a=0}^{A} \sum_j \left(F_{mult} S^{s,cur}_{MSY,j,a} w^s_{a+\frac{1}{2}} N^s_{pr,a} e^{-M_a/2} \right) \qquad \text{8h}$$

MSY is found by solving for the F_{mult} value that maximises equation 8g or 8h, and the corresponding $F_{prop,MSY}$ is calculated using equation 4b (replacing $F_{j,y}$ with F_{mult}, $S^{s}_{com,j,a}$ with $S^{s}_{MSY,j,a}$, and $N^{s}_{y,a}$ with $N^{s}_{pr,a}$). Here, equation 8g has been used for the purposes of calculating MSYR, and equation 8h for estimating $F_{prop,MSY}$. For the first approach (mature "selection"; see equation 8a) B_{MSY} is calculated using equation 8g, but replacing F_{mult} with 1; for the second approach (fishery selection; see equations 8b-c), B_{MSY} is calculated as in equation 1b, but where $N^{s}_{y,a}$ is replaced with $N^{s}_{pr,a}$ and the latter is multiplied by R from equation 8f.

Likelihood function

Survey abundance index

The contribution of the Scottish survey abundance index to the negative log-likelihood function assumes that the survey index $I_{sur,y}$ is lognormally distributed about its expected value, and is calculated as follows:

$$-\ln L_{sur,k} = \frac{1}{2}\sum_y [\ln(2\pi\sigma^2_{sur,k,y}) + \varepsilon^2_{sur,k,y}] \qquad \text{9a}$$

where k represents survey index (Q1, Q3 or Q4), $\sigma_{sur,k,y}$ is the CV of the untransformed data, $q_{sur,k}$ the survey catchability (estimated by closed-form solution), and $\varepsilon_{sur,k,y}$ the normalised residual:

$$\varepsilon_{sur,k,y} = [\ln(I_{sur,k,y}) - \ln(q_{sur,k}B_{sur,k,y})]/\sigma_{sur,k,y} \qquad \text{9b}$$

$B_{sur,k,y}$ is the "available" mid-year abundance corresponding to $I_{sur,k,y}$, and is calculated as follows:

$$B_{sur,k,y} = \sum_s \sum_a S^{s}_{sur,k,a} w^{s}_{a+\frac{1}{2}} [N^{s}_{y,a} e^{-M_a/2} - \sum_j C^{s}_{j,y,a}/2] \qquad \text{9c}$$

Commercial proportion-by-length-category

The contribution of the commercial proportion-by-length-category data to the negative log-likelihood function assumes that these proportions $p_{j,y,L}$ for fleet j and length category L (combined sex) are multinomially distributed about their expected value, and is calculated as follows (Punt *et al.*, 2001):

$$-\ln L_{pcom,j} = k_{pcom,j} \sum_y \sum_L \varepsilon_{pcom,j,y,L} \qquad \text{10a}$$

where $k_{pcom,j}$ is the effective sample size, and the multinomial residual $\varepsilon_{pcom,j,y,L}$ is:

$$\varepsilon_{pcom,j,y,L} = -\frac{n_{pcom,j,y}}{\bar{n}_{pcom,j}} p_{j,y,L} [\ln(\hat{p}_{j,y,L}) - \ln(p_{j,y,L})] \qquad \text{10b}$$

with $n_{pcom,j,y}$ representing the number of samples on which estimates of proportions by length category are based, and $\bar{n}_{pcom,j}$ the corresponding average (over y). Because actual sample sizes were not available for the commercial data (only raised sample sizes), all model runs assumed $n_{pcom,j,y} = \bar{n}_{pcom,j}$, ICES (2010) concluded that model results were not sensitive to this assumption. Four length categories are considered for the commercial proportions-by-length (16–54 cm; 55–69 cm; 70–84 cm; and 70+ cm), and the model estimates $\hat{p}_{j,L,y}$ are obtained by summing the estimated numbers caught in the relevant length category L and dividing by the total across all the length categories. The effective sample size $k_{pcom,j}$ is assumed to be 20 for all j (but a sensitivity test explored alternative assumptions and found results to be relatively insensitive to these).

Survey proportion-by-length-category

The negative log-likelihood contributions ($-\ln L_{psur,k}$) for the Q1, Q3 and Q4 survey proportions-by-length category are as for the commercial proportions, except that there are three survey abundance series (the j index is replaced by k in the above equations, representing the three survey indices), and different length categories (the 16–54 cm category is split into 16–31 and 32–54, and the 70-84 and 85+ categories are combined into a single 70+ category). The effective sample size $k_{psur,k}$ is assumed to be 10, and reflects the lower sample sizes for surveys relative to commercial catch data (Punt *et al.*, 2001).

Fecundity

The contribution of the fecundity data from two periods to the negative log-likelihood function assumes that the data are normally distributed about their expected value, and is calculated as follows:

$$-\ln L_{fec} = \frac{1}{2}\sum_{y\in Y_{fec}}\sum_{k=1}^{K_y}[\ln(2\pi\sigma_{fec}^2) + \varepsilon_{fec,k,y}^2] \qquad \text{11a}$$

where Y_{fec} represents the set of years for which there are fecundity data sets, K_y represents the sample sizes for each of the fecundity data sets, k the individual samples, and $\varepsilon_{fec,k,y}$ is:

$$\varepsilon_{fec,k,y} = [P'_{k,y} - \hat{P}'_{k,y}]/\sigma_{fec} \qquad \text{11b}$$

where $P'_{k,y}$ represents the data and $\hat{P}'_{k,y}$ the corresponding model estimate calculated by multiplying equation 3 with Q_y in equation 2b and substituting the length of the sample in equation 3 (where the age subscript a is replaced by the sample subscript k). A closed-form solution for σ_{fec} exists as follows:

$$\sigma_{fec} = \sqrt{\frac{\sum_{y\in Y_{fec}}\sum_{k=1}^{K_y}(P'_{k,y} - \hat{P}'_{k,y})^2}{\sum_{y\in Y_{fec}} K_y}} \qquad \text{11c}$$

Recruitment

Recruitment (pups) is assumed to be lognormally distributed about its expected value, with the following contribution to the negative log-likelihood function:

$$-\ln L_r = \frac{1}{2}\sum_y [\ln(2\pi\sigma_r^2) + (\varepsilon_{r,y}/\sigma_r)^2] \qquad \text{12}$$

where $\varepsilon_{r,y}$ are estimable parameters in the model, and σ_r is a fixed input (0.2 for the base case).

Total likelihood

The total negative log-likelihood is the sum of the individual components:

$$-\ln L_{tot} = -\sum_k \ln L_{sur,k} - \sum_j \ln L_{pcom,j} - \sum_k \ln L_{psur,k} - \ln L_{fec} - \ln L_r \qquad \text{13}$$

Life-history parameters and input data

Calculation of the life-history parameters M_a (instantaneous natural mortality rate), l_a^s (mean length-at-age for animals of sex *s*), w_a^s (mean weight-at-age for animals of sex *s*), and P_a'' (proportion females of age *a* that become pregnant each year) are summarised in Table 1.

Quality of assessments

WGEF has attempted various analytic assessments of NE Atlantic spurdog using a number of different approaches (see Section 2.8 and ICES, 2006). Although these models have not proved entirely satisfactory (as a consequence of the quality of the assessment input data), these exploratory assessments and survey data all indicate a decline in spurdog, with more recent assessments indicating a recovery. A comparison of different modelling approaches applied to spurdog, based on the same datasets, found relatively consistent results among the models (including the current model; see Figure 4 in Deroba *et al.*, 2015), which provides further confidence in the modelling approach adopted for spurdog.

Catch data

The WG has provided estimates of total landings of NE Atlantic spurdog, and from 2005 onwards estimates of discards, and has used these together with length frequency distributions in the assessment of this stock. However, there are still concerns over the quality of these data as a consequence of:

- uncertainty in the historical level of catches because of landings being reported by generic dogfish categories;
- uncertainty over the accuracy of the landings data because of species misreporting;
- missing discards data for some countries and métiers (e.g. for UK-England & Wales gillnets and trammel nets).

There are occasional slight (0–1%) inconsistencies in the total landings when measured by country and when measured by ICES Division. This is the result of some national revision of historical landing and the assigning of proportions of catches from generic *nei* categories as "spurdog". It is intended that these be completely reconciled before the next meeting.

Survey data

Survey data are particularly important indicators of abundance trends in stocks. However, it should be highlighted that

- spurdog survey data are difficult to interpret because of the typically highly skewed distribution of catch-per-unit effort.
- annual survey length frequency distribution data (aggregated over all hauls) may be dominated by data from single large haul.

These problems have been dealt with by adopting appropriate statistical modelling approaches when analysing survey data (see above).

Biological information

As well as good commercial and survey data, the analytical assessments require good information on the biology of NE Atlantic spurdog. In particular, the WG would like to highlight the need for:

- updated and validated growth parameters, in particular for larger individuals;
- better estimates of natural mortality.

An area of future improvement for the spurdog model is including variation in the age-length relationship in the model. The lack of progress in this regard during the 2021 benchmark (given the need to focus on other areas considered of higher priority, such as the substantial improvement in the data now included in the model) meant that it was not possible to explore sensitivity to alternative growth parameterisations. This was because the alternative growth models proposed meant that there were no longer animals in the smallest length classes, leading to zero values which were not possible to deal with during this benchmark. The growth parameters used for the final model therefore remains the values used in the previous assessment and reported in Table 1 (see also De Oliveira *et al.*, 2013).

Current assessment

As with any stock assessment model, the exploratory assessment relies heavily on the underlying assumptions, particularly with regard to life-history parameters (e.g. natural mortality and growth), and on the quality and appropriateness of input data. The inclusion of several periods of fecundity data has provided valuable information that allows estimation of Q_{fec}, and projecting the model back in time is needed to allow fecundity data sets to be fitted. Nevertheless, the likelihood surface does not have a well-defined optimum, and additional information, such as on appropriate values of MSYR for a species such as spurdog, would help with this problem. Further refinements of the model are possible, such as including variation in growth. Selectivity curves also cover a range of gears over the entire catch history, and more appropriate assumptions (depending on available data) could be considered.

In summary, the model may be appropriate for providing an assessment of spurdog, though it could be further developed if the following data were available:

- Further refinements of selectivity parameters disaggregated by gear for the main fisheries (i.e. for various trawl, long line and gillnets);
- Improved estimates for biological data (e.g. growth parameters, reproductive biology and natural mortality);
- Information on likely values of MSYR for a species such as spurdog.

Reference points

The spurdog model is an integrated assessment model that includes a function that relates pup production to mature females, and it is therefore possible to estimate reference points (such as B_{MSY}) from within the model (in much the same way that is done for biomass dynamic models) without relying on an approach such as EqSim. Furthermore, the model commences in 1905, when reported landings were relatively low, and well before the period of high exploitation experienced from the 1950s onwards, and so the model is considered to provide a reasonably reliable estimate of B_0 (the virgin total biomass level). Reference points are directly based on assessment outputs, which means that reference points are updated every time the assessment is re-run.

B_{lim}: set to 20% of B_0:

Depletion-based reference points typically range from 20% to 30% (Preece *et al.*, 2011) and these reference points are considered the default level at which serious management action should be taken to rebuild the stock (Preece *et al.*, 2011). These reference points vary between management bodies, and the value selected may also be influenced by stock productivity and level of knowledge of the stock. Several organisations, including the International Whaling Commission (IWC) and Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR), use B_{lim} as 20% of B_0, and this is the value considered here.

Depending on the time period considered and the generation time of the species, this value may also be comparable to an IUCN Critically Endangered listing under Category 2, for which "*An observed, estimated, inferred or suspected population size reduction of ≥80% over the last 10 years or three generations, whichever is the longer, where the reduction or its causes may not have ceased OR may not be understood OR may not be reversible…*" (IUCN, 2012).

Alternative approaches could include:

- Using 0.3 B_{MSY}, which is used for biomass dynamic models within ICES (ICES, 2021b). However, this would translate to a value less than 0.2 B_0 (for spurdog, 0.185 B_0) which is considered too low for an elasmobranch stock, and therefore not in line with the precautionary approach.
- Using 0.3 B_0, which was the value suggested by Sainsbury (2008) as a more precautionary approach and applicable to low productivity stocks.

Whilst the more conservative value of 0.3 B_0 could be considered for spurdog, given the low productivity of the stock, it was noted that this species is comparatively data rich (relative to other elasmobranchs), and the species is known to be capable of stock rebuilding, as seen in the NW Atlantic (e.g. Rago & Sosebee, 2013; Dell'Apa et al., 2015). Consequently, B_{lim} was defined as 0.2 B_0.

B_{pa}: set to 1.4 B_{lim}:

The ICES default formulation of 1.4 B_{lim} is adopted for B_{pa}, given that the CV of total biomass in the terminal years is 14%, which is considered too low for setting the buffer between B_{lim} and B_{pa}.

MSY $B_{trigger}$: set to B_{pa}:

In the absence of sustained fishing at $F_{prop,MSY}$ (also labelled HR_{MSY}), we have adopted the ICES approach of setting $MSY\ B_{trigger}$ at B_{pa}.

$F_{prop,MSY}$ (also called HR_{MSY}):

Estimated within the model. Details of how the MSY reference points, including $F_{prop,MSY}$ (or HR_{MSY}, averaged over the ages 5–30), are calculated, are described above. The selection pattern is taken from the period around when management measures started to become restrictive (2008 onwards).

HR_{lim}: the harvest rate that leads to B_{lim}:

It is possible to get this from the equilibrium total biomass versus harvest rate curves from within the model.

HR_{pa}: the harvest rate that provides a buffer to avoid B_{lim} with high probability:

Since HR_{pa} is more about avoiding B_{lim} with a high probability, the 2021 benchmark opted for a definition that provides a buffer from HR_{lim} that acts to avoid B_{lim} with high probability (essentially HR_{lim}/1.4).

Management considerations

Stock distribution

Spurdog in the ICES area are considered to be a single-stock, ranging from Subarea 1 to Subarea 9, although landings from the southern end of its range are likely also to include other *Squalus* species.

There should be a single TAC area. Although a new TAC has been established for other areas, given that northern Scotland is an important area for spurdog, separate TACs for the waters of 6.a and 4.a could result in area misreporting should the TAC for one area be more restrictive than the other.

Biological considerations

Spurdogs are long-lived, slow growing, have a high age-at-maturity, and are particularly vulnerable to high levels of fishing mortality. Population productivity is low, with low fecundity and a protracted gestation period. In addition, they form size- and sex-specific shoals and therefore aggregations of large fish (i.e. mature females) are easily exploited by target longline and gillnet fisheries.

Fishery and technical considerations

Those fixed gear fisheries that capture spurdog should be reviewed to examine the catch composition, and those taking a large proportion of mature females should be strictly regulated.

Since 2009, there has been a maximum landing length (MLL) to deter targeting of mature females (see Section 2.10 of ICES, 2006 for simulations on MLL). Discard survival of such fish needs to be evaluated. Those fisheries taking spurdog that are lively may have problems measuring fish accurately, and investigations to determine an alternative measurement (e.g. pre-oral length) that has a high correlation with total length and is more easily measured on live fish are required. Dead dogfish may also be more easily stretched on measuring, and understanding such post-mortem changes is required to inform on any levels of tolerance.

North Sea fisheries were regulated by a bycatch quota (2007–2008), whereby spurdog should not have comprised more than 5% by live weight of the catch retained on board. This was extended to western areas in 2008. The bycatch quota was removed in 2009, when the maximum landing length was brought in.

Spurdog were historically subject to large targeted fisheries, but are increasingly now taken as a bycatch in mixed trawl fisheries. In these fisheries, measures to reduce overall demersal fishing effort should also benefit spurdog. However, a restrictive TAC in this case would likely result in increased discards of spurdog and so may not have the desired effect on fishing mortality if discard survivorship is low.

There is limited information on the distribution of spurdog pups, though they have been reported to occur in Scottish waters, in the Celtic Sea, and off Ireland. The lack of accurate data on the location of pupping and nursery grounds, and their importance to the stock, precludes spatial management for this species at the present time.

Although there is no EU minimum landing size for spurdog, there is some discarding of smaller fish, and it is likely that spurdog of <40 or 45 cm are discarded in most fisheries. The survivorship of discards of juvenile spurdog is not known.

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Table 1. Northeast Atlantic spurdog. Description of life-history equations and parameters.

Parameters	Description/values	Sources
M_a	Instantaneous natural mortality at age *a*: $M_a = \begin{cases} M_{pup} e^{-a \ln(M_{pup}/M_{adult})/a_{M1}} & a < a_{M1} \\ M_{adult} & a_{M1} \le a \le a_{M2} \\ M_{til} / [1 + e^{-M_{gam}(a-(A+a_{M2})/2)}] & a > a_{M2} \end{cases}$	
a_{M1}, a_{M2}	4, 30	expert opinion
M_{adult}, M_{til}, M_{gam}	0.1, 0.3, 0.04621	expert opinion
M_{pup}	Calculated to satisfy balance equation 7	
l_a^s	Mean length-at-age a for animals of sex *s* $l_a^s = L_\infty^s (1 - e^{-\kappa^s (a - t_0^s)})$	
L_∞^f, L_∞^m	110.66, 81.36	average from literature
κ^f, κ^m	0.086, 0.17	average from literature
t_0^f, t_0^m	-3.306, -2.166	average from literature
w_a^s	Mean weight at age *a* for animals of sex *s* $w_a^s = a^s (l_a^s)^{b^s}$	
a^f, b^f	0.00108, 3.301	Bedford *et al.*, 1986
a^m, b^m	0.00576, 2.89	Coull *et al.*, 1989
l_{mat00}^f	Female length at first maturity 70 cm	average from literature
P_a''	Proportion females of age a that become pregnant each year $P_a'' = \frac{P_{max}''}{1 + \exp\left[-\ln(19) \frac{l_a^f - l_{mat50}^f}{l_{mat95}^f - l_{mat50}^f}\right]}$ where P_{max}'' is the proportion very large females pregnant each year, and l_{matx}^f the length at which *x*% of the maximum proportion of females are pregnant each year	
P_{max}''	0.5	average from literature
l_{mat50}^f, l_{mat95}^f	80 cm, 87 cm	average from literature

Table 2. Northeast Atlantic spurdog. Relative contribution of Swedish, Irish and UK (GBR) bottom trawl catches used as a weighting with which to combine the corresponding length frequencies, expressed as proportions at length (ICES, 2022).

	Sweden	Ireland	GBR
2007	7%	35%	57%
2008	14%	40%	46%
2009	7%	19%	74%
2010	7%	43%	51%
2011	6%	46%	48%
2012	10%	31%	59%
2013	12%	21%	67%
2014	28%	12%	59%
2015	4%	20%	76%
2016	6%	28%	66%
2017	21%	41%	37%
2018	2%	40%	59%
2019	9%	18%	73%
2020	0%	51%	49%
2021	0%	3%	97%
average	9%	30%	61%

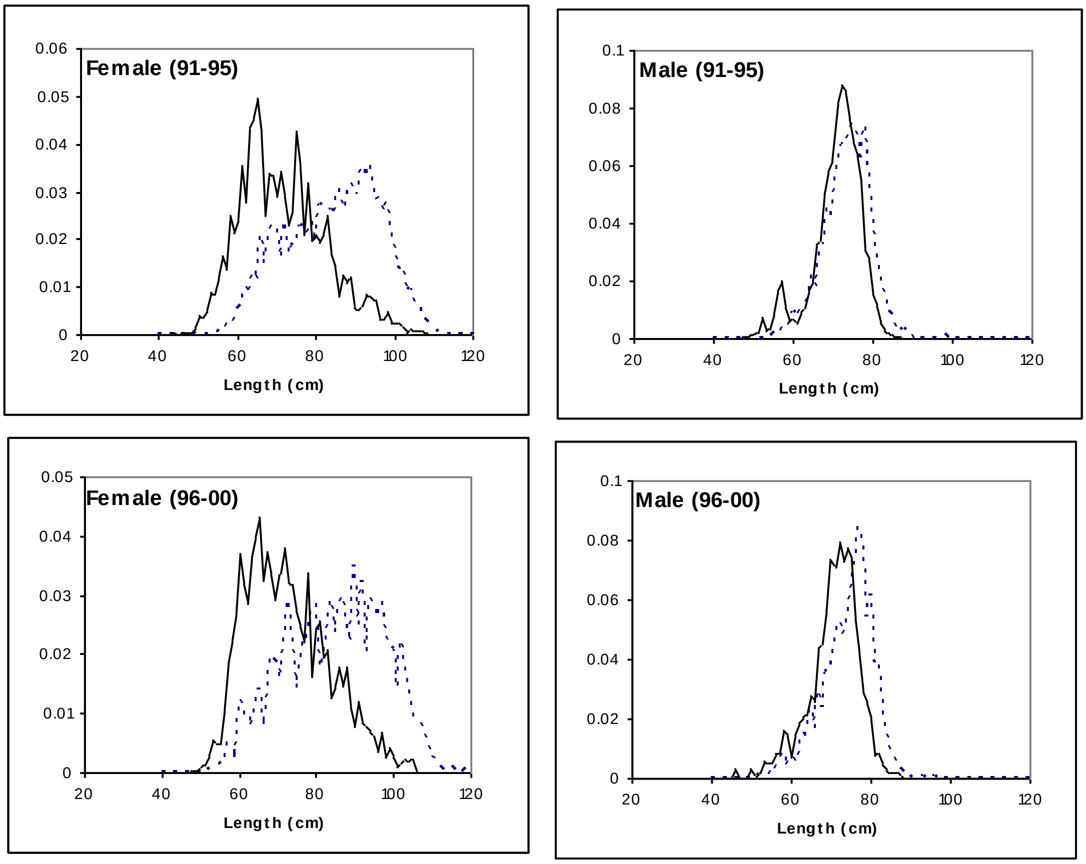


Figure 1. Northeast Atlantic spurdog. Comparison of length frequency distributions (proportions) obtained from market sampling of Scottish (solid line) and UK (E&W) (dashed line) landings data. Data are sex-disaggregated, but averaged over five year intervals.

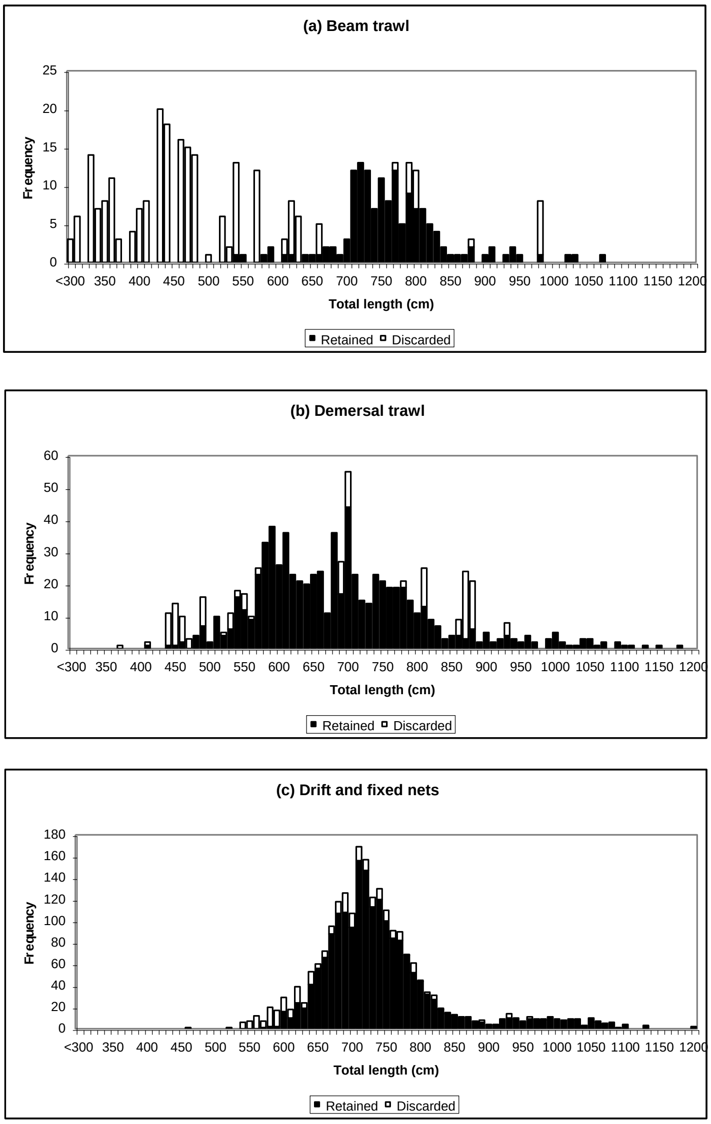


Figure 2. Northeast Atlantic spurdog. Length distribution of discarded and retained in fisheries in the North Sea and Celtic Seas ecoregions for (a) beam trawl, (b) demersal trawl and (c) drift and gillnets. These data (1999–2006) are aggregated across individual catch samples (Source: UK (E&W) Discards surveys).

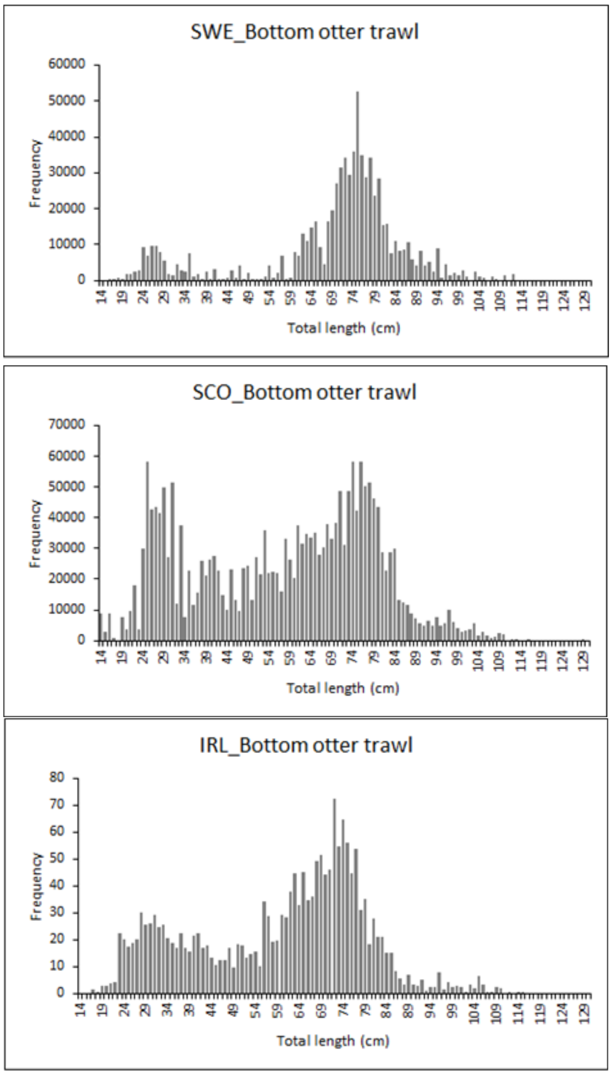


Figure 3 Spurdog in the North-east Atlantic. Length frequency information used as a basis for compiling the proportion by length category data for the "trawls & other" gear category

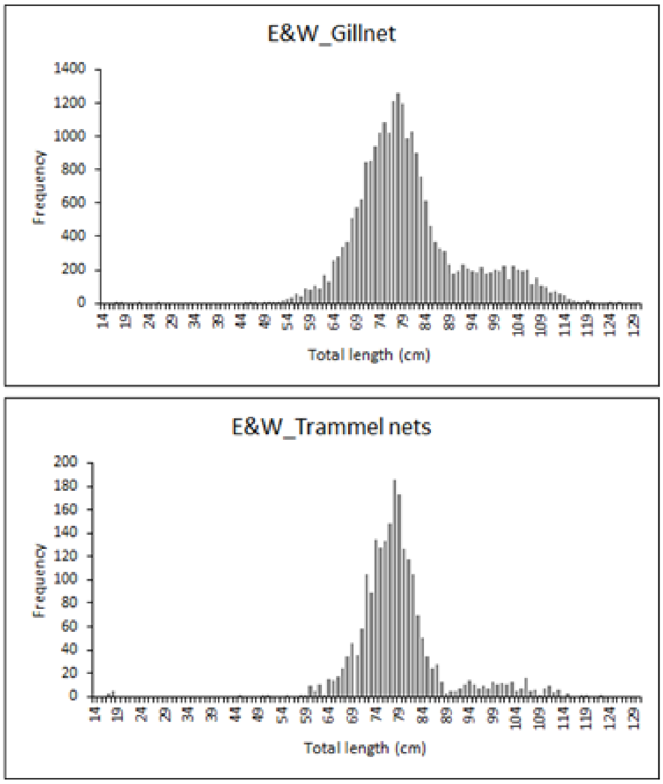
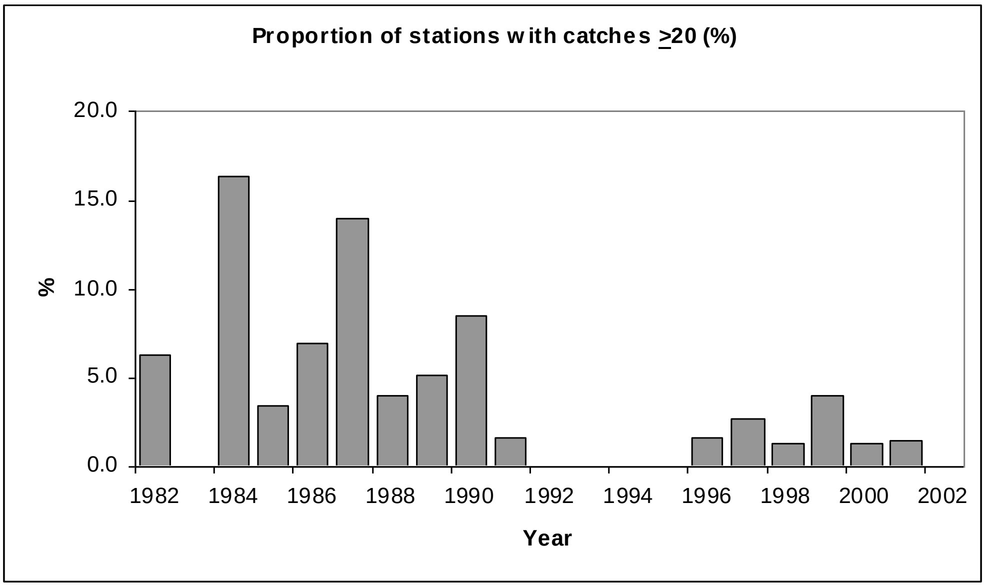


Figure 4 Spurdog in the North-east Atlantic. Length frequency information used as a basis for compiling the proportion by length category data for the "nets and hooks" gear category. These data were simply combined with equal weighting.



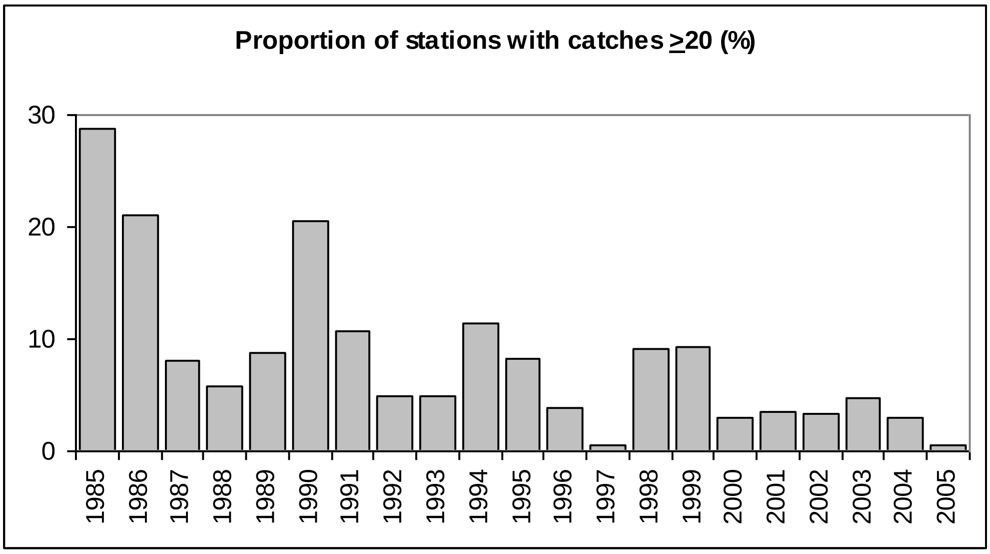
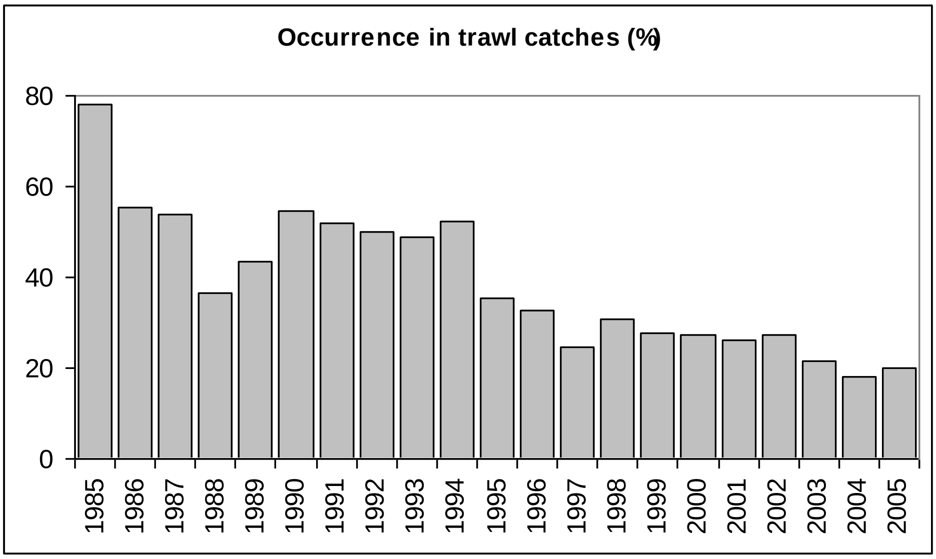


Figure 5. Northeast Atlantic spurdog. Proportion of survey hauls in the English Celtic Sea groundfish survey (1982–2002, top) and Scottish west coast (6.a) survey (Q1, 1985–2005, bottom) in which cpue was ≥20 ind.h^{-1}. (Source: ICES, 2006).

a)



b)

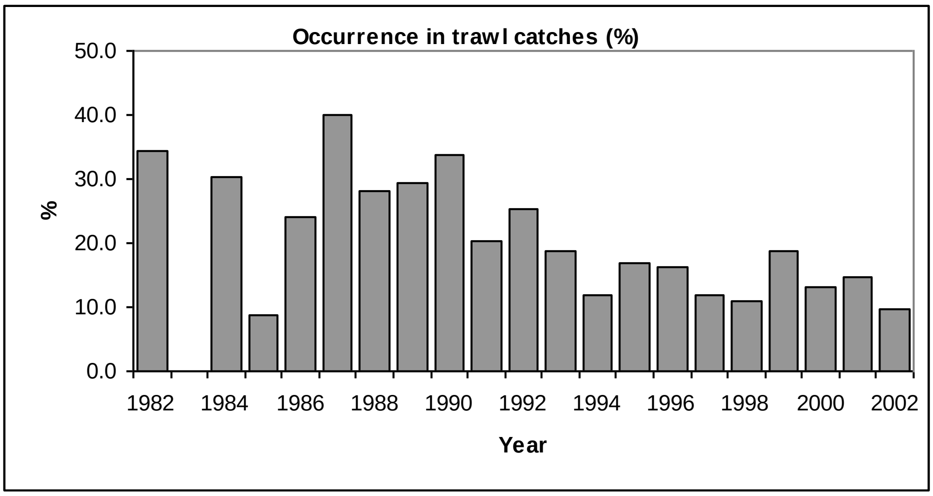


Figure 6. Northeast Atlantic spurdog. Frequency of occurrence in survey hauls in a) the English Q1 Celtic Sea groundfish survey (1982–2002), and b) the Scottish west coast (6.a) survey (Q1, 1985–2005).

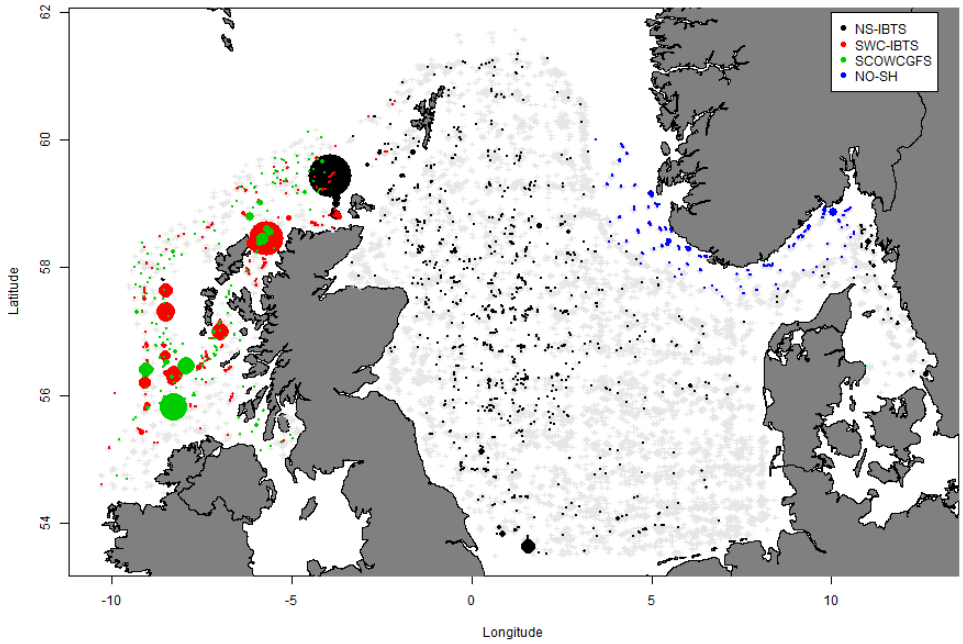


Figure 7. Northeast Atlantic spurdog. Quarter 1 survey data. spatial distribution of total catch (in weight) by survey (all hauls 1985-2020). Bubble size proportional to total catch. Pale grey crosses indicate zero values.

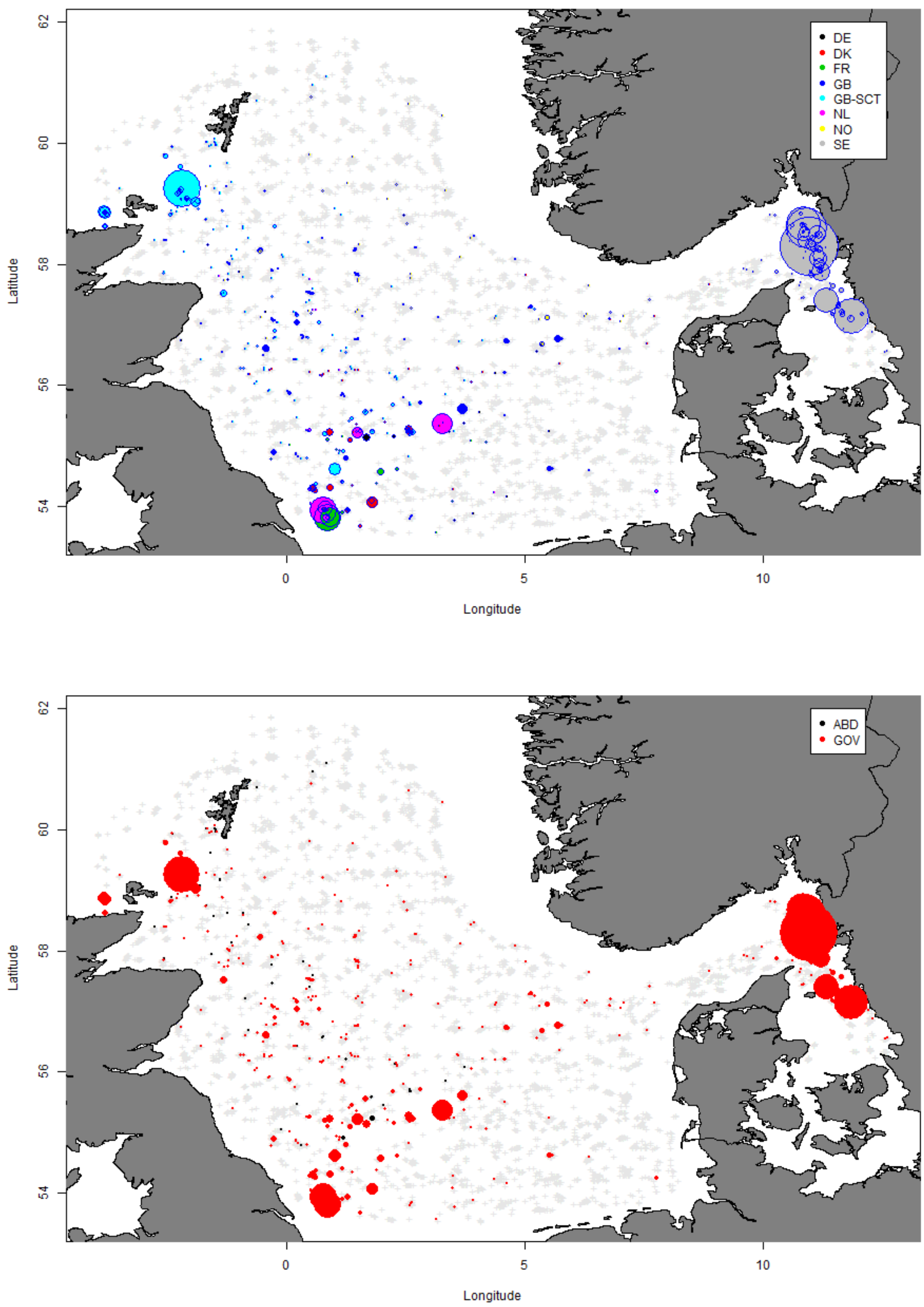


Figure 8. Northeast Atlantic spurdog. Quarter 3 survey data. Spatial distribution of total catch (in weight) by nation (upper plot) and by gear (lower plot) (all hauls 1992-2020). Bubble size proportional to total catch. Pale grey crosses indicate zero values

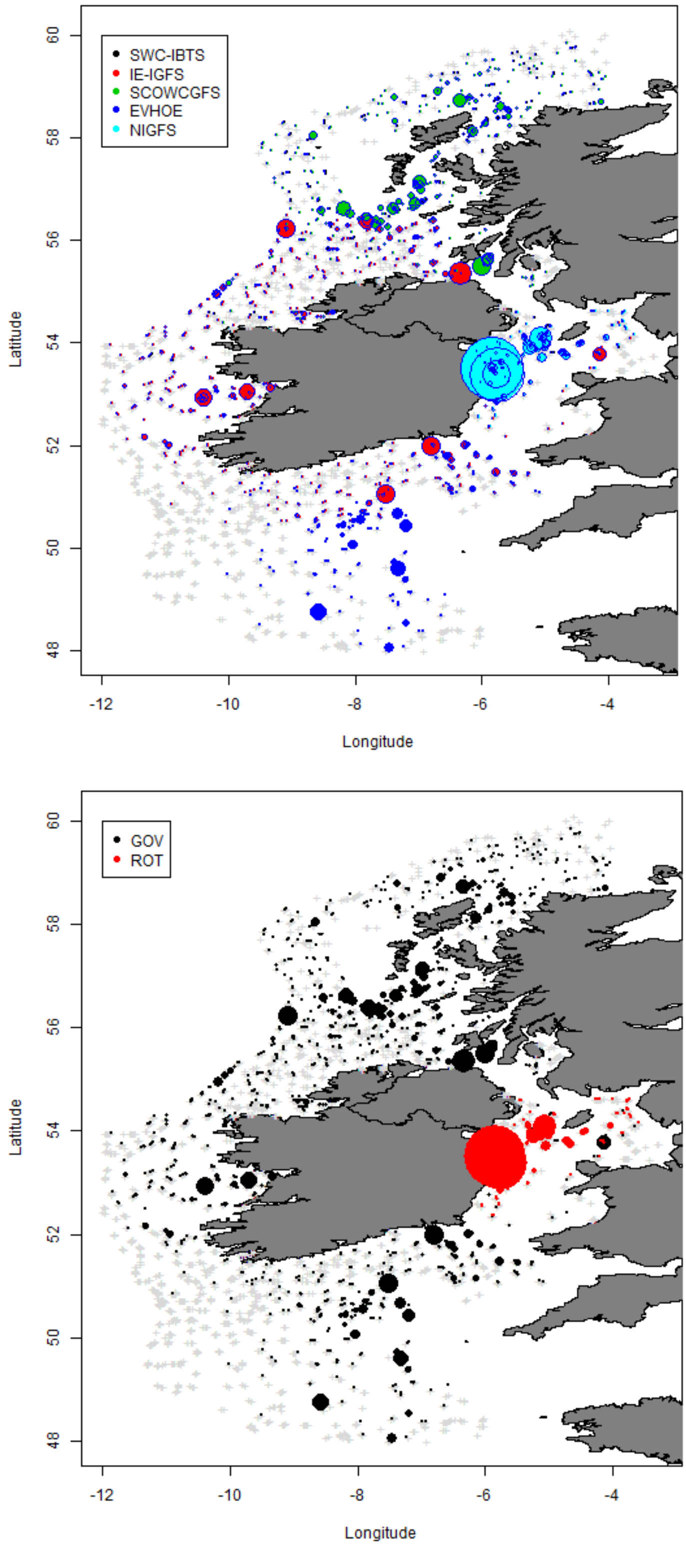


Figure 9. Northeast Atlantic spurdog. Quarter 4 survey data. Spatial distribution of total catch (in weight) by survey (left) and by gear (right) (all hauls 2003-2019). Bubble size proportional to total catch. Pale grey crosses indicate zero values.

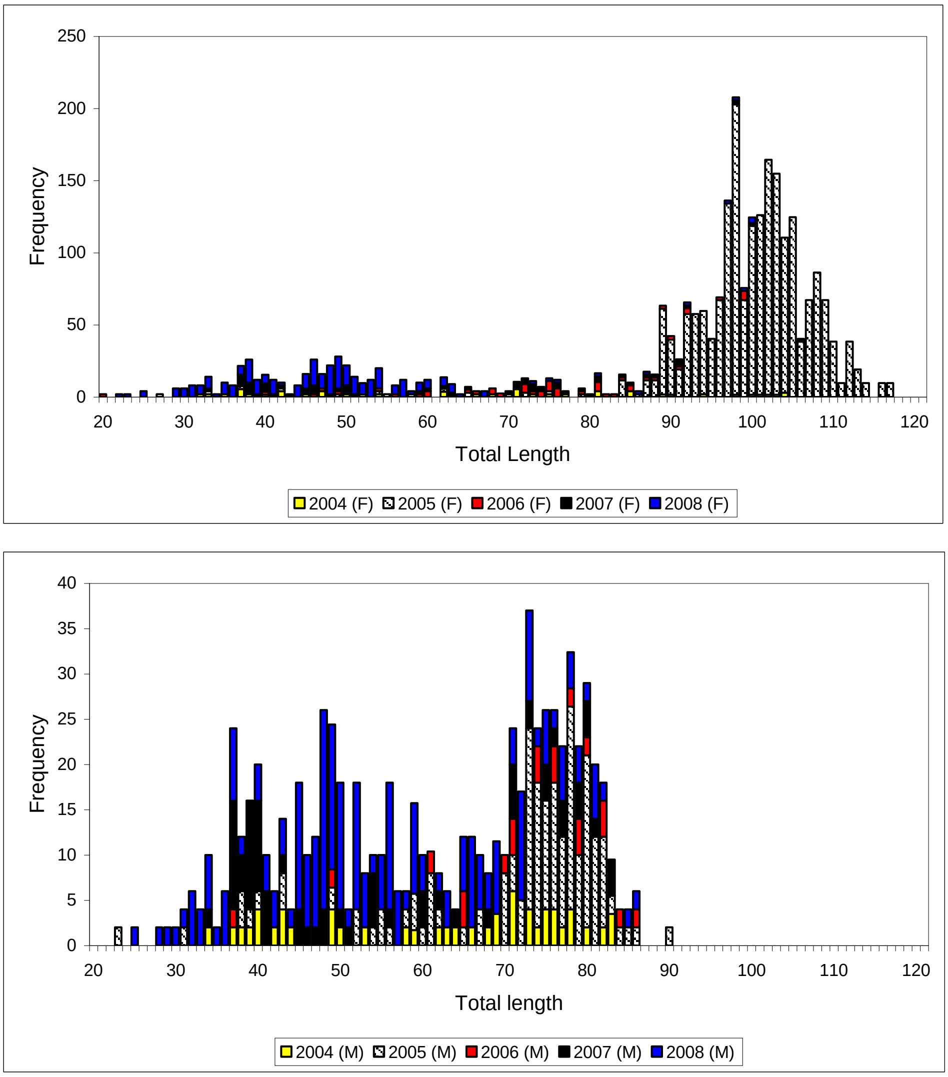


Figure 10. Northeast Atlantic spurdog. Temporal variations in length frequencies of female (top) and male (bottom) spurdog in UK (E&W) Q4 survey.

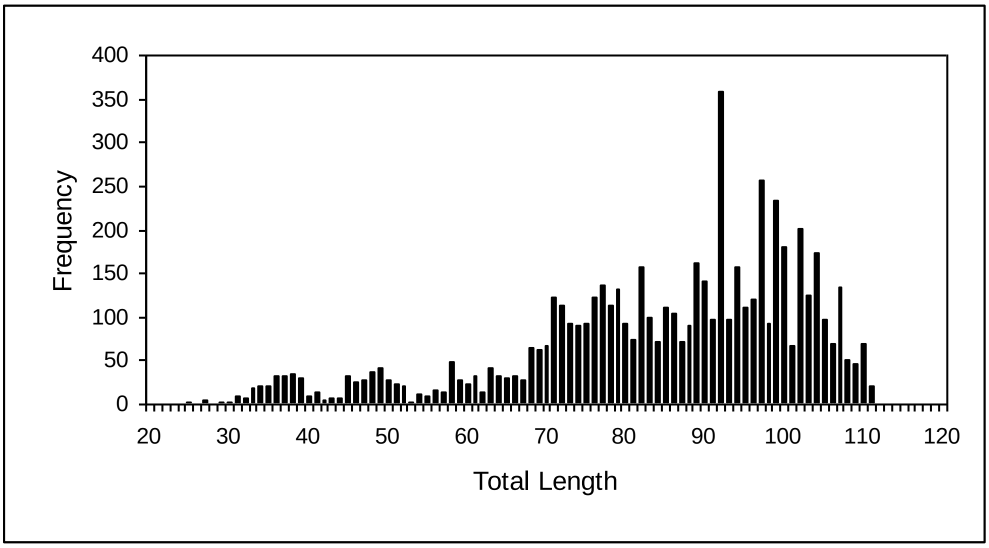


Figure 11. Northeast Atlantic spurdog. Length frequencies of spurdog in UK (NI) GFS Q4 survey 1992–2008.

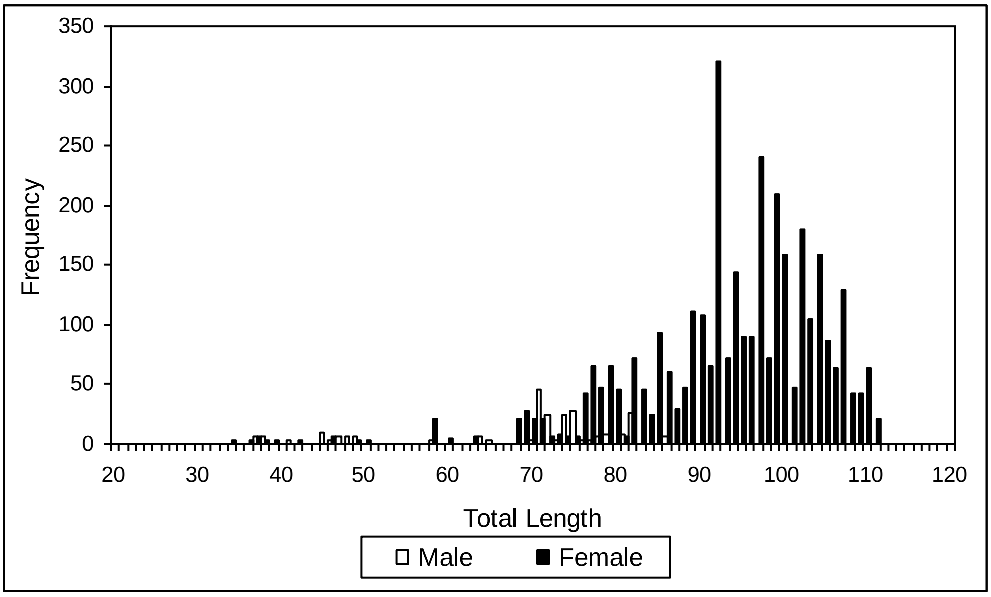


Figure 12. Northeast Atlantic spurdog Sex segregated length frequencies of spurdog in UK (NI) GFS Q4 survey 2006–2008.

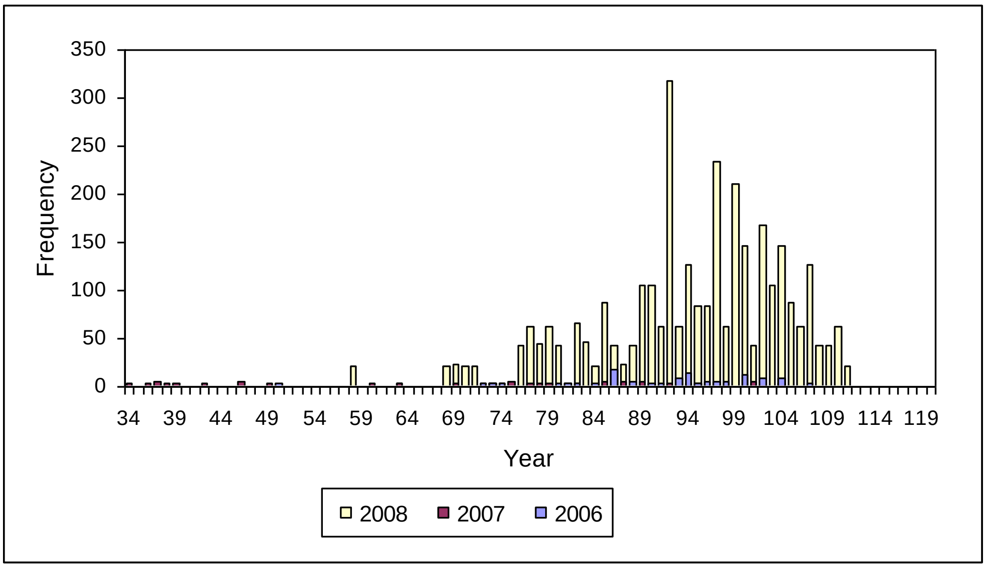


Figure 13. Northeast Atlantic spurdog. Length frequencies of female spurdog in UK (NI) GFS Q4 survey 2006–2008. Dominance of large females observed in 2008 influenced by single large haul.

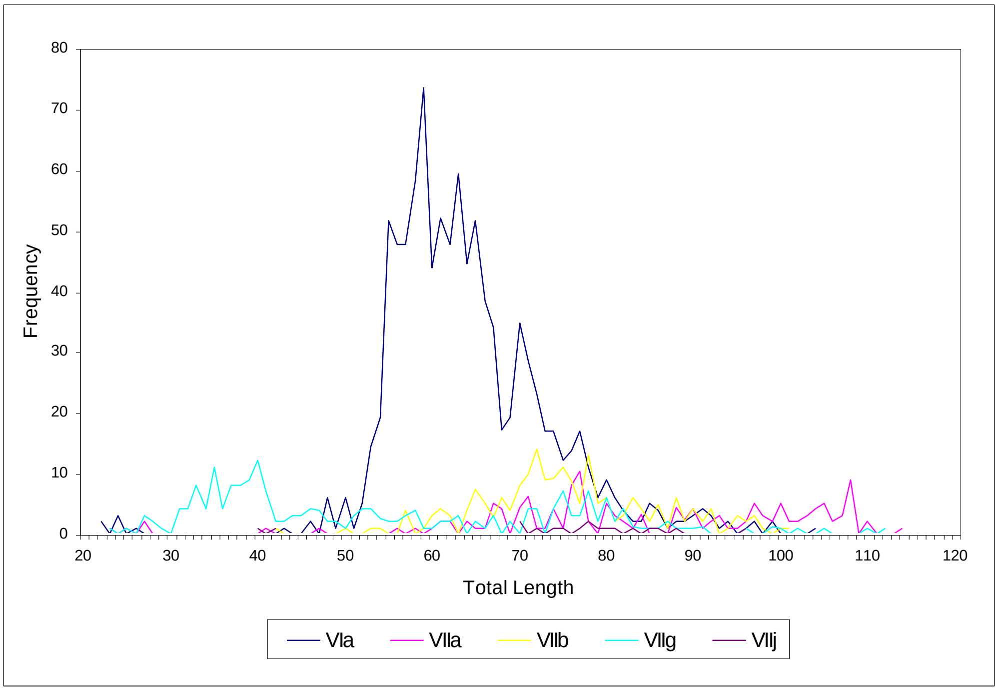


Figure 14. Northeast Atlantic spurdog. Variation in length frequencies of spurdog by region generated from MI GFS Q3 survey.

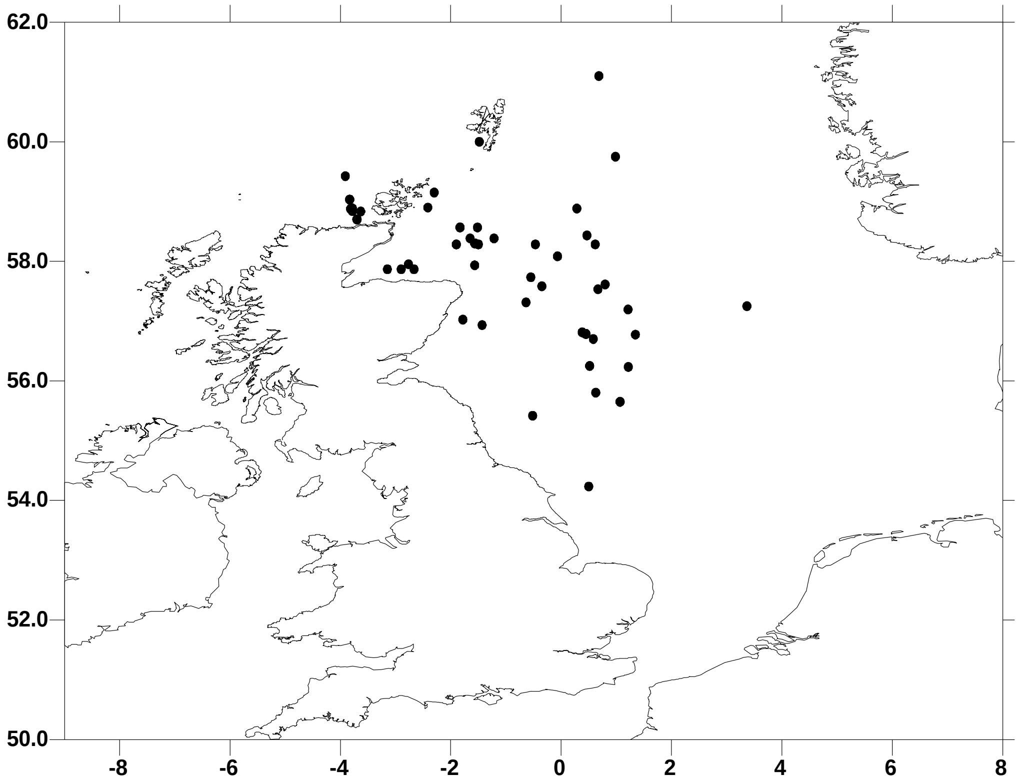
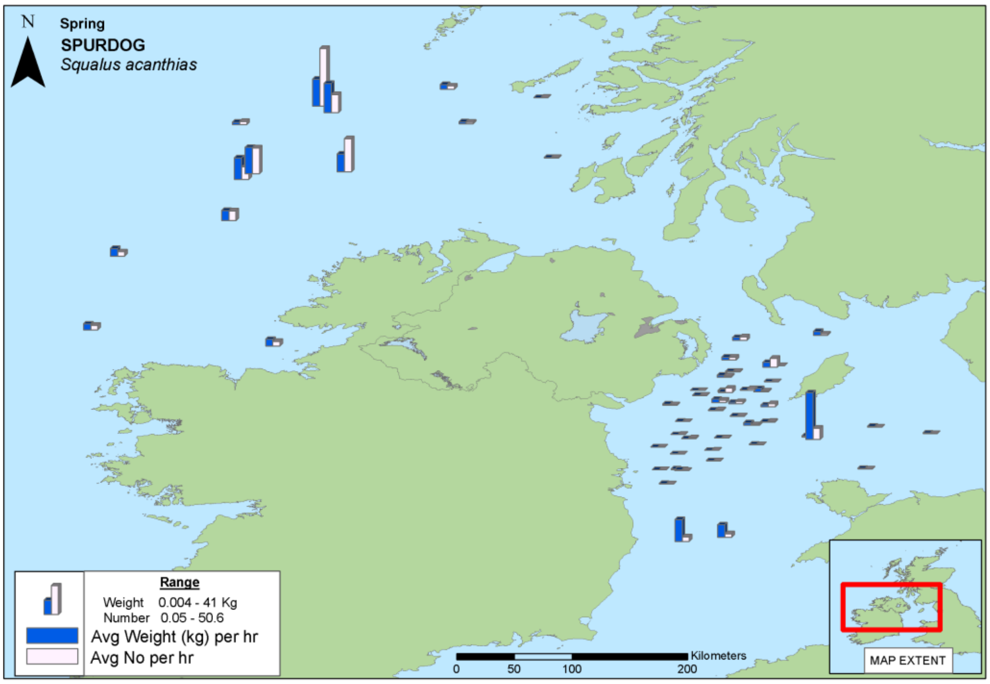


Figure 15. Northeast Atlantic spurdog. Occurrence of spurdog pups (ind. ≤250 mm) in North Sea (Source of dta: DATRAS, downloaded 25 June 2009).



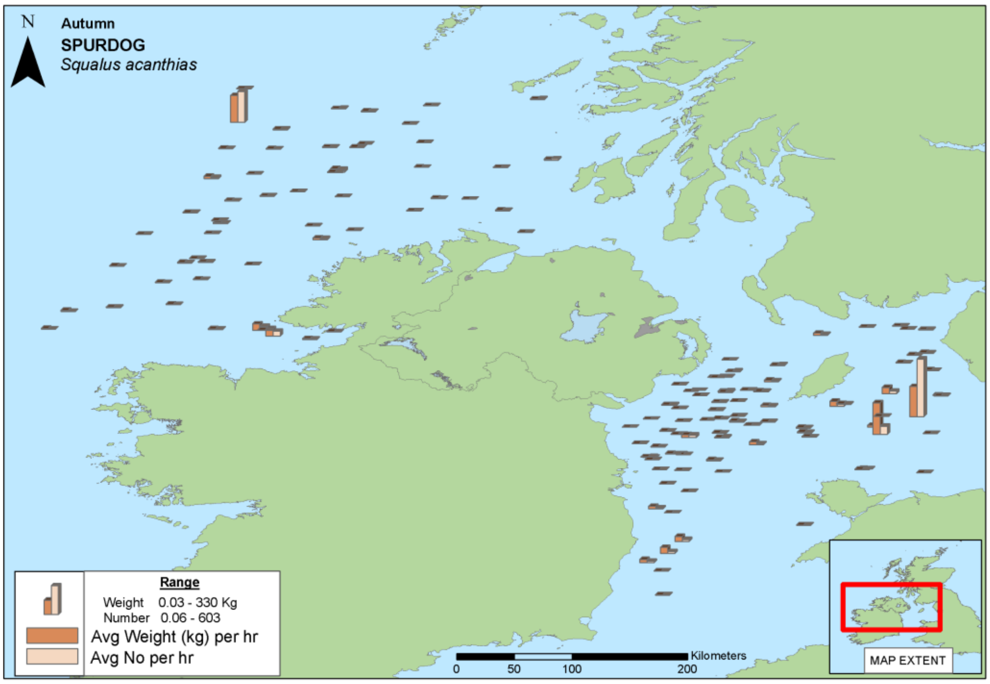


Figure 16. Northeast Atlantic spurdog. Seasonal distribution, average abundance (No. per hr.) and average weight (Kg per hr) of spurdog *Squalus acanthias* in 7.a(N) and 6.a(S) as estimated from research surveys (see NIEA. 2008).

1 Appendix 1 2011 Benchmark Review comments and responses (taken from ICES 2011a)

This appendix documents the comments made by the two external reviewers of the 2010 Spurdog model and assessment. It also includes how these comments were addressed by WGEF 2011.

Review 1

Let me begin by thanking you for the opportunity to review and comment on the assessment methodology for the Inter Benchmark Protocol Review for Northeast Atlantic spurdog. My overall impressions are that the methodology is sound, modern and appropriately applied. The working group has carefully considered the available data and appears to have crafted a synthetic model that appropriately handles the major sources of uncertainty in the data. The model also appears to capture the salient stock dynamics since 1905 although the model results are highly sensitive to several parameters. The WGEF has explored many of these uncertainties using profile likelihood methods. The WGEF is well aware of the weaknesses of the assessment, weaknesses that are driven primarily by the underlying data gaps, rather than the appropriateness of the model. There is a common tendency for reviewers to belabour obvious data gaps, to question the many necessary decisions for model application, and to request information about the model that may have been provided in an earlier version but subsequently was excluded (often because earlier reviewers suggested it was not necessary). Having sat on the other side of the review process for many years, I will try to restrain these tendencies and press only for the most critical issues.

The primary basis for this review was the ICES WGEF Report 2010 (ICES 2010). The De Oliveira *et al.* (2010) paper and Spurdog stock Annex 2010 were also reviewed but the WGEF report appears to include most of the relevant documentation on methodology. Unless otherwise specified, my references will be to the WGEF report.

Data Issues

Commercial landings and discards

Overall, the available data for landings, discards and fishery independent surveys are incomplete and variable in quality. One of the primary strengths of this assessment is a long time series of landings. The derivation of the overall time series (Table 2.1) and the overall two fleet series (Table 2.6) appears to have required a fair number of assumptions to disaggregate landings by Scottish and England/Wales fisheries. The hindcast of landings from 1905 to 1979 based on the ratio from 1980-1984 is necessary but probably has little influence on the results. The commentary in section 2.2.6 is instructive as it suggests potential biases in the series. The implementation of more stringent management measures since 2001 are likely to have changed fishing patterns and induced more discarding. The paucity of discard information is a problem for gauging the efficacy of management measures and assessing stock status. In US fisheries since 2000, the discards of spiny dogfish often exceeded landings during the period when target quotas and individual trip limits were set at very low values. It would be highly desirable to increase the observer sampling coverage in fleets that catch spurdog, particularly as the stock and fishermen respond to lower TACs.

The WGEF does not appear to have estimated total discards. The text implies that discarding patterns have probably changed so it may not be prudent to hindcast trends to earlier data. However, the discards could have important scaling implication for overall stock size, particularly in recent years. Additional investigation of any historical data sources may be warranted[R1.1].

Commercial length frequencies

It is unfortunate that the Scottish and UK size frequencies cannot be strictly compared owing to the absence of raising factors for the UK fleet. At face value these differences suggest a much different force of mortality between the fleets, a factor that must have been instrumental in the decision to model each country's landings separately in the model.

The large fraction of fish above 100 cm and overall size frequency is not consistent with a heavily exploited stock, particularly if such patterns had consisted for several decades prior to the late 1990s. The size composition of the landed females in the UK looks similar to the pre-exploitation size frequency distribution in the US. The Scottish fleet size frequencies however are more consistent with expected patterns for a moderately exploited stock. As noted in the text, this unusual pattern may be the artifact of a single large tow. I would strongly recommend that the WGEF attempt to resolve this influence and develop appropriately weighted size frequencies for the UK landings[R1.2].

The absence of length frequency samples from other countries should be addressed if possible. Similarly, differences among gears and seasonal variations in availability may have important implications for harvesting. In the US large female dogfish are seasonally available to near-shore fisheries. Reliance on such data alone can give a distorted picture of the size and sex composition of the landings and the resource as a whole[R1.3].

Fishery independent surveys

Thirteen separate surveys are listed in 2.5.1 and it appears that 8 are still ongoing. The stock Annex did not provide any additional information (perhaps I missed it) but it would be appropriate to ensure that all surveys identify by sex and develop size frequencies. I am not familiar with the details of these surveys but I presume they are design-based, with random allocation of stations within strata, or perhaps a systematic design[R1.4]. As in the commercial size frequencies the WGEF notes the dominant influence of single tows (Fig. 2.5 and 2.7). Dogfish/spurdog do segregate by size and sex so it would be useful to look at the patterns without the extreme tows[R1.5]. The populations near Scotland are similar in size and sex composition to those near Nova Scotia.

The GLM analyses of the Scottish sea indices are important (Fig. 2.14-2.15). Was a similar analysis done (and is it appropriate) for the North Sea IBTS (Fig. 2.11)[R1.6]?

It is unfortunate that there are no surveys or size composition information between 1952 and 1975. The removals were consistent over an extraordinarily long period, so even a snap shot of the historic pattern would be interesting[R1.7].

Life History Comments

I agree with the statements regarding the overall stock structure in the NE (Sec 2.1) and the other justification in the Stock Annex. Over interpretation of tagging data that fails to distinguish differences in fishing mortality, time at large, and reporting rates, often leads to inappropriately defined "stocks".

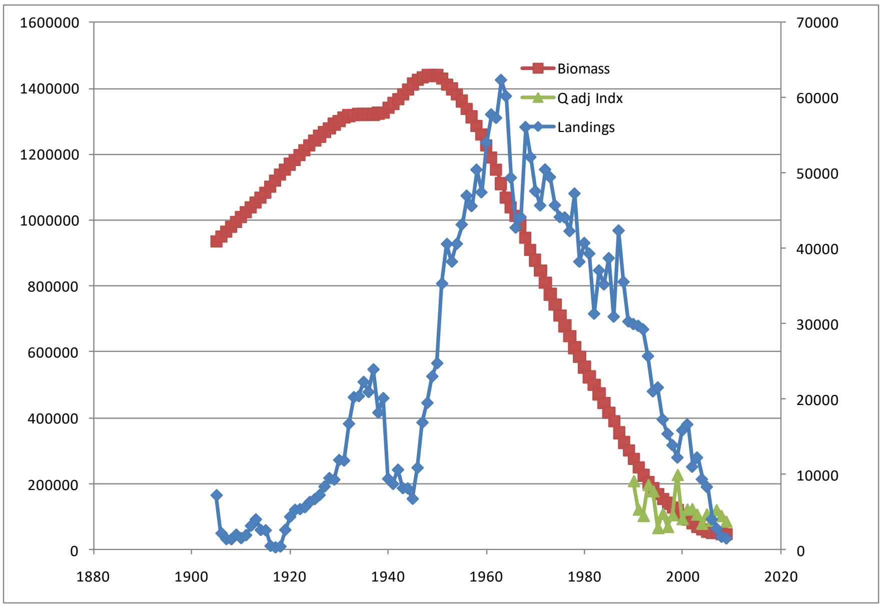
Table 2.5 and Eq. 2.7: The Mpup estimate is based on a Leslie matrix model with an eigen value of one. However no values are reported. In Fig. 2.16 it appears that Mpup is about 0.7. For spiny dogfish I have estimated a similar value of ~0.4[R1.8]. I see that that your proportion of females pregnant caps at 0.5. I presume this aliases the 2-yr gestation time and effectively puts half of the females "off line" in any given year[R1.9]. In table 2.5 I was not sure what the ln(19) means in the equation for Pa''[R1.10]

There may be a labelling problem in Fig. 2.21b: the solid line doesn't seem to go with the open triangles nor is there agreement with Fig 2.21a[R1.11].

Given the foregoing comments on the size composition of commercial landings and surveys, it would be useful to generate some expected size frequencies based on a length-based equilibrium life history model. I realize the assessment model uses 4 bins but the upper bin may be obscuring information related to size-selective mortality[R1.12].

Modelling Concerns

Overall this implementation of the Punt and Walker model seems appropriate and well executed. As a quick heuristic check I did a simple 3 parameter (B(0), r, q) mass balance model using the 1905-2009 landings (table 2.6) and tuned it to 1990-2009 GLM indices for the Scottish survey (Table 2.7) . The model was B(t+1)= rB(t)-C(t) with B(t)=q I(t). I got an initial biomass of 943,933 mt and a q of 0.000811. This contrasts with the base model estimates of about 1.6 M mt (Fig. 2.25) and q=0.000923. My "r" parameter was 1.016903. At any rate it convinced me that the model scale was appropriate and it looks similar to the Qfec=3.98 plot.



The WGEF model appears to incorporate a manageable degree of complexity. The density dependent formulation pup reproduction is indeed useful and provides a useful control variable for analyzing model behaviour (eg. Fig. 2.17 and 2.27a, 2.27b) . The WG insights into the confounding of parameters was appreciated as it reduces fruitless searching of parameter space. It would be useful to plot the Qy and Npup,y outputs over time to get a better handle on the density dependent process[R1.13].

The time trend in Fig. 2.23 is probably consistent except near the origin. What is the reason for the sharp change in slope when Nfpreg is about 40,000[R1.14]?

The premise of a virgin stock in 1905 is a strong assumption but reasonable. My linear model has the population increase to about 1.44 M mt by 1949. The WGEF model has a higher initial condition, and controls population size via a more realistic stock recruitment process.

I'm not sure if I understand the derived survey and commercial selectivity patterns. The strong domes for both above 15 yr (Fig. 2.22, Fig. 2.28a) seem odd for a species such as spurdog. Is there any hypothesis for this effect? Mature females do seem to be absent from the Scottish survey but not in the IBTS. Is the low selectivity aliasing movement out of the survey area[R1.15]. Was there any sensitivity analyses to the fixing the selectivity to 1 for the oldest ages. If selectivity for fish above 85 cm is set to one in Eq 2.5a then can selectivity exceed one for smaller size groups, resulting in an $S_{com,j,a}$ that is less than one for 85 cm and up in Eq 2.5b[R1.16].

All of the model implementation details and construction of the likelihood functions seem appropriate. The WG seems to have chosen an appropriate set of sensitivity analysis scenarios for consideration. The model does not have much of a retrospective pattern but this may because there is not too much data to disagree with in Tables 2.7, and 2.8. The size comp info in Table 2.9 is not affected by the truncation and there is not much trend in the last 5 years of data in Tables 2.7 and 2.8.

In summary, spurdogs are a complicated species to model. Differences in growth, maturation, and distribution of males and females are important for understanding the dynamics of this species. The WG has chosen a reasonably compact set of parameters to describe the population. The approach is consistent with some severe data limitations, well acknowledged in Section 2.9. One major concern would be the importance of the dome-shaped selectivity patterns on the assessment. These are particularly important when applying the contemporary selectivity to the historic data. It could severely overestimate the historic abundance and therefore exaggerate the estimated decline[R1.17].

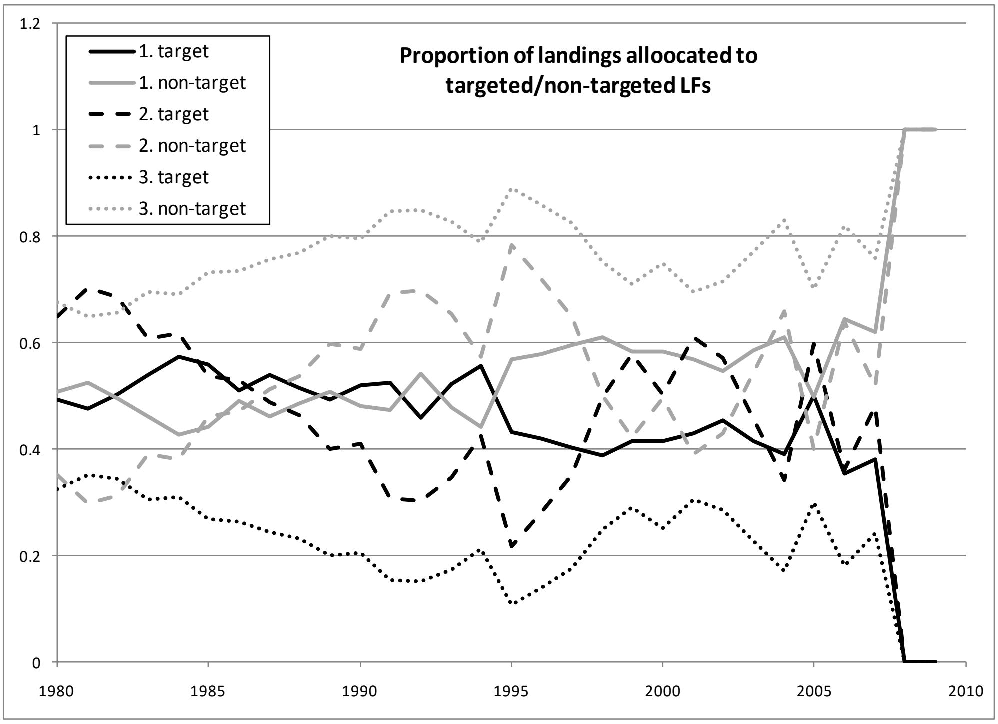
Thank you again for the opportunity to comment.

Response to comments by Reviewer 1:

R1.1. Discarding patterns are thought to have changed since the introduction of restrictive management measures in the North Sea (from 2007) and elsewhere (from 2008). There are limited discard data available, but these have not been considered sufficiently representative to be raised up to fleet level and therefore are not included in the assessment. However, it is acknowledged that an appraisal of recent discarding (of dead fish) is required to get improved estimates of recent removals from the stock (following the introduction of the more restrictive management measures). Information on discard survival is very limited for this species.

R1.2. Due to the lack of appropriate raising procedures, commercial length frequencies for England and Wales (E&W) are thought to be heavily biased towards targeted fisheries. The approached used up until now was to simply raise all E&W landings to these length frequencies, and to use this together with the Scottish length frequencies to raise the remaining landings (total minus E&W and Scotland) in proportion to the E&W-Scottish split in the landings.

In order to address some of the concerns expressed by the reviewer, raising is instead performed by defining target and non-target fisheries, where the E&W length frequency is considered to represent a target fishery (i.e. for larger fish, particularly the female component of the stock), and the Scottish data representing a non-target fishery. An analysis of the E&W landings for the period for which E&W length frequencies were available (1983-2001) indicated that approximately half the E&W landings were by target fisheries (lines, and part of the gillnet catch), so only half the E&W landings are raised by the targeted LF, and the remainder by the non-targeted LF for the period 1980-2007. All the Scottish landings are considered non-target for the period 1980-2007. Considering the period 1980-2007, landings for all remaining nations apart from Denmark, France, Ireland, Norway and Sweden are considered non-target. Landings for France and Sweden are treated in the same way as E&W (half target, half non-target), while landings for Norway are treated as exclusively targeted (as they are known to have targeted spurdog, and their national minimum landing size would also have resulted in proportionally more large fish being landed). Landings for Denmark are treated in the same way as E&W until 1992, then as exclusively non-target from 1993, while landings for Ireland are considered exclusively targeted from 1982-2005, and non-target outside this period. In order to provide a third alternative to what is proposed above (option 1) and what has been used until now (option 2), option 3 is similar to option 2, except that only half the E&W landings are allocated the E&W LF, with the remainder allocated the Scottish LF. The remaining landings are then allocated LFs in proportion to the E&W and Scottish landings associated with the E&W and Scottish LFs, skewing the LFs towards non-target fisheries compared to option 2. For 2008 onwards, all options assume a non-target selection. The figure below illustrates the three options considered, with option 1 adopted as the baseline.



R1.3. This is partly addressed by R1.2. The WG has been unable to obtain historic length frequency samples from other countries.

R1.4 All the existing trawl surveys considered by WGEF are internationally-coordinated through the ICES International Bottom Trawl Survey Working Group (IBTSWG). The descriptions of the surveys, in terms of the gears and sampling grids, are described in the reports of the IBTSWG and in the survey manuals (see http://datras.ices.dk/Documents/Manuals/Manuals.aspx). Some surveys have been discontinued, and have not been included in the model, and several other surveys in the western IBTS are of too short a time series for inclusion at the present time (although these surveys catch spurdog relatively frequently and may so provide useful abundance trends in the future). Further studies of North Sea IBTS and the UK (Northern Ireland) surveys of the Irish Sea need to be undertaken. Some surveys have not consistently provided sex-disaggregated information.

R1.5. In order to reduce the dominant influence of the occasional tows with large numbers of spurdog, the WG has recalculated the length frequencies by using the same area stratification that was used for the delta-lognormal GLM standardisation of the survey abundance indices. Numbers by length category and sex are summed across stations within each stratum and the proportions by length category and sex calculated; these are then averaged across all strata each year. Those strata that result in fewer than 100 dogfish being available over all years for a particular survey are ignored in this analysis.

R1.6. Although the survey data used to derive the abundance index for the assessment model covers some of the major areas of spurdog stock distribution (central/northern North Sea – a subset of the N Sea IBTS, and west of Scotland), the WG agrees that it would be useful to extend the analysis to other surveys in the future. This would require all relevant survey data to be collated ahead of the WG.

R1.7. Some historical survey information is available, but is not always available electronically. Additionally, as spurdog were not considered an important commercial species in the first part of the 20th century, catches were sometimes recorded using qualitative descriptors and/or fish were not regularly measured in early surveys. Tagging studies were undertaken in the 1960's, but recorded data from such surveys may be skewed towards larger fish. Given the issues of temporal differences in size composition, gear selectivity and potential bias in some surveys, these data may not be useful for use in the assessment, although it is acknowledged that they could provide a useful snapshot.

R1.8. M_{pup} is effectively a model estimate that is dependent on the estimates of the fecundity parameters a_{fec} and b_{fec}; the estimate for this year's assessment is 0.76, and is included in new Table 2.11b along with other parameters of interest (e.g. MSY parameters).

R1.9 . This is the correct interpretation – an appropriate note is now included in the relevant table.

R1.10 . The ln(19) is a constant usually included in the formulation of a sigmoid curve to ensure that the curve is at 95% of its maximum for the relevant value on the x-axis (in this case for ℓ^{f}_{mat95}). This is a standard formulation, so should not require further explanation.

R1.11 . This problem has arisen due to formatting issues within ICES when converting word documents to pdf. In this case, the figures did not convert properly, leading to the interpretation problems noted by the reviewer.

R1.12. Splitting the 85+ length category any further would not be possible for the surveys and for the Scottish commercial fleet, due to the already low numbers in this category. It may be possible for the England and Wales commercial fleet, but this has not been attempted. The suggestion of comparison with expected size frequencies from a length-based equilibrium life history model has not yet been attempted, but is one the WG should attempt in future.

R1.13. Figure 2.23b, now included in the report, shows the plot requested.

R1.14 This sharp change can also be seen in the estimates of recruitment shown in Figure 2.20 of the report. This reflects the recruitment needed to fit the length frequency patterns seen in the proportions by length category data from the commercial fleets, and later also from the surveys. Appropriate comments can be inserted into the report to this effect.

R1.15. That females are not taken in the Scottish western IBTS is thought to be due to the low spatial overlap between this component of the stock and the survey stations. Mature females have been caught in surveys of coastal waters of VIIa in Q4, and might also occur in coastal waters (e.g. sea lochs) in VIa.

R1.16. Selectivity parameters are estimated for each of the length categories except for the category with the highest selection (Eq 2.5b). Forcing flat-topped selection will lead to model misspecification for the fit to the Scottish commercial proportions by length category data, particularly because flat-topped selection is estimated (not forced) for the England and Wales length-category data (note that L_∞ for males < the largest length category).

R1.17 . See R1.16 and R1.15. Furthermore, Figure 2.28b (ICES 2010) explored sensitivity to historic selection and found limited sensitivity to this alternative assumptions. This is explored further in the report this year, and again finds that results are relatively insensitive to alternative targeting scenarios.

Review 2

1 Summary

My personal opinion is that there is strong evidence that spurdog is over exploited, and that a main issue is how well can the recovery plan be monitored. In addition there are likely to be valuable lessons for other shark species and data poor stocks from the assessment.

Management advice is that "Targeted fisheries should not be permitted to continue, and bycatch in mixed fisheries should be reduced to the lowest possible level. The TAC should cover all areas where spurdog are caught in the Northeast Atlantic and should be set at zero." Therefore lack of data, particularly of discards, and biases due to changes in fishing behaviour in response to management are a problem for the main stock assessment model that relies on commercial catch and effort data[R2.1].

I have tried to keep to the same structure as [Reviewer 1's] review, in order to make it easier to combine our comments into a single document, if desired. I also agree with his main points "that the methodology is sound, modern and appropriately applied" and that "paucity of discard information is a problem for gauging the efficacy of management measures and assessing stock status". However, I would go further in that the main problem is not a stock assessment problem, but a problem related to data, management and knowledge of spurdog biology.

I also think that further studies of the commercial length frequencies should be conducted and agree that "the absence of raising factors for the UK fleet" and "length frequency samples from some countries" are problems that should be addressed. Size data could provide important insights into changes in and differences between targeting by fisheries, and could also be used to develop indicators of population abundance and exploitation level.

2 Data

Data such as catch and effort, catch-at-size and survey data are available. However, since spurdog is a bycaught species problems exist due to historical mis-reporting and because estimates of total discards are not routinely available.

2.1 Catch Per Unit Effort

The assessment benefits from the availability of survey data. The diagnostics however could have included plots of

- the standardised deviance residuals against the fitted values to check for systematic departures from the assumptions underlying the error distribution
- the dependent variable against the linear predictor function as a check of the assumed link function[R2.2].

See Ortiz and Arocha (2004)

A standardisation exercise as conducted for CPUE would be very useful in order to evaluate factors affecting catch-at-size.

3 Life History

The assumptions about life history characteristics and behaviour of spurdog are very important. For example population segregation and aggregation of mature (especially pregnant) females can make some shark species highly vulnerable to fisheries particularly when stocks are seriously depleted. Also the population structure of catches appear to vary greatly in time and space. Therefore successful management needs to consider how the biology can impact on the assessment and management.

Although the Stock Annex is referred to a lot, I only found a template not the data[R2.3].

4 Modelling

The main assessment method is based on sound methodology that has been used both in Australia for sharks and the IWC for cetaceans. It is an age- and sex-structured model that also includes the biology, i.e. length-based, maturation, pup-production and growth processes. It is therefore more able to incorporate biological process, important for providing advice on sustainability. However, including more processes also requires better data and knowledge. Otherwise uncertainty can actually increase compared to a simpler model.

Assessments using simpler methods are becoming increasingly important for monitoring and management. For example for longer-lived species a truncated size composition, with only a small percentage of mature fish, can be an indication of overfishing. Shark species are increasingly attracting interest from a range of stakeholders and data rather than assessment-based rules may be a step towards opening up the debate to such stakeholders. Therefore the data and simpler model-based approaches should be investigated to see if they could provide indicators of stock status. It is also likely that such methods would be of use for many other ICES stocks[R2.4].

A variety of indicators have been proposed to monitor stocks, e.g. mean size. Punt *et al*. (2001) in a study of various indicators showed that those based on the mean length or mean weight of the catch perform better, because these quantities change in a more predictable manner with abundance than CPUE. I would have liked a range of indicators based on the data to have been considered. Not only would this have been a check of the assessment model used it would help validate such approaches for other stocks considered by WGEF[R2.5].

This could be used in the future as part of an adaptive management plan. For example where the current management plan is kept in place until a positive signal is seen in an appropriate indicator. Such an adaptive management plan would first have to be evaluated using Management Strategey Evaluation to ensure that the indicator tracked population size give uncertainty about the dynamics, ability to implement management measures and to monitor fisheries and populations. The various assessment runs already provide a set of robustness trials that could be the basis of such an exercise. The results from such an exercise would have potentially important benefits for many stocks. Particularly since use of complex assessment methods for "data-rich" stocks don't appear to be correlated with sustainability[R2.6].

5 Reference points

I agree strongly with

"As with any stock assessment model, the exploratory assessment relies heavily on the underlying assumptions, particularly with regard to life-history parameters (e.g. natural mortality and growth), and on the quality and appropriateness of input data. The inclusion of two periods of fecundity data has provided valuable information that allows estimation of Qfec, and projecting the model back in time is needed to allow the 1960 fecundity data set to be fitted. Nevertheless, the likelihood surface does not have a well-defined optimum, and additional information, such as on appropriate values of MSYR for a species such as spurdog, would help with this problem. Furthermore, the change in selection for the Scottish survey data around 2000 is currently unexplained and needs further investigation. Further refinements of the model are possible, such as including variation in growth. Selectivity curves also cover a range of gears over the entire catch history, and more appropriate assumptions (depending on available data) could be considered."

However, the only reference point quoted is a single point estimate of F_{MSY}. Biomass and yield reference points should also be calculated and estimates of uncertainty provided. Such estimates should include both estimation error (e.g. CVs) but also uncertainty due to lack of knowledge. This can be done based on the various scenarios that were run. The biomass and yield reference points should also be compared to the historical time series. However in my opinion MSY based reference points are less relevant to this stock than conservation reference points. Also reference points mainly make sense within a management framework. In this case to monitor the recovery of the stock, e.g. what is the reference point which would cause a non-zero TAC to be set?[R2.7]

I also agree with "Improved estimates for biological data (e.g. growth parameters, reproductive biology and natural mortality); information on likely values of MSYR for a species such as spurdog". This is just as true for all stocks assessed by ICES, as it attempts to provide advice on MSY since there is a marked difference between providing advice under the ICES PA framework, which mainly related to collapsed and recovering stocks, compared to providing advice for a stock being managed to MSY. In the former case recovery mainly depends upon the luck of recruitment and reducing effort. However as ICES move into MSY based management, the underlying assumptions about stock dynamics play an increasingly important role in the development of appropriate targets.

Response to comments by Reviewer 2:

R2.1 . The assessment model relies on a combined survey index of abundance derived from Scottish groundfish surveys, not on commercial CPUE.

R2.2 Diagnostic plots including the suggested figures were included in Figure 2.15. Further residual plots are included in this year's report.

R2.3. All the data used in the assessment were given in the report itself.

R2.4 . We agree that alternative indicators of stock status, based on data and simpler model-based approaches would merit further investigation; it would be useful to consider this in a context wider than just spurdog (as it may also have applications for developing metrics under the Marine Strategy Framework Directive), and in a framework that would allow simulation testing of these indicators to evaluate their utility for management; such a study is currently beyond the focus of WGEF (see also R2.5 and R2.6).

R2.5 . Given the aggregating nature of spurdog (and some other elasmobranchs), whereby surveys may happen to sample either a large aggregation of juveniles or adult fish in any given year, simple metrics of 'mean size' or the 'proportion of mature fish' may be highly variable and not indicative of wider stock status (see Section 11 of ICES 2011b). Hence, further exploratory investigations on methods to derive simpler metrics that are representative of stock status are still required.

R2.6 . We agree that Management Strategy Evaluation would provide the appropriate framework for evaluating indicators of stock status; developing such an MSE framework is time consuming and currently beyond the focus of WGEF.

R2.7 . The development of appropriate reference points is the next area of development for spurdog, having just undergone a benchmark assessment. This could feed into the development of a management plan for the stock.

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