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

Working Group: Working Group on Elasmobranch Fishes (WGEF)

Created:

Authors:

Last updated:

Last updated by:

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.

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 nation's 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 *Squalida*e 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.

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.

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.

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.

Raw market sampling data were also provided by Scotland for the years 2005–2008. However, sampled numbers have been low in recent years (due to low landings) and use of these data was not pursued.

Discard length compositions

There are no international estimates of discard length frequencies.

Discard length frequencies have previously 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.

Quality of data

Length frequency samples are only available for UK landings and these are aggregated into broader length categories and have been used in the previously presented assessments. No data were available from Norway, France or Ireland who are the other main exploiters of this stock. Over the past 20 years, UK landings have on average accounted for approximately 45% of the total. However, there has been a systematic decline in this proportion since 2005 and the UK landings in 2008 represented less than 20% of the total. It is not known to what extent the available commercial length–frequency samples are representative of the catches by these other nations.

Commercial catch–effort data

No studies of commercial cpue data have been undertaken.

Fishery–independent information

Availability of survey data

Fishery-independent survey data are available for most regions within the stock area. The following survey data are available to this group:

UK (England & Wales) Q1 Celtic Sea groundfish survey: years 1982–2002.

UK (England & Wales) Q4 Celtic Sea groundfish survey: years 1983–1988.

UK (England & Wales) Q3 North Sea groundfish survey 1977–2009.

UK (England & Wales) Q4 SWIBTS survey 2004–2009 in the Irish and Celtic Seas.

UK (NI) Q1 Irish Sea groundfish survey 1992–2009.

UK (NI) Q4 Irish Sea groundfish survey 1992–2009.

Scottish Q1 west coast groundfish survey: years 1990–2009.

Scottish Q4 west coast groundfish survey: years 1990–2009.

Scottish Q1 North Sea groundfish survey: years 1990–2009.

Scottish Q3 North Sea groundfish survey: years 1990–2009.

Irish Q3 Celtic Seas groundfish survey: years 2003–2009.

Both Ireland and UK (England and Wales) now participate in the fourth quarter westerly IBTS surveys, and further studies of these data will be undertaken in 2010.

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 3 and 4), with catch rates also decreasing, although catch rates are highly variable (ICES, 2006).

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 5).

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 6), although sex disaggregated data are only available since 2006 (Figure 7–8). A large haul of predominantly large females was caught in 2008 which has influenced the pattern of the length frequencies from this survey (Figure 8).

Length frequencies generated from the Irish Q3 GFS survey suggest spatial as well as temporal variation in the size distributions (Figure 9). 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.

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 10).

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 11).

Biological parameters

Life-history information

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.*, 2001), 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 (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.

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).

The WG has assumed a linear relationship between fecundity (F) and total length (L):

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).

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).

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.

Data exploration and preliminary modelling

At the 2006 WG meeting, an analysis of Scottish survey data was presented which investigated methods of standardizing the survey catch rate to obtain an appropriate index of abundance. Following on from this, and the subsequent comments of the most recent Review Group, further analysis was conducted in 2009. The major concern was that given the large differences in size for this species, an index of abundance in Nhr^{-1} was less informative than an index of biomass catch rates. The analysis was updated at the WG in 2009 to address these concerns.

Data from four Scottish surveys listed above (1990–2009) were considered in the analysis (Rockall was not included due to the very low numbers of individuals caught in this survey). The dataset consists of length frequency distributions at each trawl station, together with the associated information on gear type, haul time, depth, duration and location. Each survey dataset used in this analysis contains over 1000 hauls and the North Sea Q3 contains over 1500. For each haul station, catch-rate was calculated: total weight caught divided by the haul duration to obtain a measure of catch-per-unit effort in terms of g/30 min.

The objective of the analysis was to obtain standardized annual indices of cpue (on which an index of relative abundance can be based) by identifying explanatory variables which help explain the variation in catch-rate which is not a consequence of changes in population size. Due to the highly skewed distribution of catch rates and the presence of the large number of zeros, a 'delta' distribution approach was taken to the statistical modelling. Lo *et al.*, 1992 and Stefansson, 1996 describe this method which combines two generalized linear models (GLM): one which models the probability of a positive observation (binomial model) and the second which models the catch rate conditioned on it being positive assuming a lognormal distribution. The overall year effect (annual index) can then be calculated by multiplying the year effects estimated by the two models.

The analysis was conducted in stages: initially each survey was considered separately then the model fitted to all survey data combined. Because the aim was to obtain an index of temporal changes in the cpue, year was always included as a covariate (factor) in the model. Other explanatory variables included were area (Scottish demersal sampling area, see Dobby *et al.*, 2005 for further details) and month and interactions terms were also investigated. Variables which explained greater than 5% of the deviance were retained in the model. All variables were included as categorical variables.

Stock assessment

Introduction

The exploratory assessment for spurdog presented in 2006 (ICES, 2006) has been 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 provides a delta-lognormal GLM-standardised index of abundance (with associated CVs), based on Scottish groundfish surveys. The exploratory assessment assumes 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 uses 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 fits 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 are 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 assumes 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 are 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).

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:

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

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:

$$B_y = \sum_s \sum_a w^s_a N^s_{y,a} \qquad \text{1b}$$

where w^s_a 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:

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

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:

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

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 2.3, is to ensure that if parameters a_{fec} and b_{fec} are estimated, P'_a remains non-negative and the function is differentiable for $l_a^f \geq l_{mat00}^f$.

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:

$$F_{j,y} = \frac{C_{j,y}}{\sum_a e^{-M_a/2} \sum_s w_{a+\frac{1}{2}}^s S_{com,j,a}^s N_{y,a}^s} \qquad 4a$$

where $w_{a+\frac{1}{2}}^s$ is the mid-year mean weight of animals of sex *s* and age *a*, and $S_{com,j,a}^s$ 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:

$$F_{prop5-30,y} = \sum_j \frac{1}{26} \sum_{a=5}^{30} \left[\frac{\sum_s S_{com,j,a}^s N_{y,a}^s (F_{j,y} S_{com,j,a}^s)}{\sum_s S_{com,j,a}^s N_{y,a}^s} \right] \qquad 4b$$

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

$$C_{j,y,a}^s = F_{j,y} S_{com,j,a}^s N_{y,a}^s e^{-M_a/2} \qquad 4c$$

Commercial selectivity

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

$$S_{com,j,a}^{s*} = \begin{cases} S_{c2,j} & 16 \leq l_a^s < 55 \\ S_{c3,j} & 55 \leq l_a^s < 70 \\ S_{c4,j} & 70 \leq l_a^s < 85 \\ 1 & l_a^s \geq 85 \end{cases} \qquad 5a$$

so that:

$$S_{com,j,a}^s = S_{com,j,a}^{s*} / \max_j (S_{com,j,a}^{s*}) \qquad 5b$$

where l_a^s 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*) are estimated in the model.

Survey selectivity

Survey selectivity-at-age $S_{sur,a}^s$ 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 dropped from the above equations) 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 to be estimated (S_{s1}, S_{s2}, S_{s3} and S_{s4}), the first three applying to the smallest length categories (16-31, 32-54 and 55-69), regardless of sex, and the fourth (S_{s4}) 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 2.3), 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:

$$S^{s,mat}_{MSY,a} = \begin{cases} 0 & l^s_a < l^f_{mat00} \\ 1 & l^s_a \geq l^f_{mat00} \end{cases} \tag{8a}$$

However, an estimate of $F_{prop,\mathrm{MSY}}$ 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 $F_{prop,\mathrm{MSY}}$. The selectivity for the second approach is therefore calculated as follows:

$$S^{s,cur}_{MSY,j,a} = \bar{f}_{rat,j}\, S^s_{com,j,a} \tag{8b}$$

where $S^s_{com,j,a}$ is from equation 2.5b, and $\bar{f}_{rat,j}$ is a five-year average as follows:

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

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:

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

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 $\geq l^f_{mat00}$ 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:

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

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

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

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

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

and

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

MSY is found by solving for the F_{mult} value that maximises equation 8g or 8h, and the corresponding $F_{prop,\mathrm{MSY}}$ 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 $F_{prop,\mathrm{MSY}}$.

Likelihood function

Survey abundance index

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

$$-\ln L_{sur} = \tfrac{1}{2}\sum_{y}[\ln(2\pi\sigma^{2}_{sur,y}) + \varepsilon^{2}_{sur,y}] \quad \text{9a}$$

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

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

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

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

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):

$$-\ln L_{pcom,j} = k_{pcom,j}\sum_{y}\sum_{L}\varepsilon_{pcom,j,y,L} \quad \text{10a}$$

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

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

with $n_{pcom,j,y}$ representing the number of samples on which estimates of proportions by length category are based, and $\overline{n}_{pcom,j}$ the corresponding average (over y). Because actual sample sizes were not available for the commercial data (only raised sample sizes), all model runs assumed $n_{pcom,j,y} = \overline{n}_{pcom,j}$, 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 explores alternative assumptions).

Survey proportion-by-length-category

The negative log-likelihood contributions ($-\ln L_{psur}$) for the Scottish survey proportions-by-length category are as for the commercial proportions, except that there is only one survey abundance series (the j index is dropped in the above equations), 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} 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:

$$-\ln L_{fec} = \tfrac{1}{2} \sum_{y=1960;2005} \sum_{k=1}^{K_y} [\ln(2\pi\sigma_{fec}^2) + \varepsilon_{fec,k,y}^2] \qquad \text{11a}$$

where K_y represents the sample sizes for each of the periods (K_{1960}=783, K_{2005}=179), 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:

$$\sigma_{fec} = \sqrt{\frac{\sum_{y=1960;2005} \sum_{k=1}^{K_y} (P'_{k,y} - \hat{P}'_{k,y})^2}{(K_{1960} + K_{2005})}} \qquad \text{11c}$$

Recruitment

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

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

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:

$$-\ln L_{tot} = -\ln L_{sur} - \sum_j \ln L_{pcom,j} - \ln L_{psur} - \ln L_{fec} - \ln L_r \tag{13}$$

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.

Catch data

The WG has provided estimates of total landings of NE Atlantic spurdog and has used these, together with UK 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;
- lack of commercial length frequency information for countries other than the UK (UK landings are a decreasing proportion of the total and therefore the length frequencies may not be representative of those from the fishery as a whole);
- low levels of sampling of UK landings and lack of length frequency data in recent years when the selection pattern may have changed due to the implementation of a maximum landings length (100 cm);
- lack of discard information.

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 such as this where an analytical assessment is not available. However, it should be highlighted that

- the survey data examined by WGEF cover only part of the stock distribution and analyses should be extended to other parts of the stock distribution.
- 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.

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.

Exploratory 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 two 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 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. 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:

Selectivity parameters disaggregated by gear for the main fisheries (i.e. for various trawl, long line and gillnets);

Appropriate indices of relative abundance from fishery-independent surveys, with corresponding estimates of variance;

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

$F_{prop,\mathrm{MSY}}$=0.029, as estimated by the current assessment, assuming average selection over the most recent 5 years of data (2006-2010 for this estimate).

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.

References

Aasen, O. 1960. Norwegian dogfish tagging. Ann. Biol., Copenhagen, 15, 76.

Aasen, O. 1962. Norwegian dogfish tagging. Ann. Biol., Copenhagen, 17, 106–107.

Aasen, O. 1964. The exploitation of the spiny dogfish (*Squalus acanthias* L.) in European waters. Fiskeridir. Skr. Ser. Havunders., 13(7): 5–16.

Bedford, B.C., Woolner, L.E, and Jones, B.W. 1986. Length-weight relationships for commercial fish species and conversion factors for various presentations. Data Report, MAFF Directorate of Fisheries Research Lowestoft, 10: 41pp.

Cortés, E. 1999. A stochastic stage-based population model of the sandbar shark in the Western North Atlantic. In Life in the slow lane: Ecology and conservation of long-lived marine animals. Ed. by J.A. Musick. American Fisheries Society Symposium, 22: 115–136.

Coull, K. A., Jermyn, A. S., Newton, A. W., Henderson, G. I and W. B. Hall. 1989. Length-weight relationships for 88 species of fish encountered in the North East Atlantic. Scottish Fisheries Research Report Number 43.

De Oliveira, J. A. A., Ellis, J. R., and Dobby, H. 2013. Incorporating density dependence in pup production in a stock assessment of NE Atlantic spurdog *Squalus acanthias*. ICES Journal of Marine Science, 70: 1341–1353.

Diez, G., Iriondo, A., Ruiz, J., Quincoces, I., González, I., Santurtun, M. and Artetxe, I. 2006. Lesser spotted dogfish, rays and spurdog Landings Per Unit Effort and preliminary discards data of Basque fleets operating in Subareas VI, VII and VIII in the period 1994–2005. Working Document presented at the 2006 WGEF.

Dobby, H., Beare, D, Jones, E.and MacKenzie, K. 2005. Comparison of trends in long term survey data for Squalus acanthias with a preliminary stock assessment for this species. ICES CM 2005/N:01.

Ellis, J.R. and Keable, J. 2008. The fecundity of Northeast Atlantic spurdog (*Squalus acanthias* L., 1758). ICES Journal of Marine Science, 65: 979–981.

Ellis, J.R., Doran, S., Dunlin, G., Hetherington, S., Keable, J., and Skea, N. 2010. Spurdog in the Irish Sea. Cefas, Lowestoft, Fisheries Science Partnership; 2009; Programme 9, Final Report, 28 pp. (available electronically at http://www.cefas.co.uk/data/fisheries-science-partnership-(fsp)/20082009-programme.aspx).

Fahy, E. 1989. The spurdog *Squalus acanthias* (L.) fishery in south-west Ireland. Ir. Fish. Invest. Part B: March, 32: 22 pp.

Gauld, J. A. 1979. Reproduction and fecundity of the Scottish Norwegian stock of Spurdogs, Squalus acanthias (L.). ICES CM 1979/H:54, 15 pp.

Henderson, A.C., Flannery, K., Dunne, J. 2001. Growth and reproduction in spiny dogfish *Squalus acanthias* L. (*Elasmobranchii*: *Squalidae*), from the west coast of Ireland. Sarsia, 87(5): 350–261.

Holden, M. J. 1965. The stocks of spurdogs (*Squalus acanthias* L.) in British waters and their migrations. Fish. Invest., Ser. II, 24(4), MAFF, London, 20 p.

Holden, M. J. 1968. The rational exploitation of the Scottish-Norwegian stock of spurdogs (*Squalus acanthias* L.). Fishery Investigations, Series II, 25(8), MAFF, London, 27 pp.

Holden, M. and Meadws, P. S. 1962. The structure of the spine of the spurdog fish (*Squalus acanthias* L.) and its use for age determination. Journal of the Marine Biological Association of the United Kingdom, 42: 179–197.

ICES. 2006. Report of the Working Group on Elasmobranch Fishes (WGEF), 14–21 June 2006, ICES Headquarters. ICES CM 2006/ACFM:31. 291 pp.

ICES. 2009a. Report of the Working Group on the Assessment of Demersal Stocks in the North Sea and Skagerrak. Combined Spring and Autumn (WGNSSK), 6–12 May 2009, ICES Headquarters, Copenhagen. ICES CM 2009/ACOM:10. 1028 pp.

ICES. 2009b. Report of the Working Group on the Celtic Seas Ecoregion (WGCSE), 13 –19 May 2009, ICES Headquarters, Copenhagen.

ICES. 2010. Report of the Working Group on Elasmobranch Fishes (WGEF), 22–29 June 2010, Horta, Portuga. ICES CM 2010/ACOM:19. 558 pp.

Jones, T. S. and Ugland, K. I. 2001. Reproduction of female spiny dogfish, *Squalus acanthias*, in the Oslofjord. Fish. Bull., 99: 685–690.

Lo, N. C., Jacobson, L. D. and Squire, J. L. 1992. Indices of relative abundance for fish spotter data based on delta-lognormal models. Canadian Journal of Fisheries and Aquatic Sciences, 49: 2515–2526.

Mandelman, J. W., and Farrington, M. A. 2006. The estimated short-term discard mortality of a trawled elasmobranch, the spiny dogfish (*Squalus acanthias*). Fisheries Research 83: 238–245.

McEachran, J. D., and Branstetter, S. 1984. Squalidae. In Fishes of the Northeastern Atlantic and the Mediterranean Vol. 1, pp 128–147. Ed. by P. J. P.Whitehead, M.-L.Bauchot, J.-C.Hureau, J. Nielsen, and E. Tortonese. UNESCO, Paris.

Mesnil, B. and Rochet, M.-J. 2010. A continuous hockey stick stock-recruit model for estimating MSY reference points. ICES Journal of Marine Science, 67: 000-000. [doi:10.1093/icesjms/fsq055].

NIEA. 2008. Position statement on sharks, skates and rays in Northern Ireland waters BDU2/66. 198 pp.

Punt, A. E. and Walker, T. I. 1998. Stock assessment and risk analysis for the school shark (*Galeorhinus galeus*) off southern Australia. Marine and Freshwater Research 48, 719–31.

Punt, A. E., Pribac, F., Walker T. I. and B.L. Taylor. 2001. Population modelling and harvest strategy evaluation for school and gummy shark, Report of FRDC 99/102. CSIRO Marine Research, Hobart.

Simpfendorfer, C. A. 1999. Demographic analysis of the dusky shark fishery in Southwestern Australia. In Life in the slow lane: Ecology and conservation of long-lived marine animals, pp 149–160. Ed. by J. A.Musick. American Fisheries Society Symposium, 22.

Sosinski, J. 1977. Polish investigations on the Scottish Norwegian spurdog (*Squalus acanthias*) in 1974. Ann. Biol., Copenhagen, 32: 178–179.

STECF. 2009. STECF Report of the SGMOS-09-05 Working Group on Fishing Effort Regimes Regarding Annex IIA of TAC & Quota Regulations and Celtic Sea.

Stefansson, G. 1996. Analysis of groundfish survey abundance data: combining the GLM and delta approaches. ICES Journal of Marine Science, 53: 577–588.

Templeman, W. 1976. Transatlantic migrations of spiny dogfish (*Squalus acanthias*). J. Fish. Res. Bd. Can., 33: 2605–2609.

Vince, M. R. 1991. Stock identity in spurdog (*Squalus acanthias* L.) around the British Isles. Fisheries Research, 12: 341–354.

Zuur, A., Fryer, R. and Newton, A. W. 2001. The comparative fishing trial between Scotia II and Scotia III. FRS Marine Lab. Internal Report No 03/01.

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 2.7	
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 $P_a'' = \dfrac{P''_{\max}}{1 + \exp\left[-\ln(19) \dfrac{l_a^f - l_{mat50}^f}{l_{mat95}^f - l_{mat50}^f}\right]}$ 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

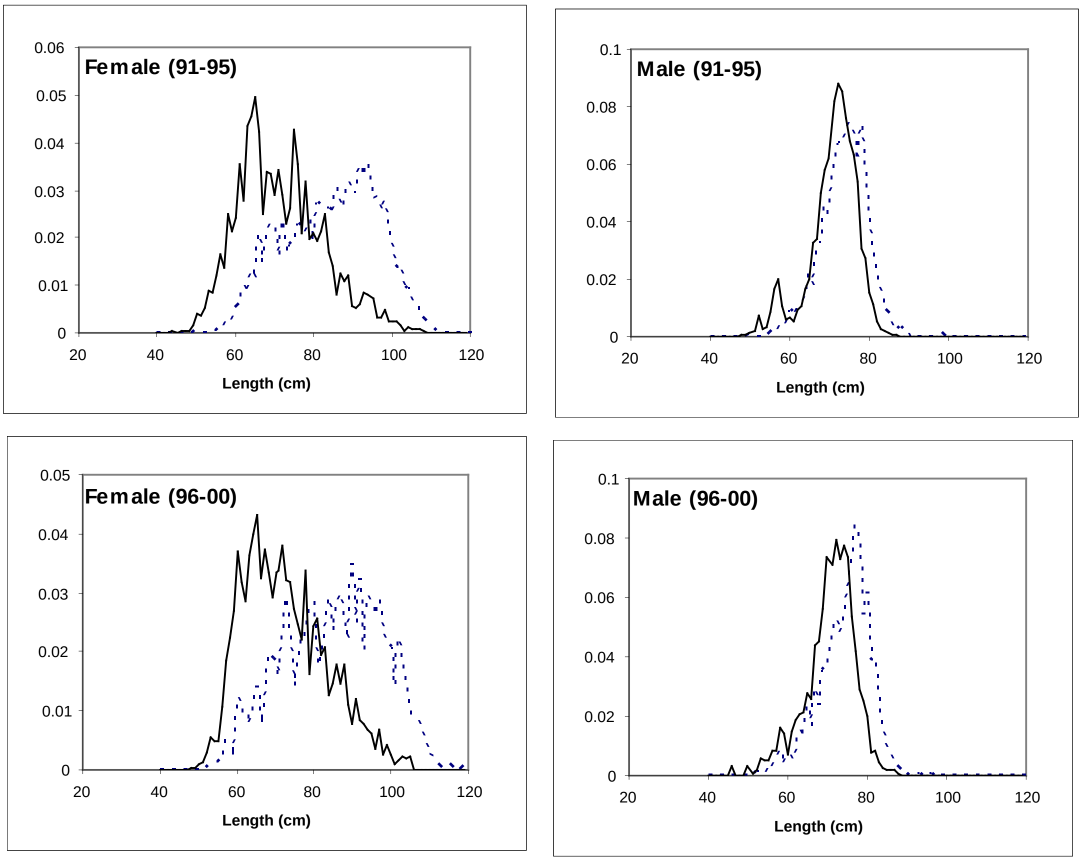


Figure 1. Northeast Atlantic spurdog. Comparison of length frequency distributions (proportions) obtained from market sampling of Scottish (solid line) and UK (E&W) (dashed line) landings data. Data are sex-disaggregated, but averaged over five year intervals.

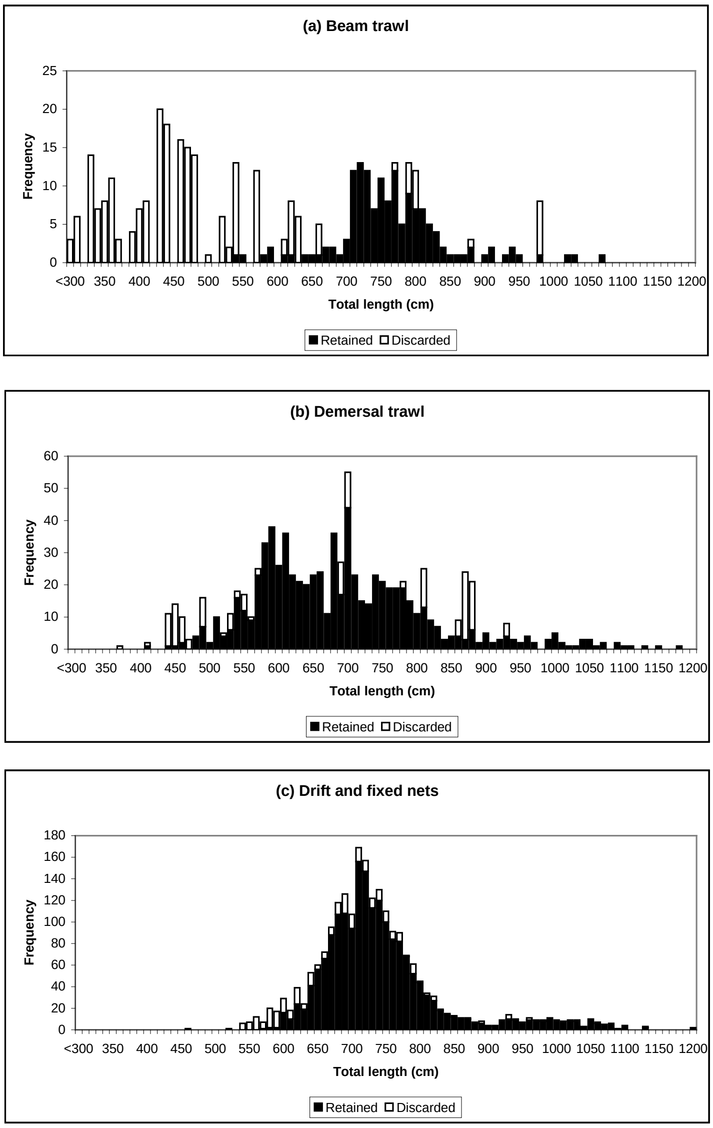
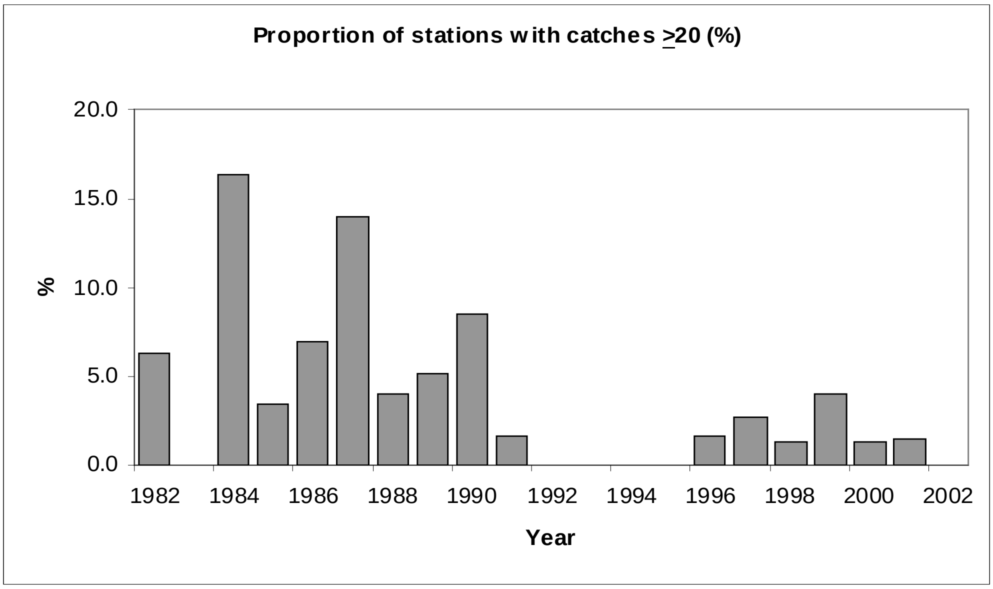


Figure 2. Northeast Atlantic spurdog. Length distribution of discarded and retained in fisheries in the North Sea and Celtic Seas ecoregions for (a) beam trawl, (b) demersal trawl and (c) drift and gillnets. These data (1999–2006) are aggregated across individual catch samples (Source: UK (E&W) Discards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



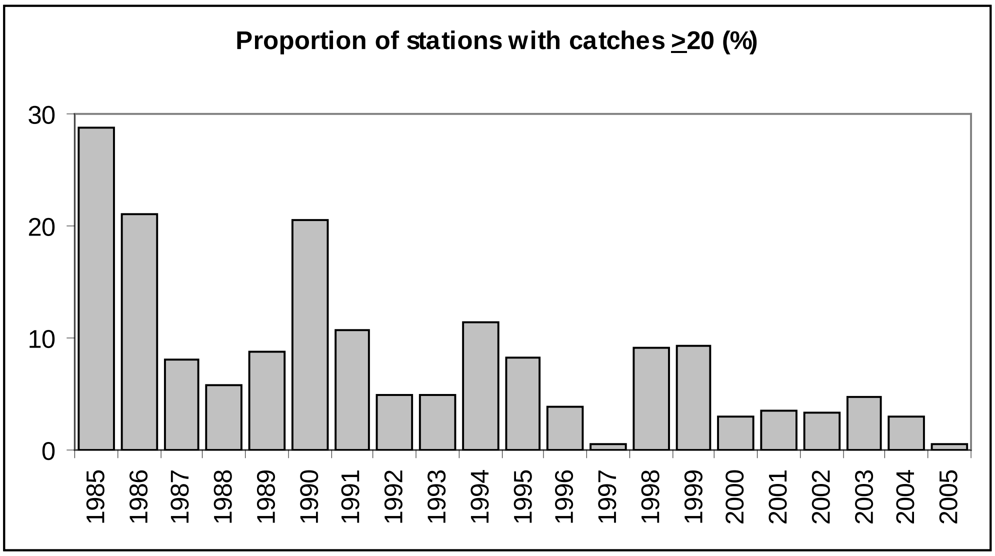
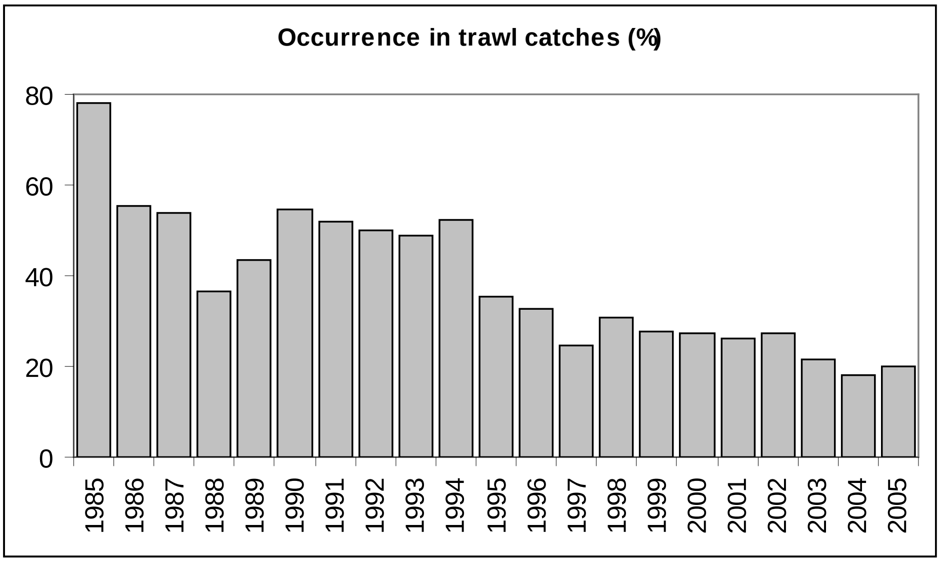


Figure 3. Northeast Atlantic spurdog. Proportion of survey hauls in the English Celtic Sea groundfish survey (1982–2002, top) and Scottish west coast (6.a) survey (Q1, 1985–2005, bottom) in which cpue was ≥20 ind.h^{-1}. (Source: ICES, 2006).

a)



b)

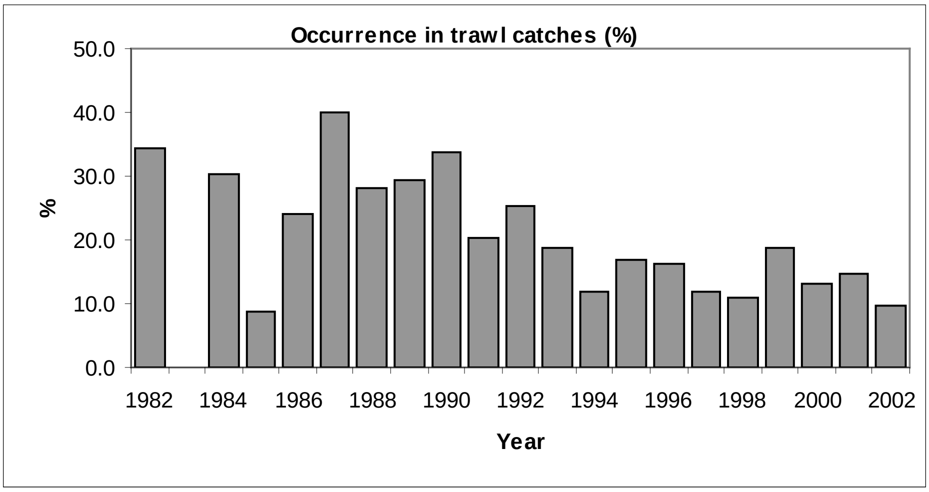


Figure 4. Northeast Atlantic spurdog. Frequency of occurrence in survey hauls in a) the English Q1 Celtic Sea groundfish survey (1982–2002), and b) the Scottish west coast (6.a) survey (Q1, 1985–2005).

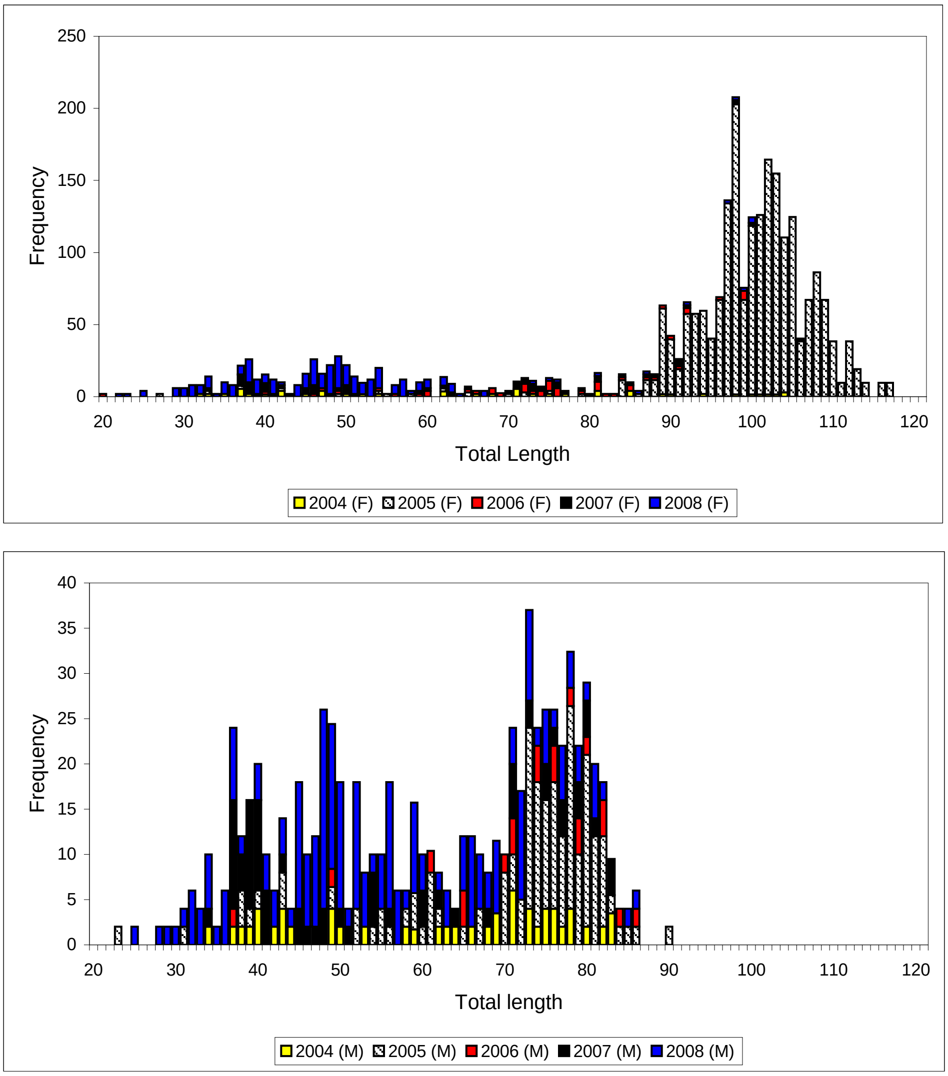


Figure 5. Northeast Atlantic spurdog. Temporal variations in length frequencies of female (top) and male (bottom) spurdog in UK (E&W) Q4 survey.

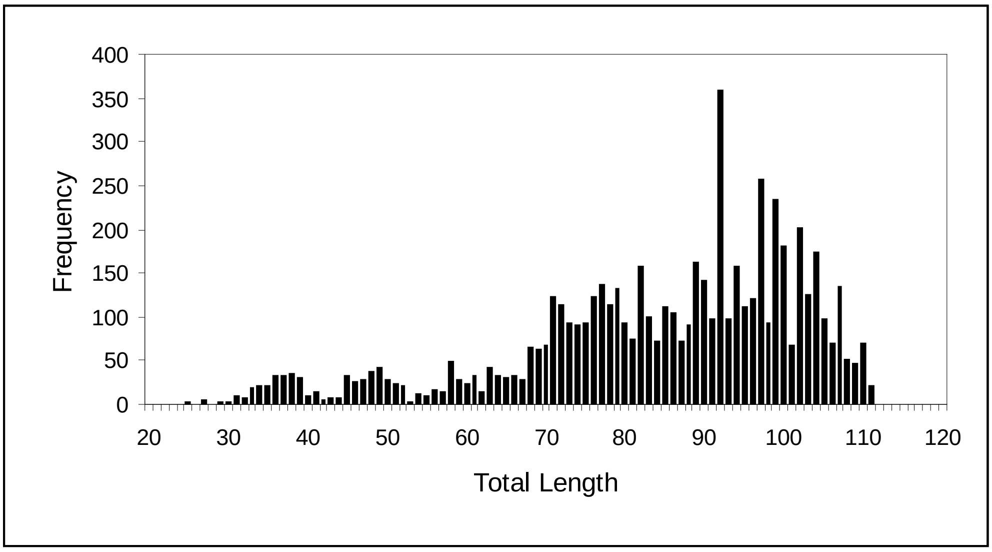


Figure 6. Northeast Atlantic spurdog. Length frequencies of spurdog in UK (NI) GFS Q4 survey 1992–2008.

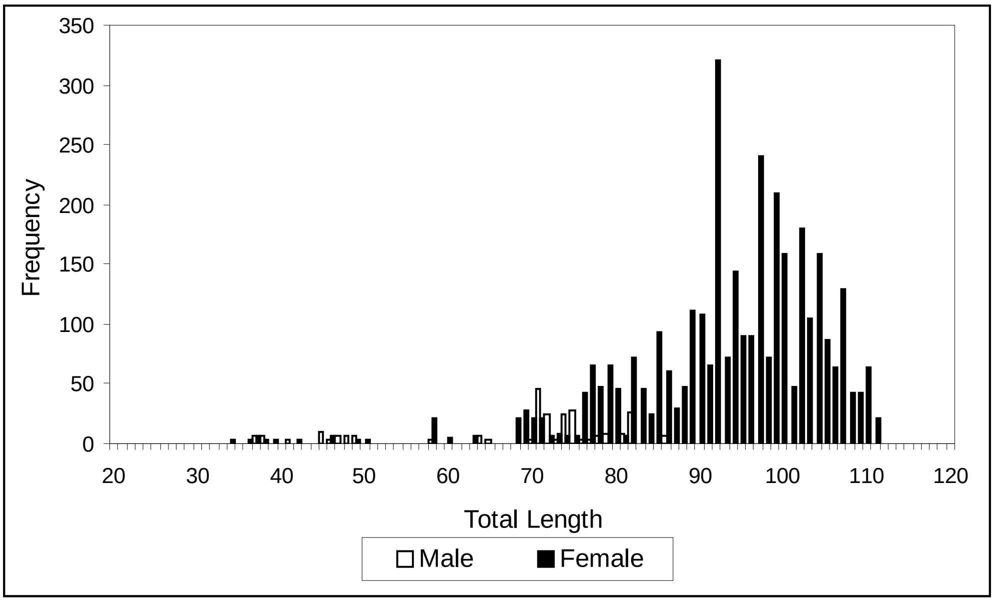


Figure 7. Northeast Atlantic spurdog Sex segregated length frequencies of spurdog in UK (NI) GFS Q4 survey 2006–2008.

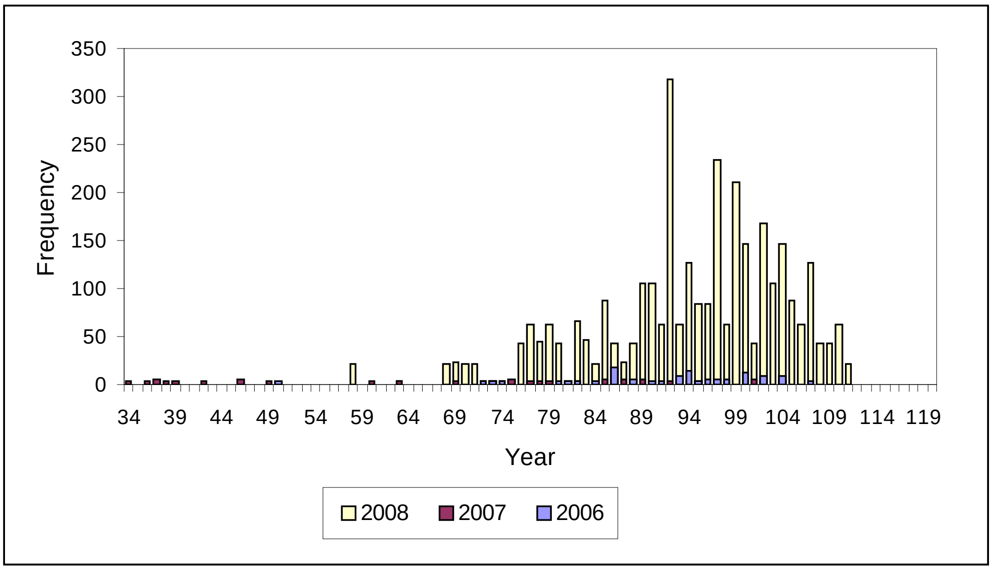


Figure 8. Northeast Atlantic spurdog. Length frequencies of female spurdog in UK (NI) GFS Q4 survey 2006–2008. Dominance of large females observed in 2008 influenced by single large haul.

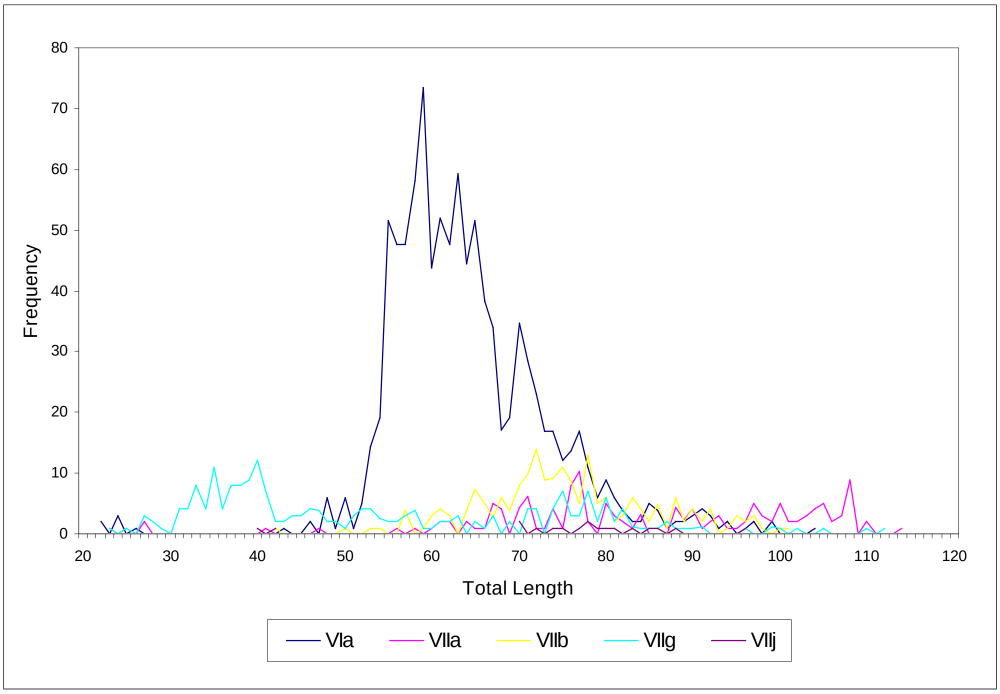


Figure 9. Northeast Atlantic spurdog. Variation in length frequencies of spurdog by region generated from MI GFS Q3 survey.

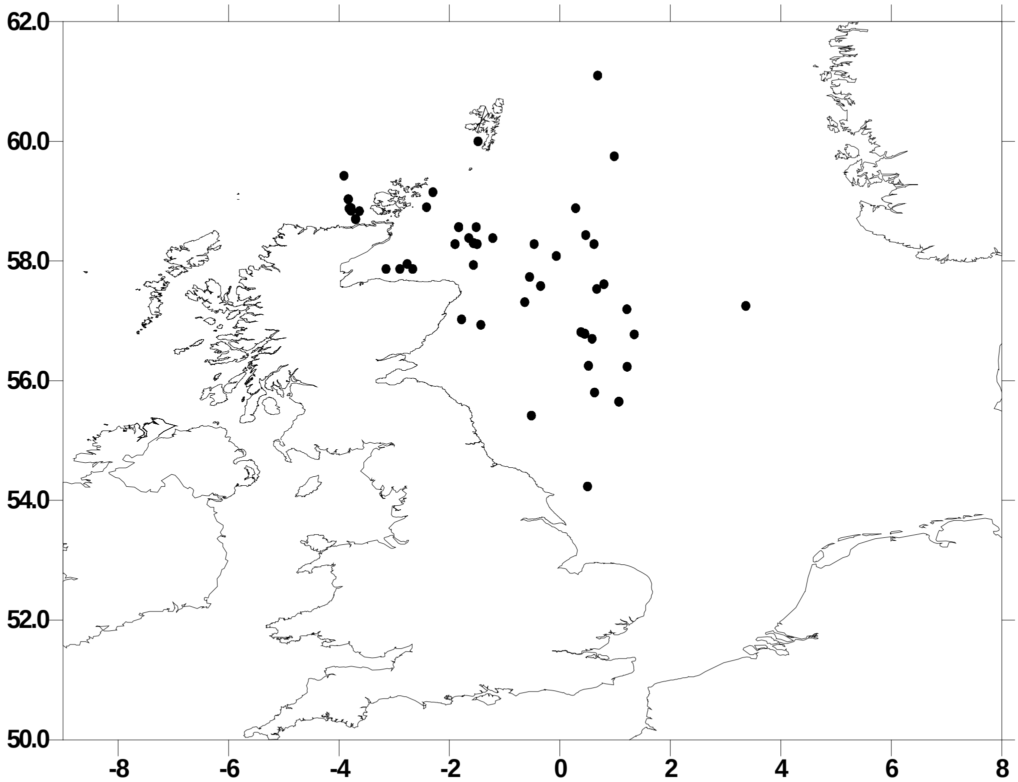
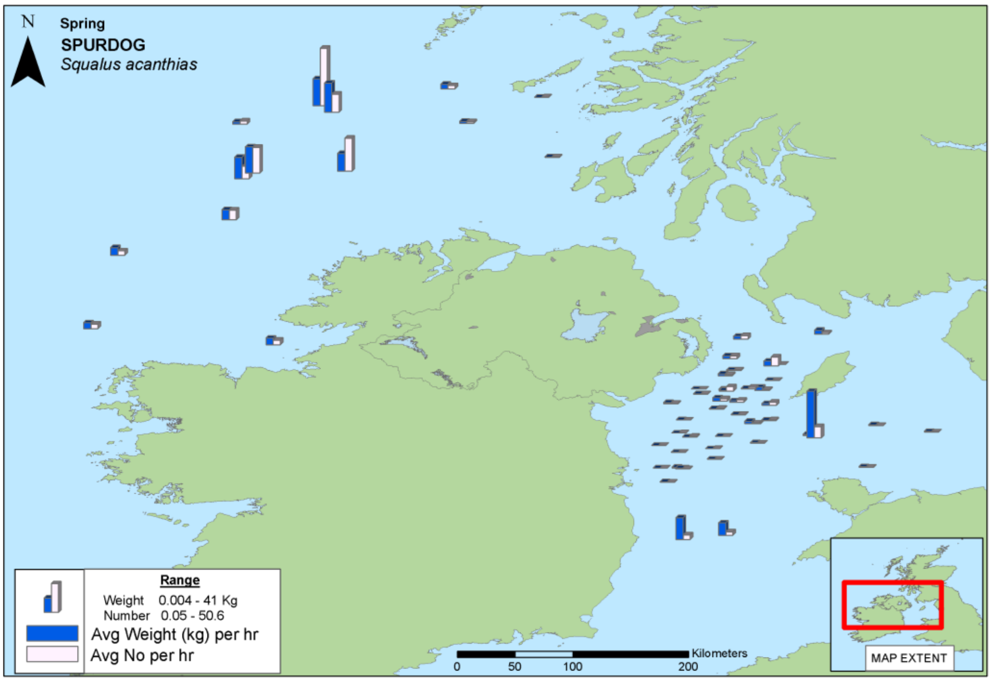


Figure 10. Northeast Atlantic spurdog. Occurrence of spurdog pups (ind. ≤250 mm) in North Sea (Source of dta: DATRAS, downloaded 25 June 2009).



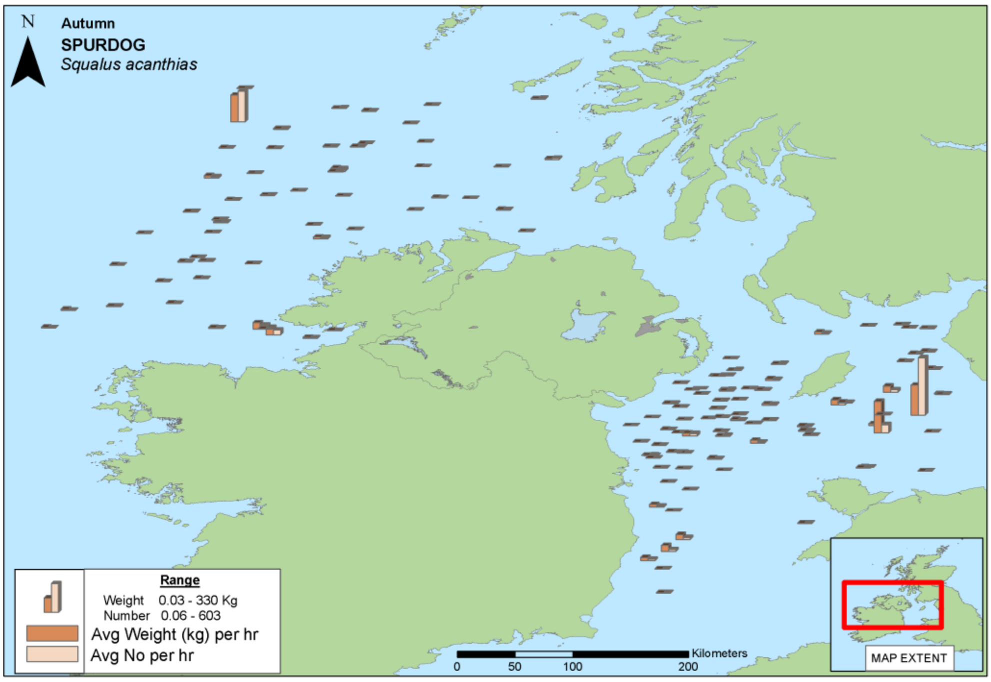


Figure 11. Northeast Atlantic spurdog. Seasonal distribution, average abundance (No. per hr.) and average weight (Kg per hr) of spurdog *Squalus acanthias* in 7.a(N) and 6.a(S) as estimated from research surveys (see NIEA. 2008).