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Bayesian Assessment of NE Atlantic Spurdog Using a Stock Production Model, with Prior
for Maximum Population Growth Rate set by Demographic Methods
(Elasmobranch Fisheries – Oral)

by

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Abstract

Schaefer-model stock assessments can be biased and imprecise because they are fitted to catch rate data (CPUE). However, consideration of life history constraints can improve parameter estimates by shedding light on maximum productivity. Therefore, we applied the methods of McAllister *et al.* (2001) to North-East Atlantic spurdog (*Squalus acanthias*) by using demographic techniques to convert prior distributions for age-specific fecundity and natural mortality (the latter based on tagging data and assumed constant) to prior distributions for the maximum rate of population growth (r). The priors for r generated in this manner were then used in a Bayesian, Schaefer-model assessment of spurdog, fitted to IBTS survey CPUE data. Thus, assessment results were coherent with life-history constraints; they also suggest the stock is depleted to about 6% of virgin biomass.

Introduction

Distribution

The spurdog *Squalus acanthias* Linnaeus, 1758 is a relatively small (<120 cm total length) squaliform shark that is distributed worldwide in temperate and boreal waters. It occurs in the NW Atlantic (Cuba to Greenland), NE Atlantic (northern Norway to Morocco, including the Mediterranean and Black Seas), SW Atlantic (Uruguay and Argentina) and SE Atlantic (South Africa). It also occurs from Japan to Mexico (including the Bering Sea) in the North Pacific and off Chile, New Zealand and southern Australia in the South Pacific (Compagno, 1984). *S. acanthias* is found throughout the water column along the continental shelf and is recorded to depths of 900 m (Compagno, 1984), although, in the North-East Atlantic, it is most common from 10–200 m (McEachran and Branstetter, 1989). In the NE Atlantic, *S. acanthias* is distributed throughout the coastal waters of North-West Europe from Iceland and the northern coasts of Norway and western Russia to the coast of North-West Africa (Compagno, 1984). Landings data from ICES indicate that *S. acanthias* is landed largely from the Norwegian Sea (IIa), Kattegat and Skagerrak (IIIa), North Sea (IVa–c), North-West Scotland (VIa), Irish Sea (VIIa), west coast of Ireland (VIIb-c), English Channel (VIIId-e), Bristol Channel (VIIIf) and Celtic Sea (VIIg-k). There are some commercial landings from the Bay of Biscay (VIII) and around the Iberian Peninsula, although it is possible that these landings also include *S. blainvillei*.

Life-history

Squalus acanthias gives birth to live young that are reliant on yolk reserves during development. General accounts of the species' reproductive biology and physiology are given by Hisaw and Albert (1947), Gilbert and Heath (1972) and Tsang and Callard (1987). The size at sexual maturity is documented for several areas, although the data shown

in Table 1 are not directly comparable because these studies vary in time. Nevertheless, within the NE Atlantic, female *S. acanthias* typically start to mature at 69–73cm, with 50% of females mature at 74–83 cm. Males mature smaller than females.

Fecundity increases with size, and various methods of estimating fecundity have given quite consistent results for this species. Gauld (1979) recorded maximum fecundity values of 16 (maximum number of oocytes), 14 (number of candled embryos) and 13 (number of free embryos). Elsewhere in the world, Hanchet (1988) reported a range in fecundity of 1–16 in New Zealand waters and Kirnosova (1989) reported a fecundity of 4–32 (average=14) in the Black Sea.

The gestation period lasts approximately 22–24 months and the sex ratio of pups is about 1:1 (Gauld, 1979; Hanchet, 1988). Estimates of mean size at birth are 27.5 cm (Holden and Meadows, 1964) and 26 cm (range = 19–30 cm, Gauld, 1989) in the North-East Atlantic; 24 cm (range = 18–30 cm) in New Zealand waters (Hanchet, 1988), and 26–27 cm in the North-East Pacific (Ketchen, 1972). The size of pups increases with maternal length (Hanchet, 1988).

Several investigators have used the annuli present on the second dorsal spine for calculating the age and growth parameters for *S. acanthias* from the North-West Atlantic (Soldat, 1982), North-East Atlantic (Holden and Meadows, 1962; Tucker, 1985) and North-East Pacific (Beamish and McFarlane, 1985; McFarlane and Beamish, 1987). Calculated estimates for the von Bertalanffy equation are given in Table 2. Other methods of age determination of *S. acanthias* include x-ray spectrometry (Jones and Geen, 1977a) and the size of the eye lens (Siezen, 1989). Recent tag returns cast doubt on the use of annuli on the spines, at least for Atlantic specimens, so caution should be used when utilising age data (Martin Vince, pers. comm.).

The observed maximum sizes of *S. acanthias* were reviewed by Ketchen (1972), who gave maximum sizes of males and females as 100 and 135cm respectively (NW Pacific), 107 and 130cm (NE Pacific), 86 and 108cm (NW Atlantic) and 83 and 110cm (NE Atlantic). Market sampling in the UK has recorded female spurdog up to 124 cm long.

Movements and migrations

British and Norwegian tagging studies commenced in 1957/58, with many thousands of fish tagged (e.g. Holden, 1967; Gauld and MacDonald, 1982). Initial studies concentrated on tagging fish from northern waters (e.g. northern North Sea and NW Scotland). Fish tagged off Scotland were regularly recaptured off the Norwegian coast (Aasen, 1960), suggesting a winter migration from Scotland to Norway, with a return migration in summer (Aasen, 1962). Preliminary examination of the data indicated little mixing between northern waters and southern areas (English Channel and southern North Sea) (Holden, 1967), with the greatest number of recaptures from Scottish and Norwegian waters. Hence, Scottish-Norwegian and Channel stocks were distinguished (Holden, 1965, 1967, 1968). There were a few recaptures from outside the area, including the Barents Sea and western coast of Ireland (Aasen, 1963) and southern North Sea, eastern English Channel and northern Bay of Biscay (Holden, 1966, 1967). The majority of returned fish, however, were from Scottish and Norwegian waters, where the major fisheries occurred. Proportionately fewer returns were from outside the area in the early years of tagging experiments, possibly due to spatial differences in fishing activity.

Although fewer fish were tagged in the south, those released in the north-western Irish Sea were recaptured from northern Scotland to the Celtic Sea (Holden, 1962), and fish tagged in the Celtic Sea were recaptured all around the British Isles (Vince, 1991). Hjertenes (1980) also reported that migration patterns of *S. acanthias* in the North Sea had changed, and that they were more frequent in the southern North Sea. Hence, the most recent analyses of tagging studies have suggested a single NE Atlantic stock (e.g. Vince, 1991). Although transatlantic migrations have been reported (Templeman, 1954, 1984), such events are infrequent and NE and NW Atlantic stocks should therefore be treated independently.

Fisheries

Spurdog are the most commercially important shark species in NW Europe. During the early-1900s, spurdog were not of great economic value and landings were small. As in other parts of the world, spurdog were viewed as a nuisance, because shoals of spurdog could cause considerable damage to fishing nets (e.g. in herring fisheries). During the 1950s and 1960s, landings of spurdog in the North Sea increased rapidly and total annual landings rose to 58 000 tons during the 1960s. During the 1980s, long-line fisheries for spurdog became relatively important in the Irish Sea, with boats targeting shoals of large females. This fishery subsequently declined. Spurdog are currently taken in mixed demersal fisheries (e.g. otter trawls), and also targeted in long-line and gill-net (e.g. Fahy and Gleeson, 1990; Fahy, 1992). Since the late-1980s, total landings of spurdog have declined, and more recent catches (1997–1999) have been around 15 000 t/yr⁻¹.

The major fishing nations for spurdog are the UK, Norway, Ireland and France. Other countries (e.g. Germany, Denmark, Poland, Belgium and Portugal) generally have much smaller landings. The main fishing grounds are the Norwegian Sea (II), the North Sea (IV), NW Scotland (VI) and the Celtic Seas (VII). Some landings are also made in the Skagerrak and Kattegat (IIIa) and off Iceland (V). Small quantities are taken in the Bay of Biscay (VIII) and off Greenland, although these areas are considered to be outside the main area of the NE Atlantic stock.

The primary aim of this paper is to bring some of the biological information mentioned above to bear on the assessment of spurdog in the NE Atlantic. We did this by feeding the results of demographic analysis into Schaefer-model stock assessment using Bayesian priors, as recommended in McAllister *et al.* (2001).

Methods and Data

Our demographic analysis required age-specific estimates of length, fecundity and maturity. Such information was based on published estimates of length at age, length at 50% maturity (L_{50}) and fecundity at length. The sources of these biological parameters are listed in Table 3.

The proportion of mature fish at each age was obtained from L_{50} , using age-specific estimates of the proportion of fish longer than L_{50} . The latter were obtained by assuming a lognormal distribution of length at age, with mode given by a published dataset, and dispersion parameter σ estimated from the variability in published lengths at each age. By taking the proportion mature at age to be the same as the proportion of fish above L_{50} , we ensured that 50% of the fish are mature at the age when most of them reach L_{50} .

We obtained fecundity at age for mature females by taking mean length at age and computing the fecundity at that length (see Table 3). The effective fecundity at age x (m_x) was computed by multiplying the fecundity and maturity at age and dividing the result by 4 to account for the two-year gestation period and the 1:1 sex ratio of pups.

We modelled uncertainty in m_x using the variability in estimates of it obtained by employing data from different studies. More specifically, we modelled estimates of m_x (as calculated above) from each of five sources. These sources were Fahy (Ireland), Holden (UK), Nammack (NW Atlantic), Jones and Uglund (Norway) and Gauld (Scotland). We assumed that each source would use their own data, when available, and an average of other sources when not. We took a weighted average of the m_x estimates from these five sources, wherein the weight assigned to each study was independent and lognormal ($\mu=0, \sigma=2$).

The probability of surviving to age x (l_x) was estimated from the tagging studies (on females >80 cm) of Aasen (1964) and Holden (1968). These researchers converted tagging study estimates of total mortality (Z) to estimates of natural mortality (M) by subtracting estimates of fishing mortality from stock assessments. Resulting estimates were converted to a prior for natural mortality, which was lognormal ($\mu=-1.76, \sigma=0.54$). Then, $l_0=1$ and $l_x = l_{x-1} \exp(-M)$.

The resulting estimates of l_x and m_x were then converted to estimates of r , using the numerical method described in McAllister *et al.* (2001). Assuming senescence at age 40, we initialised a vector of female numbers at age by

$$N_{x,0} = 10000 l_x . \quad (1)$$

The number of female pups for the next time set is then given by

$$N_{0,t+1} = \sum_{x=0}^{40} m_x N_{x,t} \quad (2)$$

and the numbers of older females at the next time set is governed by

$$N_{x,t+1} = S_{x-1} N_{x-1,t}, \quad (3)$$

wherein S_{x-1} is the probability of surviving through age $x-1$. Using equations (2) and (3), we projected the population forward until the age structure stabilized (to within $<0.00001\%$), which took a few hundred steps. Then, taking

$$P_t = \sum_{x=0}^{40} N_{x,t}, \quad (4)$$

at the equilibrium t , we computed

$$r = \log\left(\frac{P_t}{P_{t-1}}\right). \quad (5)$$

Computing a sample of more than 5 000 such r estimates and discarding any negative values (which McAllister *et al.* 2001 also obtained) lead to the prior distribution shown in Fig. 1. The fact that this technique used numbers and not biomass (as in our assessment model) was shown by those authors to make no difference.

We then carried out a Bayesian Schaefer-model assessment of spurdogs fitted to survey data from England, Scotland and Ireland (Table 4). Tables 5 and 6 show the number of hauls attempted and the number that caught no spurdogs, respectively. Figure 2 shows the time series of landings used in fitting this model. We assumed that, having had the war years to recover, the population started from the carrying capacity K in 1946.

In fitting the model, we assumed that each index i had its own catchability q_i and its own dispersion parameter \mathbf{s}_i^2 . In accordance with precedent (McAllister *et al.* 2001, Walters and Ludwig 1994), these parameters were assigned non-informative priors, uniform in log space. The same prior was also used for Schaefer-model parameter K .

Each index value $O_{i,y}$ in Table 4 was assigned a lognormal distribution, with mode equal $q_i B_y$, (where B_y is the predicted biomass in year y) and with dispersion parameter

$$\mathbf{s}_{i,y}^2 = c_i CV_{i,y}^2 \mathbf{s}_i^2, \quad (6)$$

where the $CV_{i,y}$ entries come from Table 7 and where

$$c_i = \left(\sum_y CV_{i,y}^2 \right)^{-1}. \quad (7)$$

This specification allows nuisance parameters q_i and \mathbf{s}_i^2 to be integrated out, using a slight generalization of equations in Walters and Ludwig (1994). If, for each index i , we define the statistics

$$\log(\hat{q}_i) = \frac{\sum_y (\log(O_{i,y}) - \log(B_y)) CV_{i,y}^{-2}}{\sum_y CV_{i,y}^{-2}} \quad (8)$$

and

$$SS_i = \sum_y (\log(O_{i,y}) - \log(B_y))^2 CV_{i,y}^{-2}, \quad (9)$$

then, upon integrating out both q_i and \mathbf{S}_i^2 , the posterior kernel for index i becomes

$$\left(SS_i - \log(\hat{q}_i)^2 \sum_y CV_{i,y}^{-2} \right)^{\frac{(n-1)}{2}}, \quad (10)$$

where n is the number of years of data in index i . If the $CV_{i,y}$ values were all 1, this result would be proportional (and therefore equivalent) to equation (18) of Walters and Ludwig (1994). With the nuisance parameters thus dispatched, the only remaining estimated parameters are the biological ones: r and K . We explored uncertainty in these by creating a grid of parameter values.

Note that, due to the presence of zero values in some indices, we used neither the Scotia Deepwater Trawl index nor the Scotia Monkfish Trawl index, and we discarded the 1999 observation from the Scotia Aberdeen Trawl index. We rationalise this omission by the relatively low survey effort exerted (Table 5).

Results

Assuming model assumptions are correct, most landings since 1946 were definitely above MSY (Fig. 3) and there are probably (i.e. probability 73%) <100 000 tons of spurdogs left in 2002. The probability that there are >157 280 tons is only 2.5%. It is 50% probable that the stock has been depleted to below 6% of its carrying capacity and 97.5% probable that the current population is below 11% of K . There is even a 7% chance that the population has been depleted below 3% of K .

Posterior densities for parameters r and K are shown in Fig. 4 and 5, respectively, and Figure 6 reveals a distribution function for 2002 biomass. The main result of this assessment is the downward population trajectory shown with confidence limits in Fig. 7. The harvest rate time-series is shown in Fig. 8.

Discussion

The purpose of this section is to discuss selected assumptions and difficulties involved in this approach to stock assessment. The main issues are as follows:

- The approach discards some survey observations because of the presence of zeros
- The model assumes the stock was at the carrying capacity in 1946
- The model assumes that parameters r and K have remained constant since 1946

Furthermore, there are important assumptions in the demographic approach:

- The variability in published studies was used as an index of prior uncertainty
- The estimates of natural mortality were based on published accounts on tagging studies of large females as an indication of mortality of females of all ages.

We admit that discarding CPUE index values because of the presence of zeros may induce bias towards a more optimistic assessment. One approach to fixing this problem is to add a constant to all the catch rates. This would, however, raise the awkward question of what value the constant should be. Adding 1 to all the catch rates, for example, would have quite different implications from adding 0.001. To see this, compare a fall in catch rates from 2 to 1 to a fall from 1.001 to .001. The two imply dramatically different dynamics because catch rates are assumed to be proportional to abundance. Not wanting to swap a bias with clear direction for one without, we left the catch rates as we found them.

There is a trade-off between two of our assumptions: that the population starts at K in 1946 and that r and K have remained constant. In going back to 1946, we can use more landings data in calculating depletion, but we lengthen the time-series and hence the likelihood that conditions have changed over it. We could have kept a short time-

series by introducing another parameter (for the starting population in 1977), but this would entail estimating that parameter from the same data. Given that the data are already uninformative, we chose to be parsimonious with model parameters and to accept the risk of ‘regime shifts’.

Our demographic analysis used the between-study variability in life-history parameters, e.g. growth parameters, in creating priors for them for NE Atlantic spurdog. This approach assumes similarity between life-history traits in different areas, independence between studies and randomness in the selection of study site. It is not difficult to imagine how these assumptions might have been violated to a degree. Moreover, if doubts about the spine annuli ageing method were to prove well founded, for example, then the demographic analysis will have introduced some bias. Nonetheless, we believe the risks associated with ignoring the life history information are greater than the risks entailed by using it because this assessment suggests that spurdog have been depleted to about 6% of virgin biomass. If so, conservation measures may be appropriate.

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. 1963. The Norwegian taggings of spiny dogfish (*Squalus acanthias*). *Ann. Biol., Copenhagen* **18**: 85–95.
- AASEN, O. 1964. The exploitation of the spiny dogfish (*Squalus acanthias* L.) in European waters. *Fiskeridirektoratets Skrifter Serie Havundersokelser*, **13**(7): 5–16.
- BEAMISH, R.J. and G.A. McFARLANE. 1985. Annulus development on the second dorsal spine of the spiny dogfish (*Squalus acanthias*) and its validity for age determination. *Can. J. Fish. Aquat. Sci.*, **42**(11): 1799–1805.
- COMPAGNO, L.J.V. 1984. FAO species catalogue. Vol. 4. Sharks of the world. An annotated and illustrated catalogue of shark species known to date. Part 1. Hexanchiformes to Lamniformes. *FAO Fisheries Synopsis*, no. 125, **Vol. 4**(1): 1–249.
- FAHY, E. 1988. Recent developments in the Irish fisheries for spurdog, *Squalus acanthias* (L.). ICES CM 1988/H:6, 12pp.
- FAHY, E. 1989. The spurdog *Squalus acanthias* (L.) fishery in south-west Ireland. *Ir. Fish. Invest. Part B: Mar.*, **32**: 22 pp.
- FAHY, E. 1992. The western spurdog *Squalus acanthias* L. fishery in 1989 and 1990, with observations on the further development of the gillnet fishery directed on the species. *Fish. Bull. Ireland*, **11**, 11pp.
- FAHY, E. and P. GLEESON. 1990. The post-peak-yield gill-net fishery for spurdog, *Squalus acanthias* L. in Western Ireland. *Ir. Fish. Invest. Ser. B*, **35**: 12pp.
- GAULD, J.A. 1979. Reproduction and fecundity of the Scottish Norwegian stock of Spurdogs, *Squalus acanthias* (L.). ICES CM 1979/H:54, 15pp.
- GAULD, J.A. and W.S. MacDONALD. 1982. The results of tagging experiments on spurdogs *Squalus acanthias* L. around Scotland. ICES C 1982/H:51, 14pp.
- GILBERT, P.W. and G.W. HEATH. 1972. The clasper-siphon sac mechanism in *Squalus acanthias* and *Mustelus canis*. *Comp. Biochem. Physiol.*, **42A**: 97–119.
- HANCHET, S. 1988. Reproductive biology of *Squalus acanthias* from the east coast, South Island, New Zealand. *NZ J. Mar. Freshwat. Res.*, **22**(4): 537–549.

- HICKLING C.F. 1930. A contribution towards the life-history of the spurdog. *J. Mar. Biol. Ass. U.K.*, **16**: 529–576.
- HISAW, F.L. and A. ALBERT. 1947. Observations on the reproduction of the spiny dogfish, *Squalus acanthias*. *Biol. Bull.*, **92**: 187–199.
- HJERTENES, P.O. 1980. The spurdogs (*Squalus acanthias*) in the North Sea area: The Norwegian fishery and observations on changes in migration pattern. ICES CM 1980/H:60, 18pp.
- HOLDEN, M.J. 1962. English spurdogfish tagging. *Ann. Biol., Copenhagen*, **17**: 107–108.
- 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, 20pp.
- HOLDEN, M.J. 1966. English taggings of picked dogfish. *Ann. Biol., Copenhagen*, **21**: 172–174.
- HOLDEN, M.J. 1967. Spurdogs. *Laboratory Leaflet (New Series)*, MAFF Fisheries Laboratory, Lowestoft, 23pp.
- HOLDEN, M.J. 1968. The rational exploitation of the Scottish-Norwegian stock of spurdogs (*Squalus acanthias* L.). *Fish. Invest., Ser. II*, **25(8)**, MAFF, London, 27pp.
- HOLDEN, M.J. and P.S. MEADOWS. 1962. The structure of the spine of the spurdog fish (*Squalus acanthias* L.) and its use for age determination. *J. Mar. Biol. Ass. U.K.*, **42**: 179–197.
- HOLDEN, M.J. and P.S. MEADOWS. 1964. The fecundity of the spurdog (*Squalus acanthias* L.). *J. Cons. Perm. Int. Explor. Mer*, **28**: 418–424.
- JONES, B.C. and G.H. GEEN. 1977a. Age determination of an elasmobranch (*Squalus acanthias*) by X-ray spectrometry. *J. Fish. Res. Bd. Can.*, **34**: 44–48.
- JONES, B.C. and G.H. GEEN. 1977b. Reproduction and embryonic development of spiny dogfish (*Squalus acanthias*) in the Strait of Georgia, British Columbia. *J. Fish. Res. Bd. Can.*, **34(9)**: 1286–1292.
- JONES, T.S. and K.I. UGLAND. 2001. Reproduction of female spiny dogfish, *Squalus acanthias*, in the Oslofjord. *Fish. Bull.*, **99**: 685–690.
- KETCHEN, K.S. 1972. Size at maturity, fecundity and embryonic growth of the spiny dogfish (*Squalus acanthias*) in British Columbia waters. *J. Fish. Res. Bd. Can.*, **29**: 1717–1723.
- KETCHEN, K.S. 1975. Age and growth of dogfish, *Squalus acanthias*, in British Columbia waters. *J. Fish. Res. Bd. Can.*, **32**: 43–59.
- KIRNOSOVA, I.P. 1989. Reproduction of spiny dogfish, *Squalus acanthias* in the Black Sea. *J. Ichthyol.*, **29(3)**: 21–26.
- McALLISTER, M.K., E.K. PIKITCH and E.A. BABCOCK. 2001. Using demographic methods to construct Bayesian priors for the intrinsic rate of increase in the Schaefer model and implications for stock rebuilding. *Can. J. Fish. Aquat. Sci.*, **58(9)**: 1871–1890.
- McEACHRAN, J.D. and S. BRANSTETTER. 1989. Squalidae. In: Fishes of the North-eastern Atlantic and the Mediterranean Volume 1 (P.J.P. Whitehead, M.-L. Bauchot, J.-C. Hureau, J. Nielsen and E. Tortonese, Eds.), UNESCO, Paris, 128–147.
- McFARLANE, G.A. and R.J. BEAMISH. 1987. Validation of the dorsal spine method of age determination for spiny dogfish. In: Age and growth in fish (Summerfelt, R.C. and Hall, G.E., eds.). International Symposium on Age and Growth in Fish, Des Moines, IA (USA), 9 Jun 1985, 287–300.

- NAMMACK, M.F., MUSICK, J.A. and COLVOCORESSES, J.A. 1985. Life-history of spiny dogfish off the northeastern United States. *Trans. Am. Fish. Soc.*, **114**(3): 367–376.
- SIEZEN, R.J. 1989. Eye lens aging in the spiny dogfish (*Squalus acanthias*) I. Age determination from lens weight. *Current Eye Res.*, **8**(7): 707–712.
- SOLDAT, V.T. 1982. Age and size of spiny dogfish, *Squalus acanthias*, in the Northwest Atlantic. *NAFO Sci. Counc. Stud.* **3**: 47–52.
- SOSINSKI, J. 1977. Polish investigations on the Scottish Norwegian spurdog (*Squalus acanthias*) in 1974. *Ann. Biol., Copenhagen*, **32**: 178–179.
- TEMPLEMAN, W. 1954. Migrations of spiny dogfish tagged in Newfoundland waters. *J. Fish. Res. Bd. Can.*, **11**(4): 351–354.
- TEMPLEMAN, W. 1984. Migrations of spiny dogfish, *Squalus acanthias*, and recapture success from tagging in the Newfoundland area, 1963–65. *J. Northw. Atl. Fish. Sci.*, **5**(1): 47–53.
- TSANG, P.C.W. and I.P. CALLARD. 1987. Morphological and endocrine correlates of the reproductive cycle of the aplacental viviparous dogfish, *Squalus acanthias*. *Gen. Comp. Endocrin.*, **66**(2): 182–189.
- TUCKER R. 1985. Age validation studies on the spines of the spurdog (*Squalus acanthias*) using tetracycline. *J. Mar. Biol. Ass. U.K.*, **65**(3): 641–651.
- VINCE, M.R. 1991. Stock identity in spurdog (*Squalus acanthias* L.) around the British Isles. *Fish. Res.*, **12**: 341–354.
- WALTERS, C and D. LUDWIG. 1994. Calculation of Bayes posterior probability distributions for key population parameters. *Can. J. Fish. Aquat. Sci.*, **51**: 713–722.

Table 1: Size at maturity of female and male *Squalus acanthias*.

Area	Length at maturity (cm):			Author
	First	50%	100%	
FEMALES				
NE Atlantic	60–64	–	–	Hickling (1930)
	73	82	96	Holden & Meadows (1964)
	71	83	94	Gauld (1979)
	69	74 ^a	86	Fahy (1988, 1989)
NW Atlantic	76	77.9 ^b	86	Nammack <i>et al.</i> , 1985
Black Sea	97.7–116.3 ^c	–	–	Kirnosova (1989)
New Zealand	65	71.5–74	82	Hanchet (1988)
NE Pacific	76	93.5 ^d	118	Ketchen (1972), Jones & Geen (1977b)
MALES				
NE Atlantic	55	59–60	64	Hickling (1930)
NW Atlantic	58	59.5 ^e	63	Nammack <i>et al.</i> (1985)
Black Sea	81.7–96.3 ^f	–	–	Kirnosova (1989)
New Zealand	53	57.5	64	Hanchet (1988)
NE Pacific	–	78.5 ^g	–	Jones & Geen (1977b)

Table 2: Von Bertalanffy growth parameters for *Squalus acanthias*.

Region	Sex	L_{∞} (cm)	K	t_0 (years)	Author
Ireland	Male	79.9	0.16	-1.69	Fahy (1988, 1989)
	Female	98.8	0.19	-1.57	
British Isles	Male	79.9 (86.0)	0.21 (0.14)	-2.0 (-3.13)	Holden & Meadows (1962) ^a
	Female	101.4 (104.0)	0.11 (0.11)	-3.6 (-3.28)	
North Sea	Male	81.7	0.19	-1.47	Sosinski (1977)
	Female	137.1	0.05	-4.71	
	Total	101.5	0.10	-3049	
NE Pacific	Male	99.8	0.070	-4.70	Ketchen (1975)
	Female	125.3	0.048	-4.88	
NW Atlantic	Male	82.49	0.148	-2.67	Nammack <i>et al.</i> (1985)
	Female	100.5	0.1067	-2.90	

^a Original data and recalculated values (as given by Fahy (1989)) in parentheses

Table 3: Source data for life history parameters.

Parameters	Source
Length at age	Fahy (1988, 1989), Holden and Meadows (1962, 1964), Nammack <i>et al.</i> (1985), Soldat (1982), Jones and Ugland (2001), Aasen (1964)
Fecundity at length	Fahy (1988), Gauld (1979)
Natural mortality	Aasen (1964), and Holden (1968)
Length at 50% maturity	Jones and Ugland (2001), Fahy (1988), Gauld (1979), Holden and Meadows (1964), Nammack <i>et al.</i> (1985)

Table 4: Mean catch per unit effort (kg.h⁻¹) from UK groundfish surveys.

Vessel	Cirolana	Cirolana	Cirolana	Corystes	Explorer	Lough Foyle	Scotia	Scotia	Scotia	Scotia	Mean CPUE
Gear	GOV	Granton	PHHT	Granton	Aberdeen Trawl	Rockhopper Otter Trawl	Aberdeen Trawl	Deepwater Trawl	GOV	Monkfish Trawl	
1977		2.50			147.19						74.84
1978		10.23			11.35						10.79
1979		2.41			11.54						6.97
1980		9.44			0.54						4.99
1981		7.53			12.53						10.03
1982		5.72	12.67				1.21				6.53
1983		6.15	2.66				0.66		6.22		3.92
1984		3.30	16.25				0.69		2.84		5.77
1985		4.95	13.82				1.66		35.95		14.10
1986		28.56	11.23				1.08		9.20		12.52
1987		13.54	22.83				7.62		0.35		11.09
1988		4.69	5.68	8.36			2.55		8.91		6.04
1989		1.20	5.26	0.39			0.71		2.97		2.11
1990		2.30	5.14	3.55			0.78		7.04	44.48	10.55
1991	3.58	0.49	1.30	3.53		6.03	0.10		5.75		2.97
1992	3.14		0.83	3.70		3.74	0.24		4.67		2.72
1993	0.96		1.24			7.30	0.35		4.47		2.86
1994	2.56		1.10			1.48	0.12		5.50		2.15
1995	1.44		0.58			3.85	0.04		3.48		1.88
1996	0.26					3.22	0.07	0.00	2.78	0.00	1.05
1997	0.53		1.18			2.54	0.19	0.00	1.61		1.01
1998	0.32		0.81			5.04		0.62	1.97	0.00	1.46
1999	0.18		14.44			3.61	0.00	2.61	1.80	0.00	3.23
2000	0.06		0.94			3.42		0.15	6.25	14.39	4.20
2001	0.47		1.26			1.65			0.42		0.95
Mean CPUE	1.23	6.87	6.28	3.91	36.63	3.81	1.06	0.68	5.90	11.78	6.01

Table 5: Survey effort in number of hauls, by gear and year.

	Cirolana	Cirolana	Cirolana	Corystes	Explorer	Lough Foyle	Scotia	Scotia	Scotia	Scotia	Total	
Year	GOV	Granton	PHHT	Granton	Aberdeen Trawl	Rockhopper Trawl	Otter Aberdeen Trawl	Deepwater Trawl	GOV	Monkfish Trawl		
1977		126			24						150	
1978		120			55						175	
1979		126			41						167	
1980		126			55						181	
1981		125			65						190	
1982		75	112					79			266	
1983		74	41					82	50		247	
1984		84	110					84	12		290	
1985		75	110					85	67		337	
1986		87	98					85	106		376	
1987		84	121					143	68		416	
1988		79	116	12				133	122		462	
1989		89	64	12				129	110		404	
1990		91	70	14				132	159	54	520	
1991	68	89	62	20		70		132	253		694	
1992	153		70	12		132		129	224		720	
1993	150		71			132		137	218		708	
1994	160		36			127		134	212		669	
1995	168		23			77		132	221		621	
1996	86					82		127	12	225	7	539
1997	81		80			89		131	32	245		658
1998	79		80			89		89	20	280	11	559
1999	78		87			86	13	45	332	6	647	
2000	76		86			85		38	274	36	595	
2001	79		73			102			320		574	
Grand Total	1178	1450	1510	70	240	1071	1887	147	3498	114	11165	

Table 6: Number of hauls that caught no spurdogs, by gear and year.

	Cirolana	Cirolana	Cirolana	Corystes	Explorer	Lough Foyle	Scotia	Scotia	Scotia	Scotia	
Year	GOV	Granton	PHHT	Granton	Aberdeen Trawl	Rockhopper Trawl	Otter Aberdeen Trawl	Deepwater Trawl	GOV	Monkfish Trawl	Grand Total
1977		92			7						99
1978		77			27						104
1979		93			9						102
1980		94			48						142
1981		93			49						142
1982		50	76				58				184
1983		47	30				62		29		168
1984		63	75				68		5		211
1985		57	85				65		21		228
1986		68	50				73		77		268
1987		64	79				109		60		312
1988		66	78	6			120		99		369
1989		72	47	10			110		84		323
1990		69	48	12			119		121	17	386
1991	48	81	50	12		52	122		186		551
1992	122		53	8		98	114		155		550
1993	130		59			100	121		130		540
1994	121		32			101	123		148		525
1995	146		19			62	126		161		514
1996	79					60	122	12	160	7	440
1997	78		71			68	120	32	181		550
1998	72		72			67		19	218	11	459
1999	74		72			66	13	27	264	6	522
2000	75		74			61		36	213	16	475
2001	76		63			87			295		521
Grand Total	1021	1086	1133	48	140	822	1645	126	2607	57	8685

Table 7: The coefficient of variation (CV, just standard error/mean) in survey CPUE (Table 2), for the survey indices used.

Vessel	Cirolana	Cirolana	Cirolana	Corystes	Explorer	Lough Foyle	Scotia	Scotia	
Gear	GOV	Granton	PHHT	Granton	Aberdeen Trawl	Rockhopper Otter Trawl	Aberdeen Trawl	GOV	Average
1977		0.26			0.68				0.47
1978		0.57			0.72				0.64
1979		0.27			0.37				0.32
1980		0.39			0.42				0.40
1981		0.65			0.40				0.52
1982		0.49	0.51				0.34		0.45
1983		0.50	0.44				0.35	0.54	0.46
1984		0.39	0.37				0.34	0.44	0.39
1985		0.40	0.45				0.38	0.36	0.40
1986		0.89	0.38				0.50	0.58	0.59
1987		0.53	0.45				0.74	0.36	0.52
1988		0.77	0.26	0.52			0.77	0.89	0.64
1989		0.36	0.45	0.79			0.39	0.58	0.51
1990		0.32	0.44	0.95			0.62	0.72	0.61
1991	0.28	0.48	0.48	0.54		0.60	0.35	0.64	0.48
1992	0.46		0.34	0.76		0.28	0.28	0.63	0.46
1993	0.27		0.41			0.76	0.36	0.27	0.41
1994	0.21		0.58			0.30	0.42	0.47	0.40
1995	0.31		0.54			0.57	0.52	0.62	0.51
1996	0.44					0.30	0.54	0.29	0.39
1997	0.64		0.49			0.37	0.45	0.21	0.43
1998	0.46		0.53			0.69		0.27	0.49
1999	0.73		0.89			0.31	0.00	0.22	0.43
2000	1.00		0.41			0.28		0.85	0.64
2001	0.67		0.48			0.51		0.54	0.55
Average	0.50	0.48	0.47	0.71	0.52	0.45	0.43	0.50	0.49

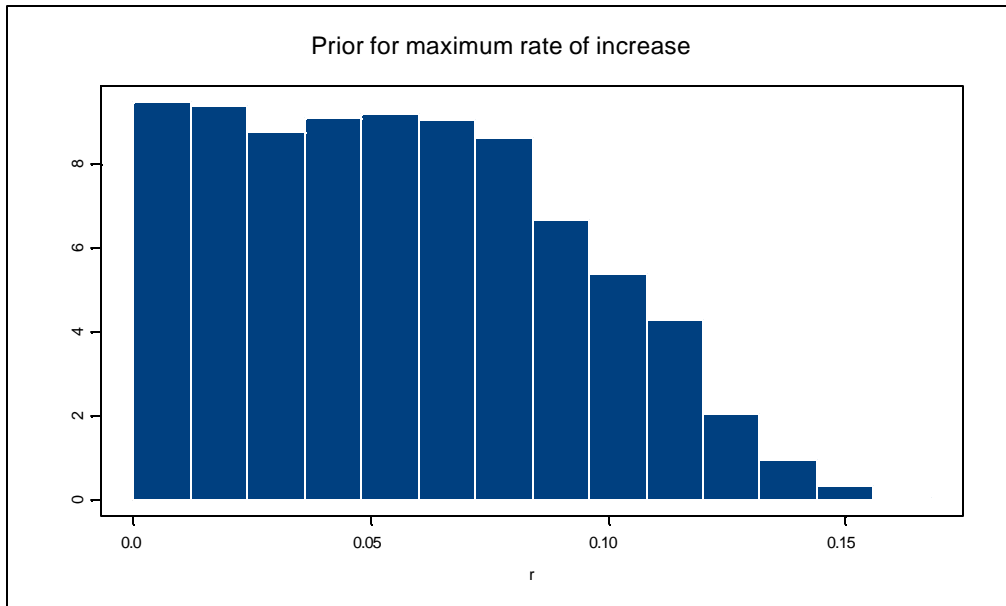


Fig. 1: The prior for maximum rate of increase (r) resulting from our demographic computations.

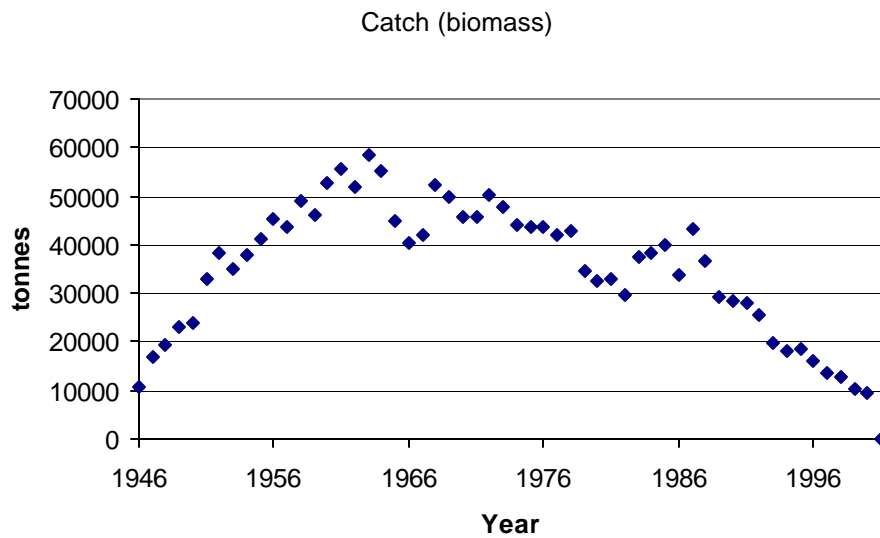


Fig. 2: Landings time-series for the whole NE Atlantic.

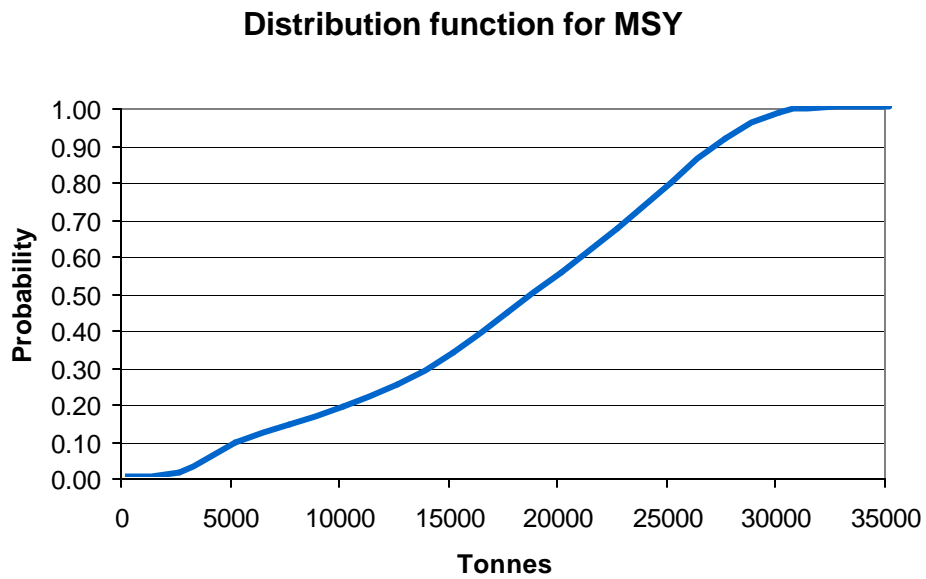


Fig. 3: The posterior distribution function for MSY for NE Atlantic spurdogs as estimated from our assessment model.

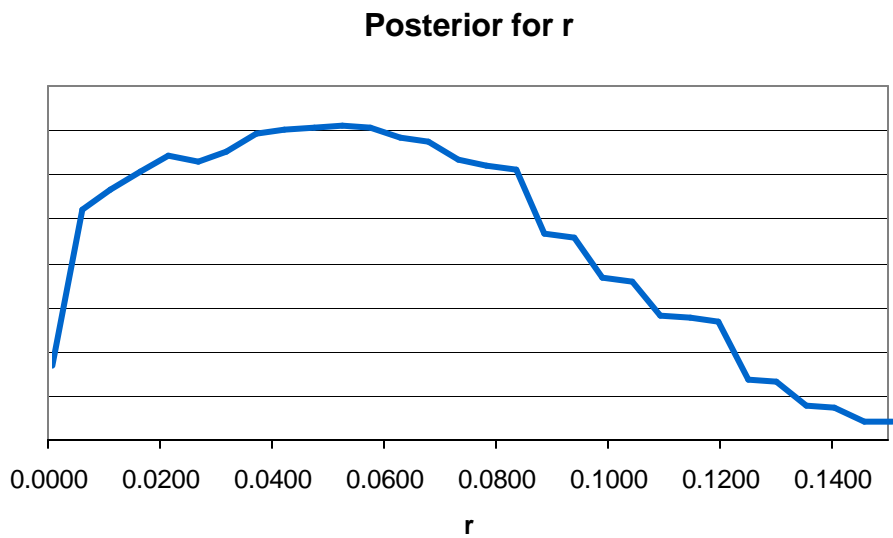


Fig. 4: The posterior density for r differs little from the prior, indicating that the data are uninformative about r .

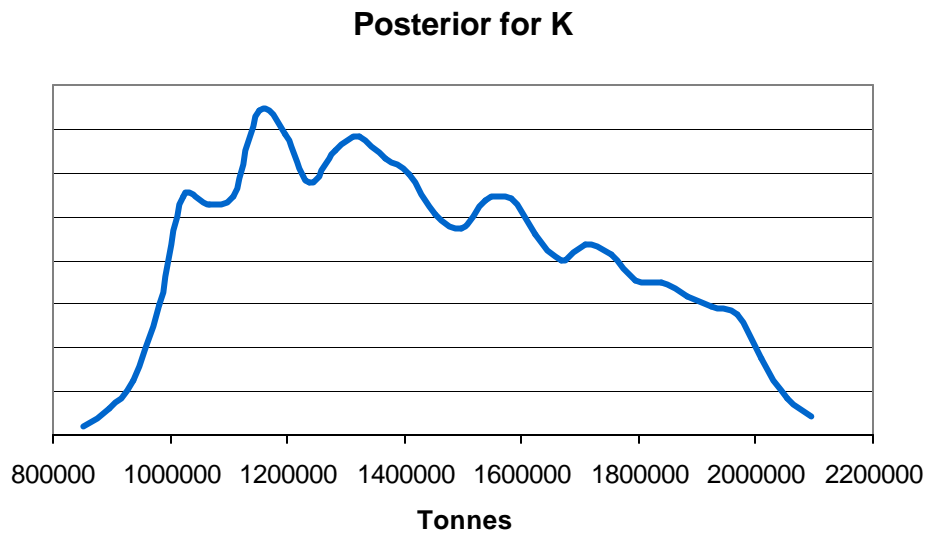


Fig. 5: The posterior density for K , in the entire Northeast Atlantic, spans the range from 0.8 to 2.1 million t.

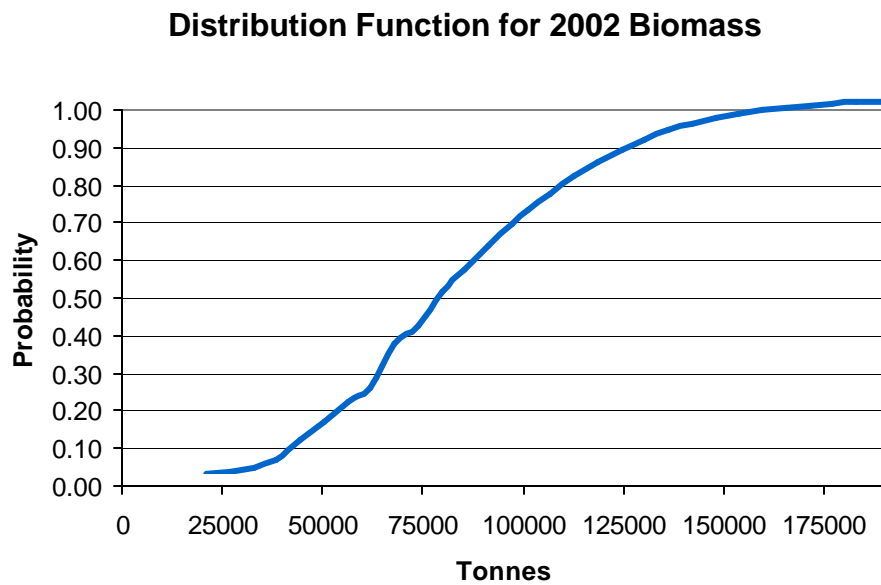


Fig. 6: The posterior cumulative distribution function for 2002 biomass.

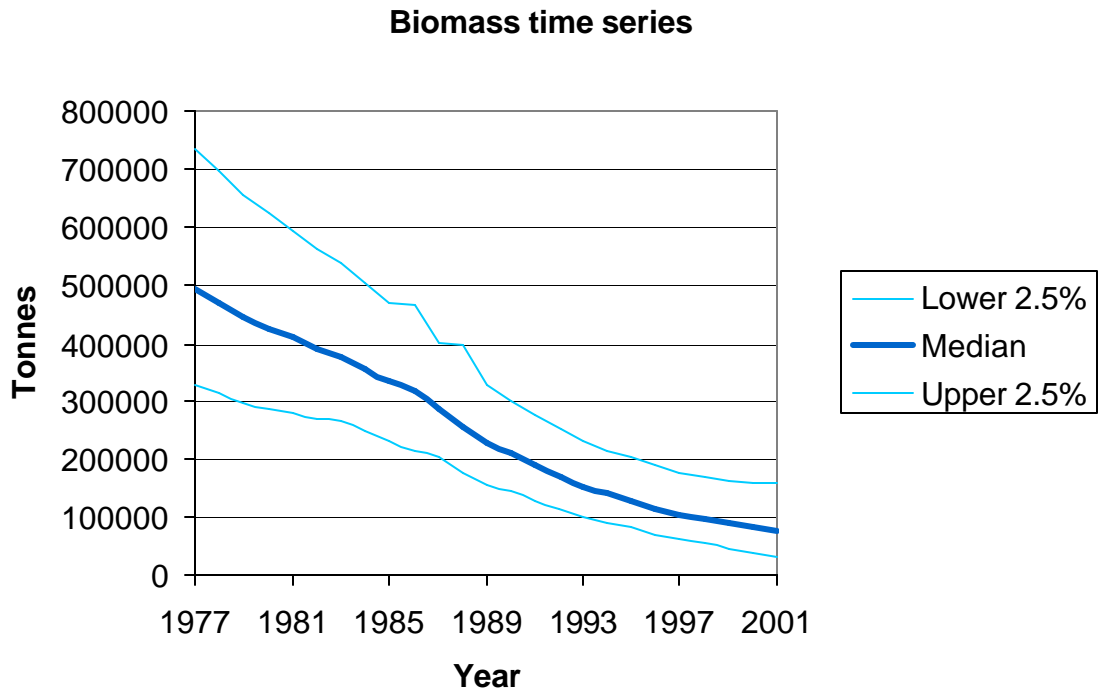


Fig. 7: The biomass time series we estimated suggests a classic downward trajectory, or ‘one-way trip’. Such trajectories are notoriously uninformative about population parameters.

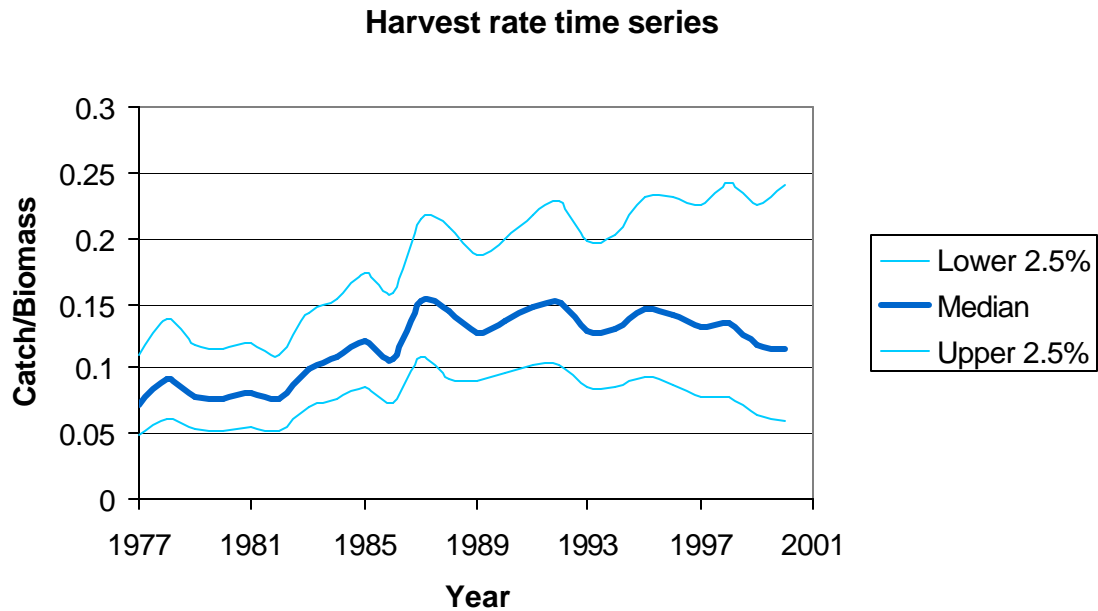


Fig. 8: The harvest rate time -series.