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The biology and exploitation of John dory, *Zeus faber* (Linnaeus, 1758) in the waters of England and Wales

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John dory have become an important by-catch for trawl gears in the western English Channel (ICES division VIIe). English and Welsh LPUE data indicated the John dory stock was centred to the south and west of the British Isles, but extended north into the Irish Sea and east into the southern North Sea during quarters three and four. The growth and exploitation pattern of John dory in the English Channel are described using length samples of commercial landings, discards, and research vessel samples taken between April 1994 and March 1996. In the English Channel the seasonal peak in landings during quarters three and four coincided with the period of recruitment. Recruitment was at a length of approximately 23 cm, most commercial landings were in the length range 23–39 cm, and the maximum observed length was 59 cm. A seasonal growth model fitted to quarterly length data indicted that recruitment took place at age 1+. The mean length of first maturity was estimated at 26 cm in males and 34.5 cm in females, and suggested that the eastern English Channel (ICES Division VIId) was a seasonal nursery ground for John dory. Some options for stock conservation are discussed.

Key words: *Zeus faber*, English Channel, exploitation, fisheries management, distribution.

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Introduction

The John dory, *Zeus faber* (Linnaeus, 1758), is a distinctive fish in the mixed species fisheries of southern England and Wales. It has been a highly regarded food fish for many years, but there have been no detailed descriptions of its fishery, no stock assessment, and no specific management measures have been introduced for its conservation. In UK waters, catch limits (Total Allowable Catches or TACs) for many commercial species (e.g. sole *Solea solea*; plaice *Pleuronectes platessa* and cod *Gadus morhua*) established under the Common Fisheries Policy of the European Community have become very restrictive. Consequently, there is the potential for fishing effort to be redirected towards species with no such protection, such as John dory.

The current status of the John dory population in UK waters is unknown, and investigations of the biology of John dory in the Northeast Atlantic have been limited. Cunningham (1892), Jenkins (1936), Duncker (1960), Wheeler (1969), and Quero and Robles-Pariente (1977) give general information on the species and some details of distribution. Warnes and Jones (1995) give its distribution in research vessel trawl catches in the Western Approaches, and Janssen (1979) describes the occurrence of small numbers of John dory in the Dutch commercial fisheries. More detailed investigations describe the length frequency in the Bay of Biscay and western Channel (Debrosses, 1939), length frequency and distribution in Portuguese waters (Silva, 1992), and diet in the Mediterranean Sea (Stergiou and Fourtouni, 1991), and in the waters to the west of Scotland (Gibson and Ezzi, 1987).

This paper describes the landings of John dory in the commercial fisheries of England and Wales, and uses more detailed catch data and biological samples from the English Channel (ICES Divisions VIId and VIIe) to

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Table 1. The total reported annual landings (tonnes) of John dory by ICES area and year made by vessels registered in England and Wales, with mean unit price and total value for all areas combined.

Year	VIIa	VIId	VIIe	VIIf	VIIg	VIIh	VIIj,k	IV	V, VI, VIIb-c	Unit price (£ kg^{-1})	Total value (£000s)
1980	0.0	0.1	33.5	10.0	0.2	0.6	0.5	0.1	0.4	1.59	72.4
1981	0.0	0.4	41.3	9.7	0.9	0.6	0.4	0.2	0.8	1.39	76.2
1982	0.0	1.9	42.7	20.8	0.3	1.3	0.4	0.4	0.0	1.33	90.4
1983	0.0	1.1	49.9	6.7	0.6	0.9	0	0.2	0.1	1.58	94.2
1984	0.0	1.7	43.8	12.6	0.3	2.7	0	0.2	0.0	2.08	128.2
1985	0.1	0.5	25.5	5.9	0.9	2.3	0.3	0.1	0.1	3.00	107.3
1986	0.1	0.9	34.9	10.7	0.8	3.8	0.2	0.1	0.1	2.49	129.1
1987	0.8	3.4	70.5	14.5	0.8	8.5	0.2	0.3	6.3	1.85	195.5
1988	1.5	1.6	89.7	12.4	1.5	11.6	0.4	0.8	6.5	2.26	284.6
1989	1.5	2.9	114.3	13.0	1.0	4.8	0	1.1	0.3	2.33	324.1
1990	0.5	2.9	105.6	18.4	0.4	15.0	0.1	0.1	0.1	2.95	423.1
1991	0.8	1.4	55.0	10.1	0.4	2.2	0.1	0.3	1.1	3.08	219.9
1992	2.6	2.5	84.5	17.0	3.4	5.5	4.7	0.6	0.5	2.90	351.7
1993	3.7	3.0	100.6	16.3	2.7	7.4	0.4	0.5	0.2	3.11	420.2
1994	3.8	3.3	162.3	32.0	8.0	42.7	3.5	2.3	1.9	3.17	826.1
1995	4.2	2.3	139.9	32.6	12.1	87.0	5.0	2.2	1.6	3.79	1087.8
1996	0.7	0.6	85.7	22.4	21.2	46.4	34.1	0.4	10.4	3.89	865.4
1997	1.0	1.2	48.3	23.6	5.0	42.7	21.0	0.3	4.4	4.68	691.2

Derived from data supplied by MAFF.

give an insight into the impact these fisheries may be having on the stock.

Material and methods

Fishery data

Data on fishing effort and landings of John dory made by all vessels registered in England and Wales were extracted from the Ministry of Agriculture, Fisheries and Food (MAFF) Fisheries Activity Database, for the years 1980–1997. It is possible that these data underestimated the true landings of John dory, as there was no statutory requirements for vessels to report landings of non-TAC species. However, my samples (see Biological Samples) indicated that the non-reporting of John dory landings during 1994–1996 was probably low, as only two out of the 118 boat trips sampled (31 out of a total of 2861 fish) subsequently failed to appear in the MAFF statistics. Although John dory were almost always landed gutted, the MAFF statistics are in live weight, where gutted weight was converted to live weight using a constant conversion factor of 1.125 (MAFF, unpublished data). Landings per unit of effort (LPUE) have been calculated from these data as kg (live weight) of John dory landed per day fished. These values should provide a more reliable index of catch rates or abundance of John dory than for species where landing constraints exist. Nevertheless, they are still affected by variations in boat power and size, net efficiency and size, actual duration of fishing activity, skipper ability, the species targeted, the proportion discarded etc. The LPUE were not corrected for these sources of error, as they were considered adequate for determining stock limits (Pawson, 1995).

In order to clarify the monthly patterns of landings and LPUE for fishing fleets in the English Channel, the annual component of variation was removed by expressing each monthly value as a percentage of the maximum value for that year, and then averaging these monthly values across years.

Biological samples

Quarterly length samples were collected from commercial landings made at ports on the south coast of England over the two year period April 1994–March 1996. The total lengths of 2861 John dory were measured to the cm below. For each of the 118 length samples, the sample weight and total weight landed (kg), date and place of landing, vessel registration, gear used and area fished was recorded. The sex and maturity of these fish could not be determined because the gonads had been removed when the fish were gutted prior to landing. Length samples were raised by weight (live weight), first to the total weight landed for the boat trip, then to the total landings by gear, region and quarter, and finally to the annual total landed weight.

Additional samples of the length–frequency distribution of John dory in commercial catches (both landings and discards) were available from a separate MAFF-funded survey made during 1995. This survey covered all

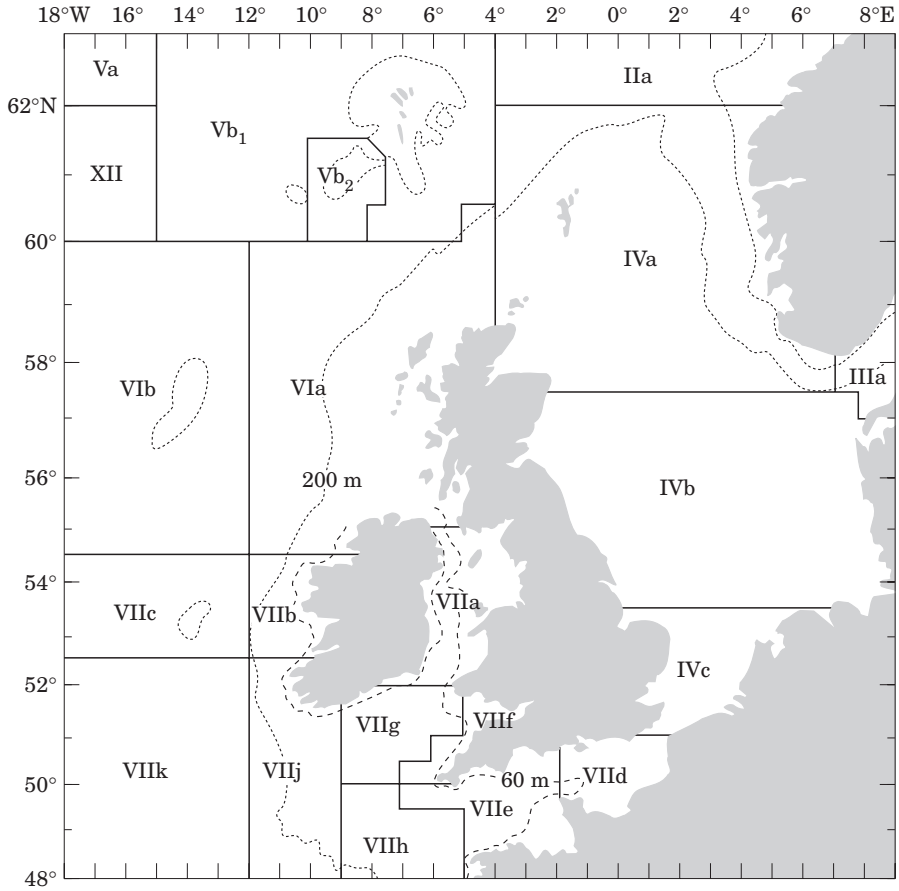

Figure 1. Map showing areas in the Northeast Atlantic. The approximate position of the 60 m and 200 m isobaths are indicated.

species, but sampled only towed gears (trawls and dredges). Onboard samples of usually one to two baskets of the whole catch were taken from each haul. In each sample the total lengths and combined weight of John dory were recorded. Samples were then raised by volume to the total for the haul. The haul-raised data were provided to this study further aggregated by quarter, gear and area fished (B. Lart, pers. comm.).

A final 68 John dory were available from the MAFF RV "Cirolana" cruise of the Western Approaches and Celtic Sea during March 1995 (Warnes and Jones, 1995). For each of these fish the total length, weight, sex, a macroscopic assessment of maturity, and the date and place of capture were recorded.

Bhattacharya's method (Bhattacharya, 1967) was used to identify the mean length and standard deviation of clear modes in the quarterly length frequency samples. Because there did not appear to be a consistent seasonal pattern of growth (see Results), both a standard and a sine wave form of the von Bertalanffy growth model (von Bertalanffy, 1957; Pitcher and Macdonald, 1973) were fitted to the modal progression using least squares. The standard von Bertalanffy growth model has the form:

$$L_t = L_\infty\{1 - \exp[-K(t - t_0)]\}$$

where L_t is total length (cm) at time t, L_∞ is the asymptotic length, K is the growth constant, and t_0 is the hypothetical time at which the model predicts zero length. The sine wave form of this model is:

$$L_t = L_\infty\{1 - \exp[-K(t - t_0) - C\sin 2\pi(t - t_2)]\}$$

where C controls the magnitude of the oscillations, and t_s is the starting time of the sine wave. Because there

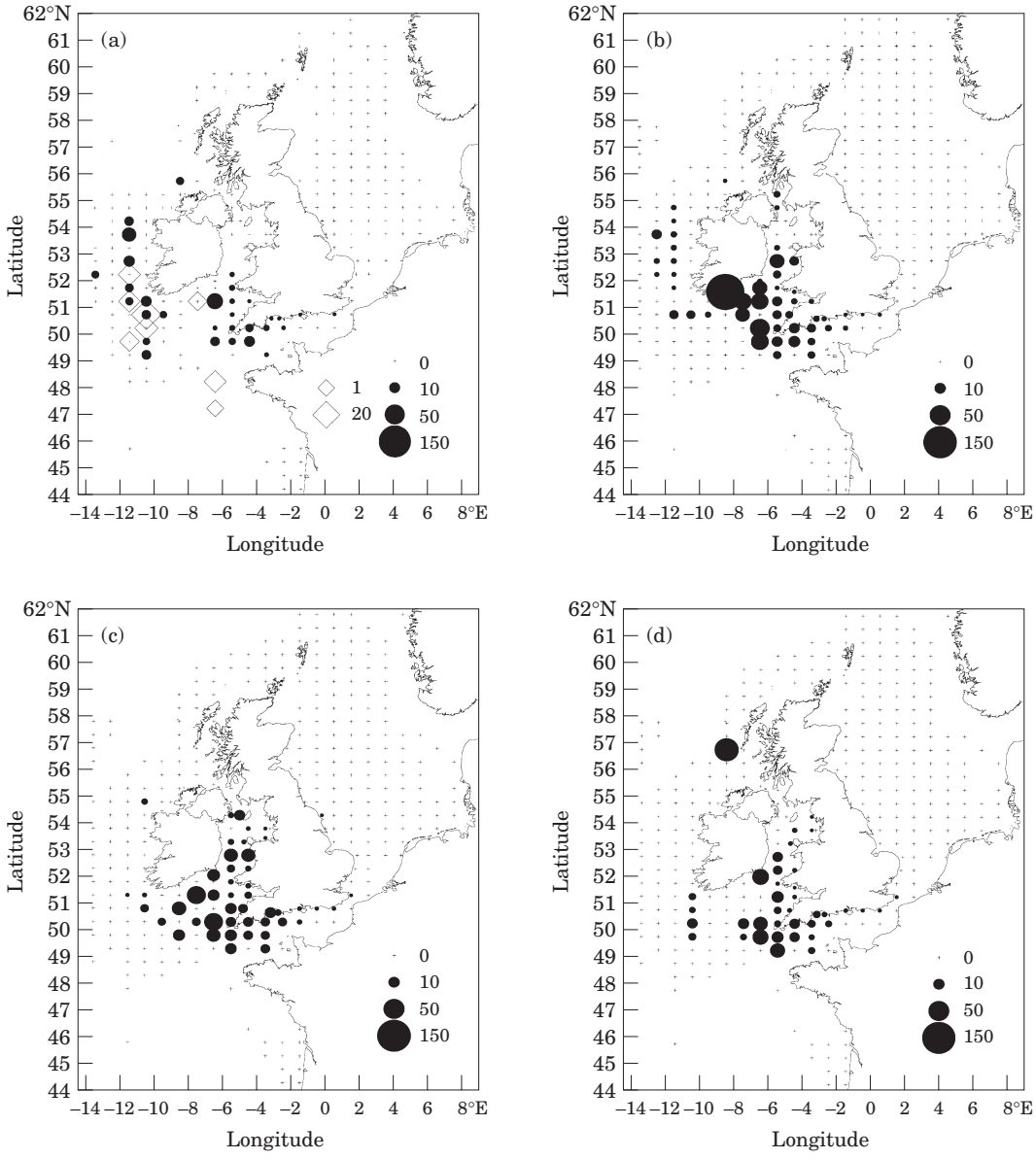

Figure 2. Spatial distribution of fishing effort by otter trawlers registered in England and Wales (crosses), with LPUE (kg d^{-1}) of John dory (filled circles). Data averaged for (a) quarter one 1995 and 1996, (b) quarter two 1994 and 1995, (c) quarter three 1994 and 1995, and (d) quarter four 1994 and 1995. Catches of John dory by RV "Cirolana" in March 1995 are shown in Figure 2(a) (diamonds).

were relatively few data points to fit the models the least squares function used was:

$$SSQ(m)/(N - 2n)$$

where SSQ(m) is the sum of squares for model m, N is the number of observations (data points) used, and n is the number of parameters used in model m (Efron and Tibshirani, 1993). This penalises additional model complexity by effectively removing two data points for each additional parameter.

Results

Current status of the England and Wales fishery

The landings of John dory have shown a general increase since 1980, although landings in the years

1985–1986, 1991 and 1997 were particularly low, and in 1994–1995 were particularly high, relative to the general trend (Table 1). The majority of John dory have consistently been landed from the western English Channel (ICES Division VIIe) (Figure 1), although the landings from the Western Approaches and Celtic Sea (VIIg, h, j and k) have increased since 1993. There have been relatively few landings of John dory from the eastern Channel (VIId), North Sea (sub-area IV), Irish Sea (VIIa), and areas to the west and north of Ireland (V, VI, VIIb–c).

The unit value of John dory at first sale steadily increased from approximately £1.50 kg^{-1} between 1980 and 1983 to over £4 kg^{-1} in 1997, and the value of annual landings by England and Wales vessels rose from approximately £70 000 in 1980 to over £1 million in 1995 (Table 1). This is a significant contribution to the total value of all demersal landings from the southwest (VIIe–h; approximately £38 million in 1995; MAFF Fisheries Statistics). The relative importance of John dory has also increased. During the last decade, the value of all England and Wales demersal finfish landings increased 1.5-fold, whereas John dory increased more than sixfold (1985–1987 compared with 1995–1997).

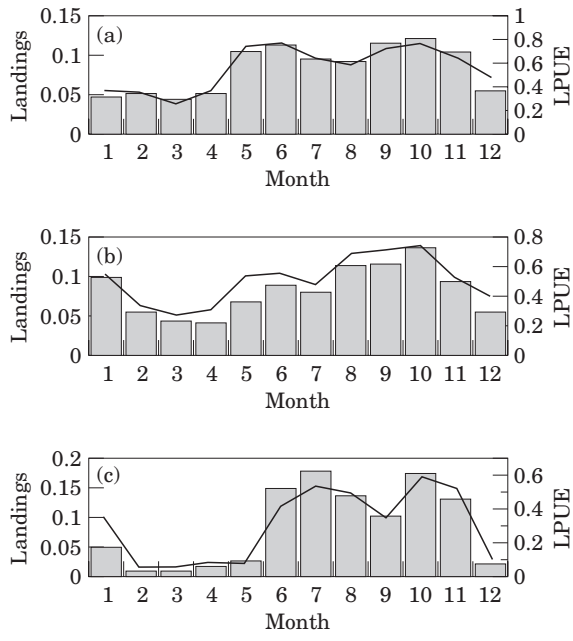

Figure 3. Monthly average landings (bars) and LPUE (lines) in the English Channel for the years 1990–1996 by (a) otter trawls in VIIe, (b) beam trawls in VIIe, and (c) otter trawls in VIId. Monthly values have been expressed as a percentage of the maximum value for each year averaged across years.

Spatial and seasonal distribution of LPUE

The spatial distribution of LPUE indicated that the centre of the population(s) of John dory were to the south and west of the British Isles (Figure 2). Landings of John dory from commercial vessels were not recorded further north than roughly 57°N on the west coast of Scotland, further south than the Brittany peninsula (roughly 49°N), and further west than 14°W. To the east the limit was in the coastal waters of the southern North Sea at roughly 54°N and 2°E. It is important to note that to some extent these limits represent limits of activity for England and Wales registered boats, and not necessarily the limits of distribution of the species.

Quarterly LPUE indicated that during quarter one there were two centres of abundance, one to the west and south of Ireland, and the other in the western Channel and Celtic Sea [Figure 2(a)]. During quarter two these concentrations began to extend eastwards into the eastern Channel and northwards into the Irish Sea [Figure 2(b)], reaching the southern North Sea and the Isle of Man by quarter three [Figure 2(c)]. The possibility that the concentration on the west coast of Ireland moved northwards into Scottish waters, areas which were rarely fished by otter trawlers from England and Wales, is not supported by Scottish landings data (S. A. Reeves, pers. comm.). During quarters three and four no landings were recorded from the west coast of Ireland [Figure 2(c) and (d)]. In quarter four John dory declined in abundance at the eastern and northern limits, although some remained in the Irish Sea and southern North Sea [Figure 2(d)].

Exploitation pattern in the English Channel

The most important England and Wales fleet in the English Channel exploiting John dory was the otter trawl fleet in VIIe, where roughly 200 boats in 1994–1995 landed approximately 125 t yr^{-1}. Otter trawlers operated throughout the region, but effort was concentrated in inshore waters (water depth <60 m; Tétard *et al.*, 1995) as the relatively small size of most boats (mean overall length of 12.5 m) prevented them from making long trips and thus fishing further afield (trip length was usually one day). Most fishers used the minimum allowable codend mesh size (80 mm). Although John dory were landed all year round, the largest landings were made between May and November [Figure 3(a)]. John dory were usually considered a valuable by-catch by these boats, although some seasonal targeting was also observed.

Beam trawls in VIIe accounted for the majority of the remaining landings of John dory in the Channel, with roughly 100 vessels landing approximately 30 t yr^{-1} during 1994–1995. Beam trawlers were generally larger (mean overall length of 23.5 m) than otter trawlers, and were eqipped to fish further offshore and for longer periods (trip length was usually 3–7 days). In addition,

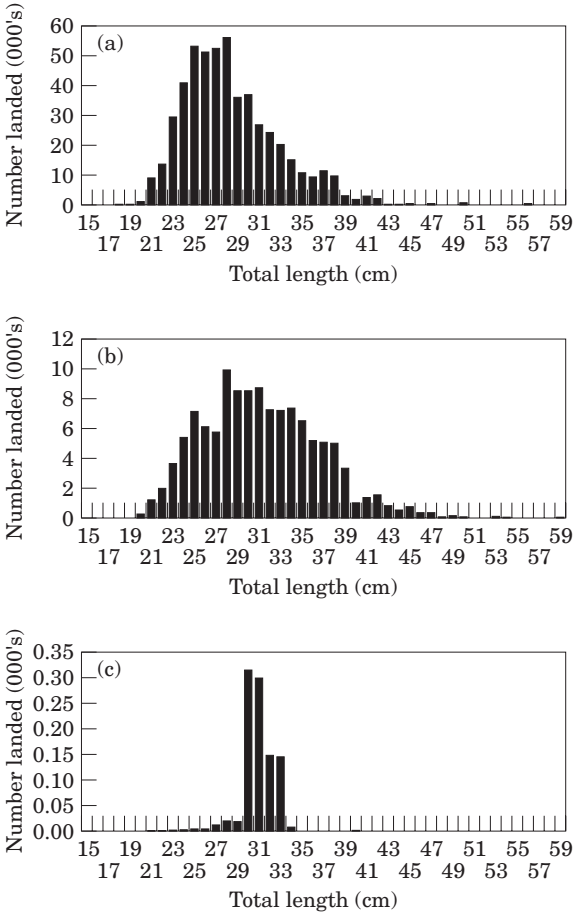

Figure 4. Raised length frequency distribution of John dory landed in the English Channel between April 1994 and March 1996 by (a) otter trawls in VIIe, n=1598, (b) beam trawls in VIIe and offshore in VIId, n=1075, and (c) otter trawls and inshore beam trawls in VIId, n=165. *n* indicates the total number of John dory sampled in each fleet.

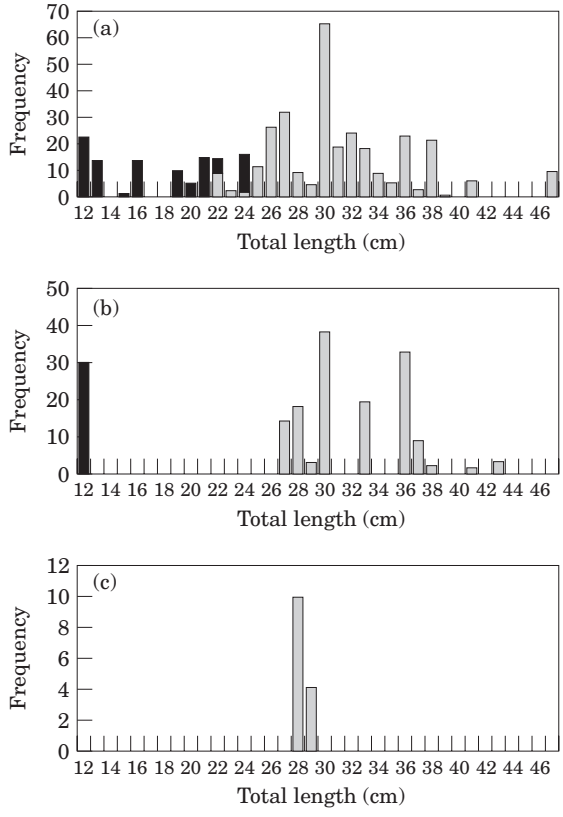

Figure 5. Length frequency distribution of John dory landed (light bars) and discarded (dark bars) in the English Channel from samples of catches during 1995 by (a) otter trawls in VIIe, n=408, (b) beam trawls in VIIe, n=174, and (c) otter trawls in VIId, n=14. *n* indicates the total number of John dory sampled in each fleet.

approximately 50% of the beam trawlers were move powerful than 221 kW, and were consequently restricted under EC law to fishing further than 12 nautical miles from the coast. As a result, most fishing activity took place on the offshore grounds (water depth <60 m; Tétard *et al*., 1995). Landings of John dory were made all year around, with the largest landings generally between August and October [Figure 3(b)]. John dory were also considered a valuable by-catch for this fleet.

Landings of John dory by other gears and from other areas in the English Channel were largely insignificant (<10 tonnes in total). However, the landings from VIId showed a much greater seasonality with John dory almost absent from the inshore landings between December and May [Figure 3(c)].

The smallest fish measured in the samples was 18 cm, the largest 59 cm. The majority of the fish landed from the Channel were between 23–39 cm (Figure 4). The discard survey revealed that smaller John dory of 12–22 cm were caught but subsequently discarded (Figure 5). Discards were most common in the otter trawl fishery in VIIe [Figure 5(a)], but also occurred in the beam trawl fishery [Figure 5(b)]. Most discards occurred during winter and spring. Because there was no legal restriction on the size of John dory that could be landed, discarding reflected market value and preferences.

Few fish greater than 34 cm, and none greater than 40 cm, were found in samples of landings from inshore waters in VIId [Figure 5(c); Figure 6]. Further, in VIIe a smaller proportion of larger fish (>36 cm) were found in samples of landings from otter trawls [Figures 6(a) and 7(a)] compared to beam trawls [Figures 6(b) and 7(b)]. It is reasonable to assume that discarding practices were similar between fleets, indicating that the majority of fish entering inshore waters in VIId during the summer and autumn were small (<36 cm), whilst both small and large fish occurred all year around in inshore waters of VIIe.

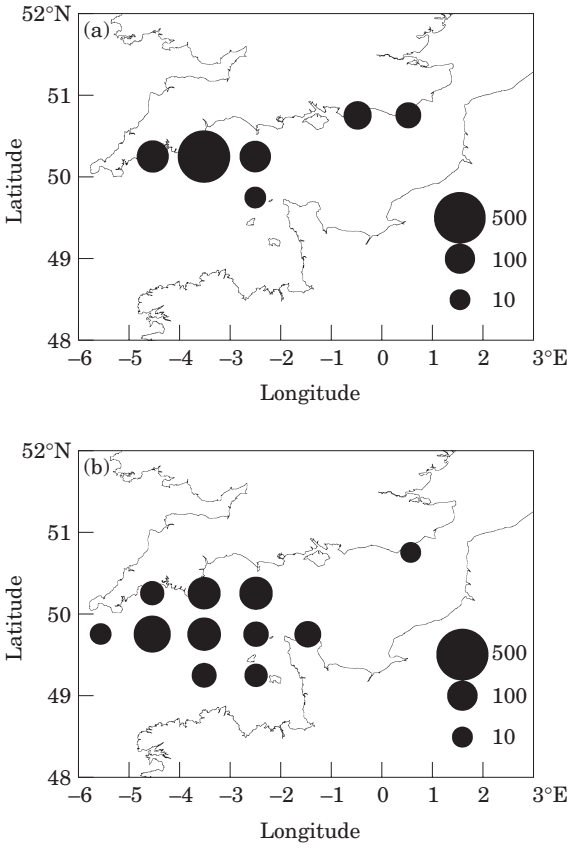

Figure 6. Number of John dory measured in samples of commercial landings between April 1994 and March 1996 made by (a) otter trawls and (b) beam trawls, plotted to the centre of the ICES rectangle to which they were reported.

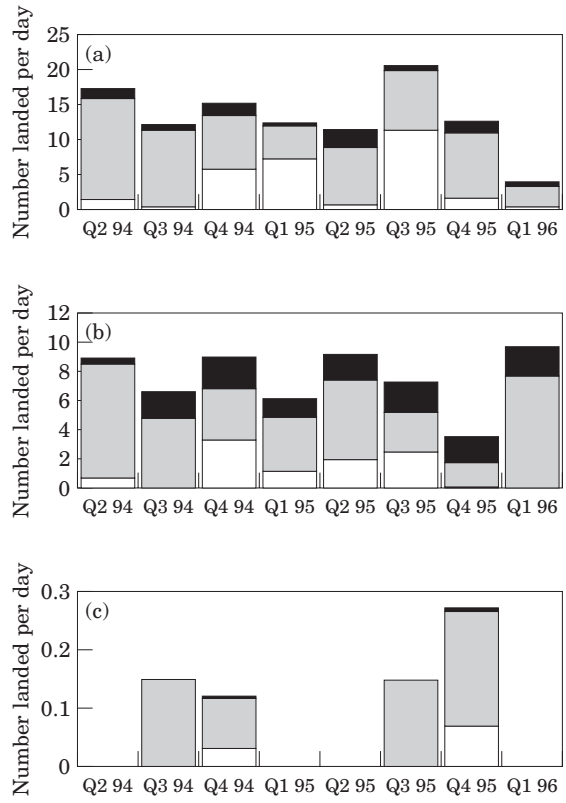

Figure 7. Quarterly numbers of John dory landed from the English Channel per day fished by length group between quarter two 1994 and quarter one 1995, by (a) otter trawls in VIIe, (b) beam trawls in VIIe and offshore in VIId, and (c) otter trawls and inshore beam trawls in VIId. Open <26 cm; stippled 26–35 cm; filled >35 cm.

If there was no difference in size-specific catchability between otter and beam trawls, then larger John dory were more abundant on the offshore grounds (Figure 7). The small (<21 cm) fish found in discard samples in VIIe [Figure 5(a)] were not observed in VIId [Figure 5(c)]. However this could be a consequence of the relative scarcity of John dory in VIId, combined with relatively few discard samples in quarters three and four (12 hauls sampled in VIId; 100 hauls sampled in VIIe).

Figure 7 further indicates that small fish recruited in quarter four 1994 and quarter three 1995. Recruitment appears to have been relatively good in 1995, with subsequent growth from the <26 cm to 26–35 cm size class and retreat from the inshore otter trawl grounds to the offshore beam trawls ground by quarter one 1996.

Growth in the English Channel

Bhattacharya's analysis determined between two and four cohorts in each quarter between April 1994 and March 1996 (Figure 8). It is likely that older cohorts were often present, but the samples were insufficient for older length modes to be confidently identified. The seasonal pattern of growth from modal progression was not always clear; for example, the apparent slowing of growth in winter 1994–1995 was not observed in winter 1995–1996.

Although John dory as small as 18 cm were landed, the discard surveys suggest that there could be positive bias in the mean length of the first mode due to discarding when the modal length was in the region of 20–25 cm. For this reason, the first mode in quarter three 1994 was excluded from the growth model fitting procedure. The last two modes in quarter three 1994 and the last mode in quarter four 1995 and quarter one 1996 were also excluded from the fitting procedure because they were considered potentially unreliable due to the small sample size. The best fit to the remaining mixed sex length data was given by the sine wave growth model, which is shown overlaid on Figure 8 (see also Table 2). Inclusion or exclusion of the data point at 12 cm in quarter two 1995 was influential to the fit of the standard von Bertalanffy growth model, but made little

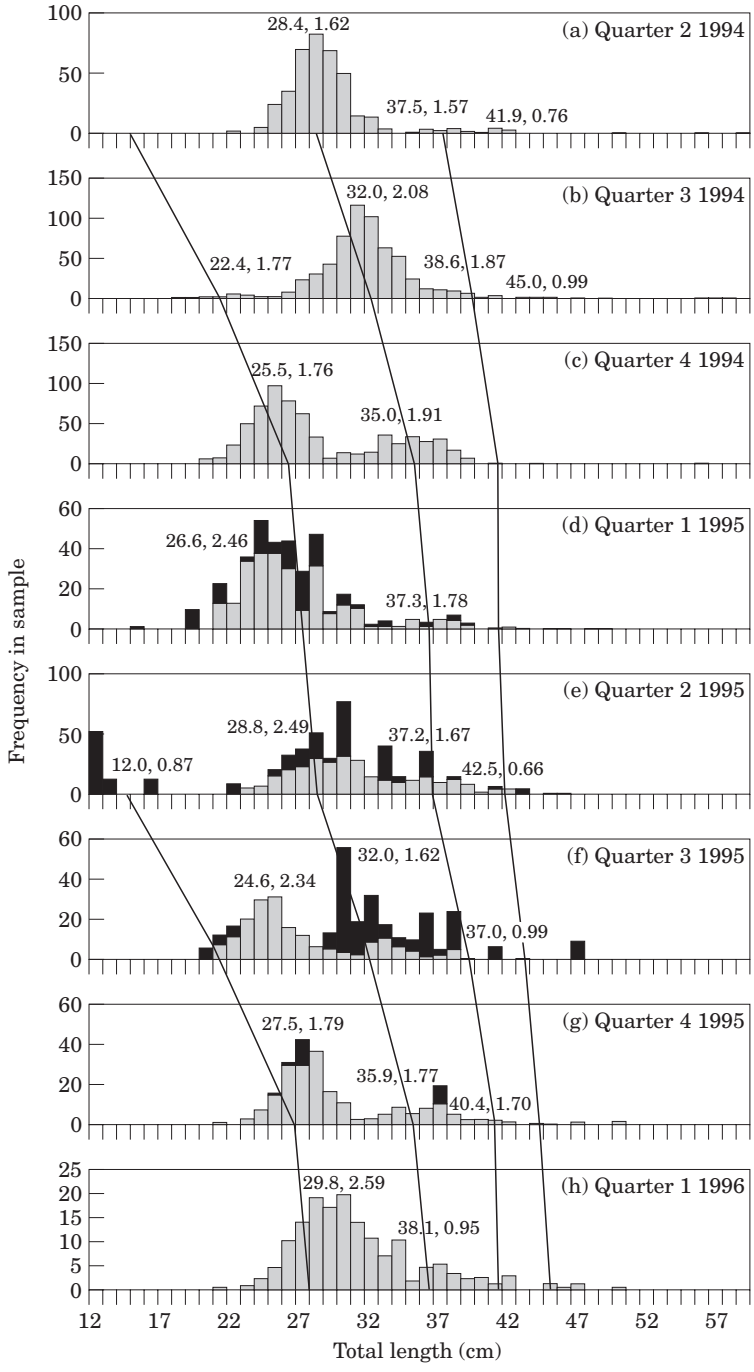

Figure 8. Quarterly length–frequency distribution of John dory in samples of commercial landings (light bars) and samples of both discards and landings (dark bars), from the English Channel. The mean length and standard deviation identified using Bhattacharya's analysis are shown next to each mode. The best fit of the sine wave growth model is indicated by the overlaid lines.

difference to the fit of the sine wave model. Both models confirmed that most recruitment took place in quarter four 1994 and quarter three 1995, and indicated that new recruits were one year old.

Maturation estimated from RV samples

The area from which the samples were taken is shown in Figure 2(a), and the sample length distribution is shown

Table 2. The parameters of the standard and sine wave von Bertalanffy growth models fitted to the modal progression of mixed sex John dory.

L_∞	43.3	50.8
K	0.80	0.47
t_0	− 1.13	− 1.47
C	—	− 0.08
t_s	—	0.16
SSQ	5.44	5.01

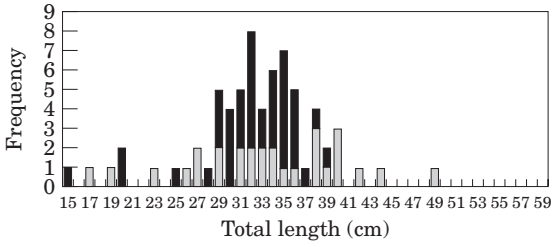

Figure 9. Length frequency distribution of male (dark bars) and female (light bars) John dory in samples from the cruise of RV "Cirolana" in March 1995.

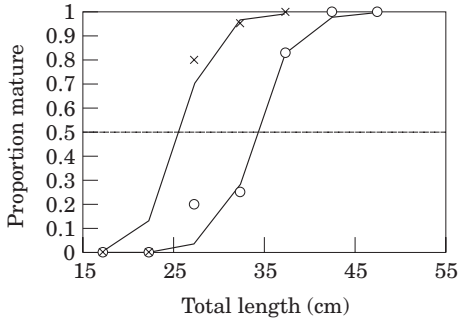

Figure 10. Proportion of male (x) and female (o) John dory mature in each 5-cm length class in the samples from RV "Cirolana" in March 1995. A logistic model has been fitted to the data to calculate the mean length of first maturity (50% mature: indicated by the broken line).

in Figure 9. The mean length at first maturity was estimated as 26 cm in males and 34.5 cm in females (Figure 10). As the number of samples was small (40 males; 28 females) and from a restricted area there is a high degree of uncertainty in these estimates.

Discussion

This study indicates that John dory were most abundant in the waters to the south and west of the British Isles, which is consistent with the general description given by Wheeler (1969). It also indicates that the larger fish of 40–59 cm did not enter the inshore waters of the eastern Channel. The seasonal occurrence of smaller (<40 cm) John dory in the inshore waters of the eastern Channel and southern North Sea is supported by the observations of Janssen (1979) who, between 1960 and 1977, found John dory of only 11–42 cm in Dutch waters during June–November. The size of first maturation I have estimated is in good agreement with the estimates by Duncker (1960), who estimated first sexual maturation of males at 25–28 cm, and females at 34–38 cm. If this size of maturation is correct, then the fish found in the eastern Channel were mostly immature, and inshore areas of the eastern Channel and southern North Sea can be regarded as seasonal nursery grounds for John dory. On the same premise, the Irish Sea may also be a seasonal nursery ground for John dory.

The pattern of growth is in good agreement with the description of Debrosses (1939), and with Janssen (1979), who applied the crude age–length key of Wheeler (1969) to Dutch length samples, but is somewhat different from that indicated by Silva (1992) for Portuguese waters. Silva observed a modal length of 10–14 cm in summer growing to 18–22 cm by the autumn, and reaching 23–26 cm by the following summer (Silva, 1992). This is consistent with the first mode observed by Silva (1992) being 0-group originating from an earlier spawning further south, a phenomenon which has been observed for many other species (Laevastu and Hayes, 1981). Nevertheless, knowledge of the growth of John dory remains insufficient because the detailed estimates (Debrosses, 1939; Silva, 1992; this study) are all length-based, with mixed sex samples, where sex-specific growth patterns are likely (Debrosses, 1939).

The growth model indicated that recruitment to the English Channel fishery took place in the summer and autumn at age one or more and a length of approximately 23 cm. This means that part of the seasonal peak in landings during quarters three and four could be due to recruitment, in which case some of the inter-year variation in the size of the seasonal peak in landings could be due to the size of the recruiting cohort. Given that the trawl fisheries are largely opportunistic, it is unlikely that the seasonal patterns are solely due to changes in targeting/area fished. A second hypothesis is that there was a seasonal migration of John dory into the Channel from areas to the west and/or south. This is given support by the presence of a peak in LPUE in all areas starting in quarter two (before recruitment), and the wide spatial distribution of the stock. The most likely explanation for the seasonal pattern in landings is therefore a combination of migration and recruitment.

At present, it is difficult to make a quantitative assessment of the impact of fisheries on the John dory stock using length-based assessment methods because of the complications of the seasonal size-specific distribution, and the possibly incomplete sample of the stock. Even if this was possible, the status of John dory primarily as a by-catch species effectively precludes directed stock conservation options such as limited entry

or a minimum mesh size. For similar reasons, measures such as a minimum landing size or a restrictive TAC are likely to lead only to increased discarding rather than reduced fishing mortality. Even if the capture of juvenile fish could be avoided, there would be no long-term benefit for the inshore fishing fleets, just a reduction in revenue, because the larger adult fish appear to congregate on more offshore grounds. Consequently, under current conditions in the fishery, and with current knowledge, it would not be possible to modify the exploitation pattern in such a way as to benefit the conservation of John dory.

Acknowledgements

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