

## Stock Annex: Blue ling (*Molva dypterygia*) in subareas 6–7 and Division 5.b (Celtic Seas, English Channel, and Faroes grounds)

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Stock specific documentation of standard assessment procedures used by ICES.

<b>Stock:</b>	Blue ling
<b>Working Group:</b>	Working Group on Biology and Assessment of Deep-sea Fisheries Resources (WGDEEP)
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<b>Last updated:</b>	April 2020
<b>Last updated by:</b>	P. Lorance WGDEEP 2020

### A. General

#### A.1. Stock definition

Based upon biological investigations in the early 1980s it was suggested that at least two adult stock components were found in the Northeast Atlantic, a northern stock in Subarea 14 and Division 5.a with a small component in 5.b, and a southern stock in Subarea 6 and adjacent waters in Division 5.b. This was considered supported by differences in length and age structures between areas as well as in growth and maturity (Magnússon and Magnússon, 1995). Egg and larval data from early studies also suggested the existence of many spawning grounds in ICES Division 5.a, 5.b and Subarea 6 and elsewhere and were considered suggesting further stock separation. However, in most areas, except Icelandic waters, small blue ling below 60 cm do not occur and fish appear in surveys and commercial catches at 60–80 cm suggesting scale large spatial migrations and therefore limited population structuring. There was also reported differences in length-at-age but these may have come from different interpretations of growth rings in otoliths. The formerly presumed slower growth in Icelandic waters compared to the Faroes and Shetland areas is challenged by the comparison of recent length-at-age of blue ling from Areas 5.b, 6 and 7 and mean length-at-age in Icelandic waters estimated in the 1980s (Figure 1).

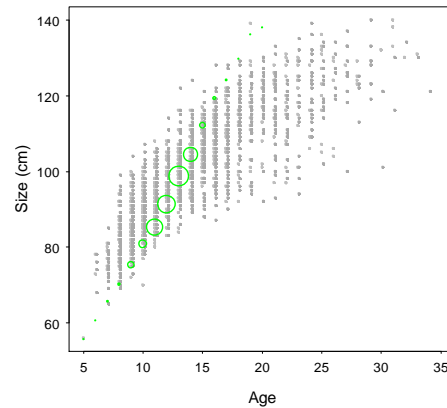


Figure 1. Age-length-key from French age estimates (years 2009–2013 combined,  $n=2222$ ), compared to mean-length-at-age estimated in Icelandic waters in the early 1980s (green circles, the diameter of circle in proportion to the number of fish,  $n=994$ , redrawn from Magnússon and Magnússon (1995).

The assessment unit was defined as ICES Division 5.b and Subareas 6 and 7. In Subareas 6 and 7, only adults fish occur, juveniles are not caught to any significant level. The situation is slightly different in Division 5.b where some small fish occur in small numbers. These were used for age and growth estimation purposes (Magnussen, 2007). However numbers caught in Faroese trawl surveys do not seem significant to the size of the exploited adult stock. Further, unlike in Icelandic waters where small blue ling caught in shallow (100 m or less) waters and blue ling of less than 60 cm caught along the upper slope make in some years more than half the total number caught in trawl surveys, blue ling is almost not caught shallower than 200 m in Faroese waters (Figure 2).

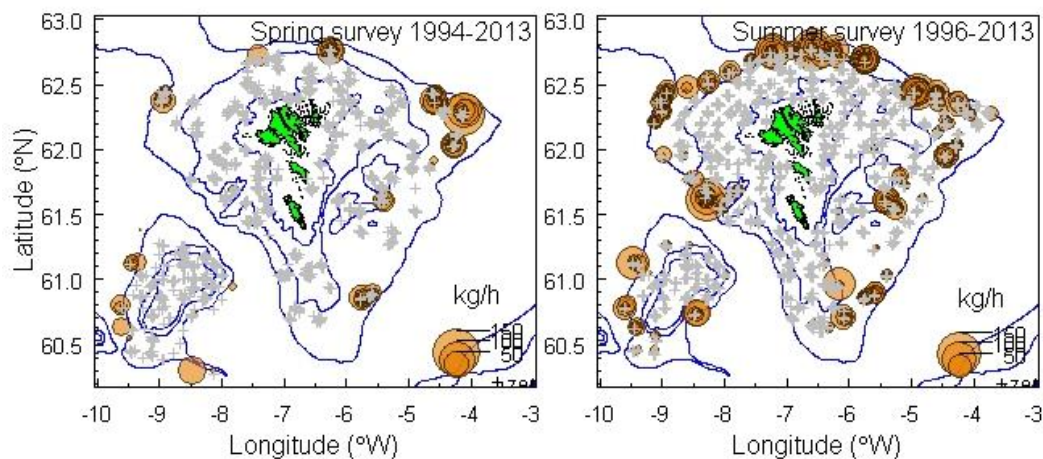


Figure 2. Spatial distribution of blue ling caught in the Faroese spring and summer surveys from the 1990s to 2013, depth contours are 100, 200 and 500 m.

Similarly, in the neighbouring ICES Division 12.b, from where landings are currently a few hundred tonnes per year but have been higher in the past, only adult fish are known to be caught and as the western Hatton Bank in 12.b is the continuation to the west of the Bank located in 6.b, ICES Division 12.b should be considered as the same stock as blue ling in 5.b, 6 and 7. This will only impact marginally the assessment results as catch in recent years in 12.b have been small compare to catch in 5.b, 6 and 7. Higher catch were caught in the past and this would result in slightly higher estimates of the initial biomass in the SRA (see below).

### Spawning areas

Blue ling spawning occurs (i) in 5.b, on the southern and southwestern margins of Lousy Bank; (ii) in 6.a along the continental slope northwest of Scotland and close to of Rosemary Bank; (iii) in 6.b on the margins of Hatton Bank (Figure 3) and is considered to take place at depths of 730–1100 m between March and May inclusive in 5.b and 6.a, and during March and April in 6.b. From 1970 to 1990, the bulk of the fishery for blue ling was seasonal fisheries targeting these aggregations. To prevent depletion of adult populations, temporal closures were introduced by the EC in 2009 within ICES Division 6.a.

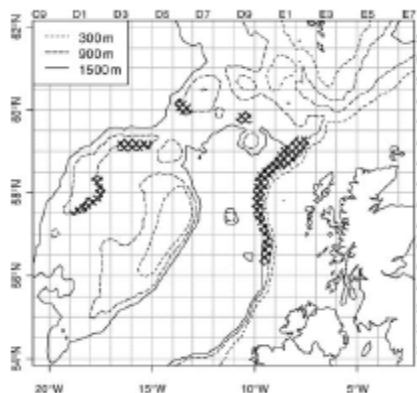


Figure 3. Known spawning areas of blue ling to the West of Scotland (from Large *et al.*, 2010).

Analyses of Faroese survey data were presented in 2018 (Ofstad, 2018, WD). Analysed data include a Faroese blue ling survey from 1995 to 2003 and the larvae data from the Faroese 0-group survey 1995-2017. These analyses reveal the occurrence of some spawning areas in Faroese waters and very small numbers of larvae were observed pelagically in the 0-group survey in June/July (see stock annex).

### A.2. Fishery

The main fisheries are those by Faroese trawlers in 5.b and French trawlers in 6, mostly 6.a, and, to a lesser extent, 5.b. Total international landings from Subarea 7 are small bycatch in other fisheries. In Subarea 5.b and Division 6, other fisheries landings blue ling are the Norwegian longline fishery for ling and tusk where blue ling is a bycatch and Scottish trawlers. Landings from these fleets have been small since the 2000s. Scottish trawlers landed the species mainly from the mid-1990s to early 2000s when their landings exceeded 1000 t/year. German vessels fished 1000 to 7000 t/year

from the late 1960s to early 1980s. Norwegian landings were also up to 4000 t in 1973 but have decreased to less than 100 tonnes after 2000.

Landings from Subareas 8 and 9 previously reported as blue ling are now ascribed to the closely related Spanish ling (*Molva macrophthalma*) and blue ling is not known to occur to any significant level in these subareas. The area of distribution of the stock is limited to somewhere between 50 and 55°N along the Porcupine Bank slope (Bridger, 1978; Ehrich, 1983, Lorange *et al.*, 2009).

Landings by Faroese trawlers are mostly taken in the spawning season. Historically, this was also the case for French trawlers fishing in 5.b and 6. However, in the 1990s and 2000s blue ling has been taken mainly in a mixed French trawl fishery for roundnose grenadier, black scabbardfish and blue ling. Increasingly in the 2010s, this fishery has been further mixed with fishing for shelf species such as saithe, hake, monkfish and megrim.

The rapid increase in the size of this fishery in the early 1970s is considered to be related to the expansion of national fisheries limits to 200 nautical miles and the resultant displacement of fishing effort and the associated development of markets.

### **A.3. Ecosystem aspects**

## **B. Data**

### **B.1. Commercial catch**

#### **B. 1.1. Landings and discards**

In 2008, the landings time-series from the southern blue ling stock was extended back to 1966 based on North Western Working Group reports from 1989–1991 and data in Moguedet (1988). Landings data in the 1980s for French freezer trawlers may be underestimated in some years but were included in 2011 for years 1988–2000. Landings by country and area for years before 2000, which are unlikely to be further revised are presented in appendix 1 of this stock annex.

Large French catches were reported as ling at the start of the fishery in 1973–1975. In order to derive a best estimate of blue ling landings in these years, the average ling landings in the years preceding the start of the French blue ling fishery were subtracted from estimates of blue ling and ling combined. It is worth noting that the time series of landings from this stock start from the onset of major fisheries for the species, when the stock was close to a "pristine" condition.

Landings data by ICES statistical rectangles have been provided by France, (UK) Scotland, UK (England and Wales), Spain (Basque country fleet fishing along the continental slope to the West of the British Isles) and Ireland and have been aggregated by quarter and plotted to display the geographical distribution of the fishery by year starting from 2005.

Blue ling is not discarded to any significant level because no small blue ling are caught in the fishery.

**B.2. Biological**

Available growth parameter in length and weight for blue ling are summarized in Tables 1 and 2 and maturity parameters in Table 3.

Table 1. Growth parameters of blue ling.

$L_{\infty}$ (CM)	$K$ (YEAR <sup>-1</sup> )	$T_0$	NUMBER OF FISH	AGE RANGE	SEX	MAXIMUM OBSERVED SIZE	AREA	REFERENCE
160	0.11	N/A	79	3-17	Combined		Faroe Bank	Magnussen, 2007
165.8	0.084	-0.138	N/A	? - 20	Female	147 (1)	ICES 6.a	Moguedet, (1985, 1988)
112.2	0.158	0.318	N/A	? - 19	Male	110	ICES 6.a	(1)
125	0.152	1.559	2619	5-25 (2,3)	Combined	136 (3)	5.b 6.a,b	
145.2	0.155	1.281	1412		Female		5.b 6.a,b	Ehrich and Reinsch, 1985
109.7	0.199	1.833	1391		Males		5.b 6.a,b	(4)
116.25	0.17	0.57	590	5-20+	Female	130	Faroe Islands (5)	
104.2	0.197	0.57	331	5-20+	Male	107	Faroe Islands (5)	
137.37	0.13	0.46	117	6-18+	Female	139	Shetland Islands (5)	Thomas, 1987
108.31	0.185	0.57	227	5-20+	Male	109	Shetland Islands (5)	
			563	20 +	Female	138.5 (7)	Icelandic slope	
			431	17	Male	115 (7)	Icelandic slope	
			1492	20+ (6)	Combined	137.86 (7)	Icelandic slope	
			?	?	Combined	145-150 (8)	Iceland and RR (9)	Magnússon and Magnússon, 1995
			?	?	Female	140	Spawning aggreg. RR (9)	
			?	?	Male	124	Spawning aggreg. RR (9)	
			1399		Combined	130-135 (10)	West of the British Isles	Bridger, 1978
					Female	ca 145 (11)	West of the British Isles	Ehrich, 1983
					Males	ca 112 (11)	West of the British Isles	
			240 (♂+♀)		Female	150-155 (12)	West of the British Isles	Gordon and Hunter, 1994
			240 (♂+♀)		Male	110-115 (12)	West of the British Isles	Gordon and Hunter, 1994
			197		Combined	140	Norwegian Deep	Bergstad, 1991

(1) from sampling in 1984-85; Female  $\geq 130$  cm were 3% of total female numbers; (2) the bulk in age groups 7–20; (3) from length distribution of German landings 1980 and 1982; (4) estimates based upon length and age data from sampling of German blue ling landings (Ehrich and Reinsch, 1985). (5) based upon sampling in 1977 and 1979 (Shetland Islands) and 1977 and 1978 (Faroe Islands); areas are defined according to Figure 1 (Thomas, 1987). (6) Magnússon and Magnússon (1995) reported mean length by age for the years 1978–1982. In their sample ( $n=1492$ ), there was seven fish of the age group 20+ . (7) From age estimation sample; mean length of the oldest age group: six individuals for females, one for males, seven combined; (8) visually from length distribution plots; few fish above 130 cm; (9) RR: Reykjanes Ridge; (10) from a plot of length distribution by 5 cm length classes. Largest length class was 130–135 cm. It included 1–2% of total number of fish measured, they modal size class was 95–99 cm; (11) from plot, modal size by 120 cm for females and 95 cm for males. (12) From SAMS surveys (unpublished data), from histogram by 5 cm size classes. Modal sizes of 95–100 cm for males and 105–110 for females,  $n=240$  (sex combined).

Table 2. Growth parameters in weight.

$W_{\infty}$ (G)	K	$T_0$	NUMBER OF FISH AGED	LENGTH RANGE (TL, CM)	AGE RANGE (Y)	SEX	REFERENCE	AREA
19 688	0.094		79	NA	3 - 17	Combined	Magnussen, 2007	Faroe Islands
5191						Male	Ehrich and Reinsch, 1985	
13 166						Female	Ehrich and Reinsch, 1985	

Table 2. Maturity parameters, A50: age at 50% maturity; m: rate at which the population attains maturity (Magnussen, 2007); L50 length at 50% maturity; M50 weight at 50% maturity.

SEX	AREA	A50	M	L50 (CM)	M50 (G)	REFERENCE
Combined	Faroe Bank	6.2	1.66	79	1696	Magnussen, 2007
Female	Iceland	11	N/A	88	N/A	Magnússon and Magnússon, 1995
Male	Iceland	9	N/A	75	N/A	Magnússon and Magnússon, 1995
Female	Faroe Islands	8.1	N/A	N/A	N/A	Thomas, 1987 (1)
Male	Faroe Islands	6.4	N/A	N/A	N/A	Thomas, 1987 (1)
Female	South and West of the Faroe Islands	7	N/A	85		Magnússon et al., 1997
Male	South and West of the Faroe Islands	6	N/A	80		Magnússon et al., 1997
Combined	ICES IIa	N/A	M/A	75		Joenes, 1961

(1) The author specified that not too much significance should be given do the result because very few immature fish were caught and stated "it might be sufficient to know that the fish mature at an age between 6 and 8 years".

**Table 3. Coefficient a and b of weight–length relationship  $W=a*L^b$  for blue ling (all available decimal kept in view of the ICES rounding.**

AREA	SEX	A	B	NUMBER OF FISH	SIZE RANGE (CM)	WEIGHT RANGE (G)	REFERENCE
ICES 6	Combined	0.00191	3.14882	280	62 - 142		Dorel, 1986
ICES 6	Males	0.002	3.02	NA	69 - 109	715 - 2900	Moguedet 1988
	Females	0.0023	3.00	NA	74 - 142	1150 - 8600	Moguedet 1988
ICES 5b*	Combined	0.001843162	3.18805	1054	31-139	92 - 12370	Observed weight length relationship in the summer Faroese survey

\*: relationship used for calculating the weight of measured samples and raising length distribution to total landings.



### B.2.1. Length composition

Length compositions of the landings have been available from Faroese trawlers in Division 5.b since 1996 and French trawlers in Division 6.a since 1984. Mean length of blue ling from the Norwegian reference fleet in divisions 5.b, 6.a, 6.b are also provided. Age estimation of blue ling was carried out in the past and was disrupted because consistency between readers was considered poor. Nevertheless, there is a general agreement that blue ling recruits to this stock at a size of 70–80 cm have an age of 6–8 years. Age estimation of blue ling sampled from French landings was resumed in 2009 in application of DCF. Reading scheme for estimating the age of blue ling does not significantly differ for that of most gadoid species although the number of growth increments to count is higher (Figure 4). Nevertheless, age estimations for this species are unvalidated.

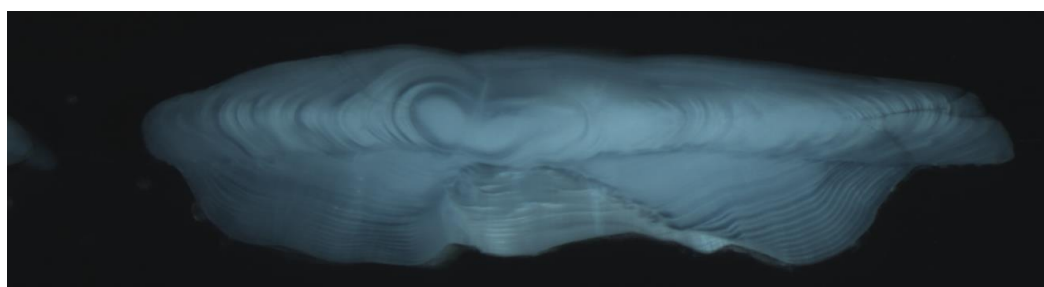


Figure 4. Thin sections of blue ling otolith.

### B.2.2 Weight-at-age

No time-series but overall weight-at-age are derived from age-length keys and length-weight relationships. There is not quarterly weight-at-age data.

Weight-at-age are assumed similar in the stock and in landings.

### B.2.3. Maturity and natural mortality

Natural mortality ( $M$ ) was estimated using the relationship (Annala, J. H., Sullivan, K. J. (1996):

$$M = \ln(100)/\text{maximum age}$$

In this relationship, the maximum age should be set at the age where 1% of a year class is still alive. Based on Faroese and French age readings and considering a maximum age for blue ling at 30 years  $M$  has been presumed in the order of 0.15. In a compilation of published age data as part of the EU DEEPFIHSMAN project more than 4000 individual age data were found, none exceeded 25 years. Based on this the maximum age was refined as 25. As a consequence,  $M$  estimated from the relationship from Hoenig (Hoenig, 1983; Hewitt and Hoenig, 2005) and from was maximum age relationship above has been refined to 0.18. The empirical relationship from Pauly (1980) applied by WKLFIE) with growth parameters  $K=0.152$  and  $L_{\infty}=125$  for both sex combined (Ehrich and Reinsch, 1985) returns a similar  $M$  of 0.19.

Higher ages are estimated from fish sampled in French landings since 2009 in application of the Community framework for the collection, management and use of data in the fisheries sector, with ages older than 30 years being estimated. The age estimation method is considered using the best recent standards but age obtained are unvalidated.

Older age estimated in recent years and comparison of stocks numbers estimated in the two models used from assessment (SRA and MYCC see below) led to assume a natural mortality of  $M=0.11$  (ICES 2014).

Juvenile blue ling are not known to occur on the fishing nor in Subareas 5.b, 6 and 7 to any significant level. Fish recruit to this area and to the spawning stock at an age of 6 to 8 years. All blue ling occurring in 5.b, 6 and 7 can be considered as mature fish.

### B.3. Surveys

Weight and number per hour trawling in the Faroese spring survey since 1994 have been provided. Number have been provided for small (<80 cm) and large (>80 cm) fish. However, it was stressed that these surveys are limited to depth shallower than 500 m. These data may provide useful information on recruitment.

An index of abundance in number per hour was available from the Marine Scotland Deep-Water Science Survey to the west of Scotland for years 1998–2011. The fish community of the continental shelf slope to the northwest of Scotland has been surveyed by Marine Scotland-Science since 1996, with strictly comparable data available between 1998 and 2008. This has focused on a core area between 55–59°N, with trawling undertaken at depths ranging from 300 to 1900 m with most of the hauls being conducted at fixed stations, at depths of around 500 m, 1000 m, 1500 m and 1800 m. Further hauls have been made on seamounts in the area, and on the slope around Rockall Bank, but these are exploratory, irregular and are not taken into account in the index of abundance. This survey was conducted biennially, in September, until 2004, and annually in 2004–2009. Locations of trawl sites between depths of 500–1500 m are shown in Figure 5. From 1998 to 2008 the bottom trawl was rigged with 21" rock-hopper groundgear, however in 2009, a switch was made to lighter groundgear, with 16" bobbins.

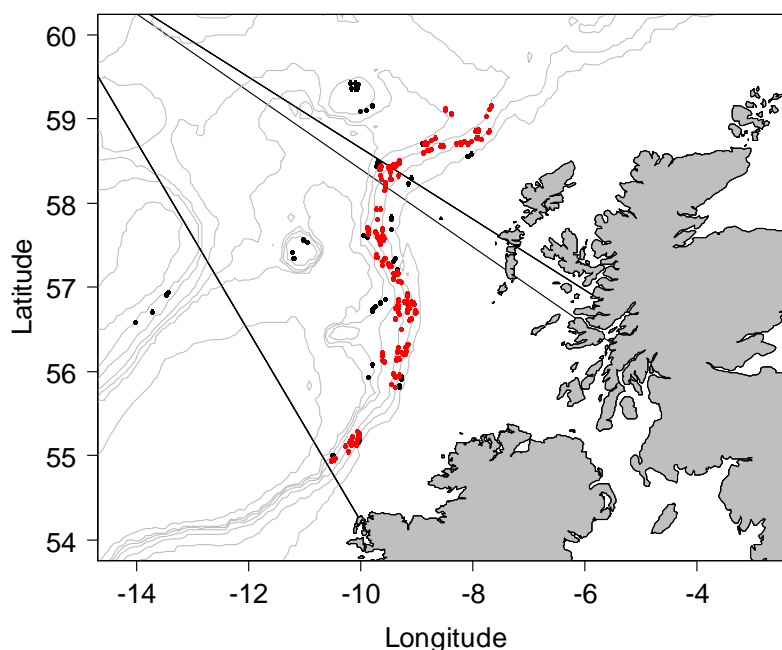


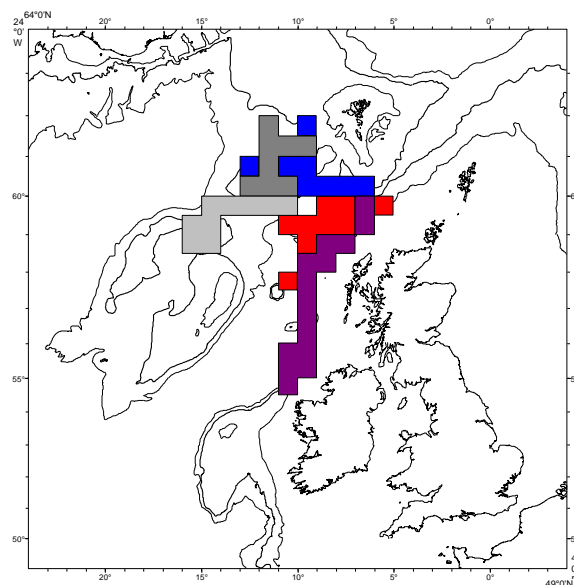
Figure 5. Sites of valid hauls in the 500–1500 m depth band in the Marine Scotland Deep-Water Science Survey, 1998–2009 (in red). Valid hauls at other depths are shown in black.

An index of abundance was available from an Irish deep-water trawl survey of the fish community of the continental shelf slope to west and northwest of Ireland carried out from 2006 to 2009. The sampling protocol of this survey was standardised in accordance with the Marine Scotland Deep-Water Science Survey with trawling at fixed stations around 500 m, 1000 m, 1500 m and 1800 m. The gear used throughout the surveys series was the same as that used by Scotland in 2009. To be consistent across the years the haul data used for the index calculation only includes the areas that are covered in all four years and the depth bands (500–1500 m) that are covered in all four years. In total, the dataset comprised 42 valid hauls.

#### B.4. Commercial cpue

A French deep-water tallybook database (based on fishers' own records) developed by the French industry is used to compute Landings per Unite of Effort (lpue) indices starting from year 2000 (Lorance *et al.*, 2010). The database includes more years back to 1992 with landings of blue ling back to 1993. However, there is not enough data on blue ling before 2000 because of different components of deep-water vessels being included and small catch of blue ling from vessel contributing to the data in 1993–1999. The abundance index is standardized using a GAM model.

To represent the spatial aspect in the model, five small areas where the fleet has caught blue ling were defined as clusters of ICES rectangles (Figure 3). Fishing area definition was based on a working paper presented at WGDEEP 2006 on an analysis of logbook data. In this working document fishing grounds, exploited since the 1990s were denoted ref5 (for reference 5), edge6 (for edge of continental slope) and other6 (for other fishing grounds in 6. New fishing grounds, i.e. not fished by French trawlers for fresh fish before 2000 in ICES Division 5.b and Subareas 6 were denoted new5 and new6 respectively (Figure 6).



**Figure 6.** Areas (clusters of statistical rectangles) used to calculate French lpue for blue ling. Dark grey, new grounds in ICES Division 5.b (new5); light grey, new grounds in Subarea 6 (new6); red, others in Subarea 6 (other6); purple, edge in 6 (edge6); blue, reference in Division 5.b (ref5).

The GAM models used to standardize the haul-by-haul catch data has the form:

$$\log(E[\text{landings}]) = s(\text{haul duration}) + s(\text{depth}) + \text{month} + \text{vessel.id} + \text{rectangle} + \text{year:Area}$$

where  $E[]$  denotes expected value,  $s()$  indicates a smooth nonlinear function (cubic regression spline),  $vessel.id$  the vessel identity and  $year:area$  an interaction term. The dependent variable is landings and not  $lpue$ , which allows including haul duration as explanatory variable and have a non-proportional relationship between landings and fishing time. The fit was done assuming a Tweedie distribution of the dependent variable with a log-link function using the *mgcv* package in R (Wood, 2006).

The Tweedie distribution has mean  $\mu$  and variance  $\varphi\mu^p$ , where  $\varphi$  is a dispersion parameter and  $p$  is called the index. As a Poisson-Gamma compound distribution was used,  $1 < p < 2$ , the index  $p$  could not be estimated simultaneously with the model parameters. In 2010, a detailed study was carried out and  $p=1.3$  provided the best fit (Lorance *et al.*, 2010).

In 2009, the model fit was restricted to haul durations from 60 to 300 minutes and depth 200–1100 m covering the species depth range and excluding too short and long hauls for which there are a few data. This  $lpue$  standardisation method allowed estimating  $lpue$  time-trends for the five small areas. The model provided  $lpue$  time-trends for the five areas. To derive standardized estimates for the whole study zone,  $lpue$  values are predicted for January, for all rectangles in each area (using the average haul depth in each rectangle), a 5-h haul duration, and a vessel that operated during the whole period as prediction variables. Predictions for the entire study zone were then derived as the weighted average of the five area (rectangle average) estimates, with the weights being the number of rectangles in each area (Lorance *et al.*, 2010). Some changes occurred in the fishery: protection areas for blue ling spawning were introduced in 2009. As these limited the possibility for fishing for blue ling in these areas, hauls carried out throughout the time-series were excluded. The small areas *new5* and *new6* were not fished in 2011 by vessels contributing to the tallybooks. As a result, the index for based upon the catch in three areas only. The depth and haul duration range was adjusted to reduce the confidence limits of the estimated. Depth range of 500–1200 m and duration of 120–480 minutes were used. The change in these selections impacted little the estimates but reduced the confidence interval.

### B.5. Other relevant data

No other relevant.

## C. Assessment: data and method

Two assessment methods are used for this stock. A model call multiyear catch curve (MYCC) which is a random effects population dynamics model based on proportion-at-age and removal is used to estimate the total mortality (Trenkel *et al.*, 2012) and an age-structured Stock Reduction Analysis (SRA) is used to assess the trajectory in the population biomass over the catch history starting from 1966. International landings were small before the early 1970s so that biomass in the 1960s can be considered at of close to unexploited levels.

### Multiyear catch curve

The multiyear catch curve model was carried out to estimate total annual mortality  $Z_t$  taking account of interannual variations in recruitment. The data used are proportions-at-age in numbers by year and total catch (landings) in numbers by year.

The population dynamics in numbers are modelled as:

$$N_{a,t} = N_{a-1,t-1} e^{-Z_{t-1}} \quad a_r \leq a \leq A_+ \quad t = 1, \dots, T \quad (1)$$

$$N_{A_+,t} = (N_{A_+-1,t-1} + N_{A_+,t-1}) e^{-Z_{t-1}} \quad (2)$$

where  $N_{a,t}$  are population numbers-at-age  $a$  in year  $t$ ,  $A_+$  is an age plus group and  $Z_t$  are annual total ~mortality rates. Recruitment-at-age  $a_r$  is assumed to vary randomly over time following a lognormal distribution

$$N_{1,t} = R_t \quad R_t \sim \log N(\mu_R, \sigma_R) \quad t = 1 \dots T \quad (3)$$

where  $\mu_R$  is the mean recruitment and  $\sigma_R$  the standard deviation. For ease of interpretation the coefficient of variation ( $CV_R$ ) instead of  $\sigma_R$  was calculated making use of the fact that  $var(\ln(x)) \approx \ln(CV(x)^2 + 1)$ . Recruitment is treated as a random effect in model fitting.

Annual total mortality  $Z_t$  is modelled by a random effect using a random walk over time:

$$Z_t = Z_{t-1} + \varepsilon_t \quad \varepsilon_t \sim N(0, \sigma_Z) \quad t = 1, \dots, T \quad (4)$$

The initial state vector at the beginning of year  $t=1$  is calculated assuming constant historic total mortality  $Z_0 = M + F_0$

$$N_{a,1} = e^{(a_r - a)Z_0} R_{a_r+1-a} \quad a_r < a \leq A_+ \quad (5)$$

where  $F_0$  is constant historic fishing mortality.

The initial numbers in the plus group  $N_{A_+,1}$  are estimated by an infinite sum over previous years.

The observation model has two parts, the first one for population numbers-at-age  $Y_{a,t}$  and the second for total catch in numbers. Numbers-at-age, assumed to follow a multinomial distribution.

$$Y_{a,t} \sim \text{Multinom}(p_{a,t}, m_t) \quad a_r \leq a \leq A_+ \quad t = 1, \dots, T \quad (6)$$

where  $p_{a,t}$  are proportions-at-age and  $m_t$  is the effective sample size in year  $t$ . Due to the clustered nature of individuals, the sample size in trawl surveys or harbour sampling programs does not correspond to the number of individuals measured but is rather much smaller (Pennington and Vølstad, 1994). As a result the observed variability is much larger than would be expected given the number of measurements. Therefore the effective sample size was estimated from the sampling data using a Dirichlet-multinomial distribution and the dirmult package in R by Twedebrin272 k, Twedebrink (2009).

The second observation model for the total catch (in numbers) which is assumed to follow a Gamma distribution with parameters  $\alpha$  and  $\beta$ .

$$C_t \sim \text{Gamma}(\alpha, \beta) \quad (7)$$

$$E[C_t] = \left( \frac{Z_t - M}{Z_t} \right) (1 - e^{-Z_t}) \sum N_{a,t} \quad (8)$$

The coefficient of variation ( $CV_c$ ) of the Gamma distribution is related to the  $\alpha$  parameter as  $CV_c = 1/\sqrt{\alpha}$  and  $\beta = \alpha / E[C_t]$ . The model is parameterised in terms of  $CV_c$ .

Not all model parameters  $\theta = \{Z_0, \dots, Z_t, M, F_0, \mu_R, \sigma_R, NA_{+,1}, CV_R, CV_c\}$  can be estimated and some need to be fixed. The fixed parameters where set as follows:

- natural mortality  $M=0.11$
- coefficient of variation of landings or catch ( $CV_c=0.05$ ) to allow for some misreporting

Estimation of free model parameters  $\theta$  is carried out by maximum likelihood based on the observation vector  $y = (C_1, \dots, C_T, Y_{ar,T}, \dots, Y_{A+,T})$  which has conditional density  $f_\theta(y | u, v)$  where  $u = (R_1, \dots, R_n)$  is the vector of the latent random recruitment variable with marginal density  $h(u)$   $v = (Z_1, \dots, Z_{T-1})$  is the total mortality random effect variable with marginal density  $g(v)$ . The marginal likelihood function is obtained by integrating out  $u$  and  $v$  from the joint density  $\mathcal{L}$

$$\mathcal{L}(\theta) = \iint f_\theta(y|u, v) h_\theta(u) g_\theta(v) y(u) y(v) \quad (9)$$

The double integral in (9) is evaluated using the Laplace approximation as implemented in the random effects module of AD Model builder and described in Skaug and Fournier (2006). AD Model builder automatically calculates standard deviations of estimates based on the observed Fisher Information matrix.

For the analysis the data are restricted to the fully recruited age classes, 9 and over, a plus group is set at-age 19, called 19+.

#### Stock Reduction Analysis: SRA

Stock reduction analysis (SRA) is a developed form of delay-difference model (Quinn and Deriso, 1999). The method uses biological parameters and information for time delays due to growth and recruitment to predict the basic biomass dynamics of age structured populations without requiring information on age structure.. A description of the general approach can be found in Kimura and Tagart (1982), Kimura *et al.* (1984) and Kimura (1985 and 1988).

The aim of stock reduction analysis is to estimate past and present biomass for a fishery. Three types of input data are required: biological parameters, abundance indices, and a complete catch history.

SRA is an iterative process, which operates with the following steps:

- A biomass  $B_0$  of the stock at the beginning of the catch history (initial biomass) is chosen;
- The stock biomass over the time-series is calculated by forward projection using, at each time-step the stock–recruitment relationship (derived from the input steepness), the natural mortality and removal to calculate number-at-age at the start of the next time interval;
- The catchability  $q$  of each time-series of biomass index and the coefficient of variation  $c$  of the index are calculated;
- The likelihood of the value of  $B_0$  and  $q$  is calculated.

These four steps are repeated for a range of  $B_0$  and the  $B_0$  that maximises the likelihood of observed abundance indices is retained.

Implicit assumptions of this age-structured SRA include that (i) there is no density-dependence in growth and natural mortality, (ii) the stock–recruitment relationship is of the Beverton and Holt type.

Software used: *FLaspm*

*FLaspm* is a package for the statistical computing environment R (R Development Core Team, 2010). The package is open source and is currently hosted at GoogleCode (the source code is freely available at <http://code.google.com/p/deepfishman/>). *FLaspm* is part of the FLR project (Kell *et al.*, 2007) and requires that the package *FLCore* is also installed ( $v > 2.3$ ). The stock reduction model used in this analysis implements the model described in Francis (1992) and is capable of fitting multiple indices simultaneously. Up to four time-series of indices are used for blue ling, namely the Landings Per Unit of Effort (lpue) from French haul-by-haul catch and effort, the Irish bottom-trawl survey from 2006 to 2009; the Marine Scotland Deep-Water Science Survey starting from 1998, with missing years (no survey) in 1999, 2001, 2003 and 2010 and an index from the Faroese survey. The two (spring and summer) Faroese surveys are combined in one single mean index. Trials have been conducted with one time-series and results were similar, as the time-series are actually similar. The two Faroese survey should not be included in the model separately because they only cover a restricted range of the stock area and included as two series they would overweight the Marine Scotland Deep-Water Science Survey, which cover areas from which there is as much or more catch.

In some case the fit does not converge, the reasons for this have not been identified and this was already reported in a working document in 2011 (Scott *et al.*, 2011). Only minor change in the data (e.g. replacing the length–weight relationship by another one producing similar weights-at-age may allow the model to converge or not. This suggests that the problem lies in the minimisation routine. The method requires time-series data of annual catches, one or more abundance index and a range of biological parameters. The effect of these biological parameters on results is investigated using sensitivity analysis. A Beverton and Holt stock–recruitment relationship with a steepness of 0.75 is used throughout.

#### Input data:

Total international landings from 1966 should be used for this assessment. Available tuning indices include: French abundance index derived from skipper tallybook data, Marine Scotland Deep-Water Science Survey (from 1998 carried out every second years since 2013), Irish deep-water Survey (2006 to 2009), Faroese Summer and Spring surveys and Norwegian CPUE from longliners in Subarea 6. Because of the short time series that does not inform on recent change the Irish survey was no longer included in the assessment since 2014.

#### Other stock indicators

A time-series of mean length in French landings is used as a further stock indicator and the consistency of this indicator with models outputs should be checked in order to detect any possible deviations from models assumptions. For example, estimated increased proportion of older fish in the MYCC should be reflected in increasing mean length in the landings or large recruitment estimates should be reflected by decrease in mean length. Length indicators from the Faroese and Marine Scotland Deep-Water Science Surveys should be used in the same way.

#### Model Options chosen:

Input data types and characteristics:

PARAMETER	SYMBOL	VALUE
Maximum age	$A_{max}$	50
Natural mortality	$M$	0.11
Steepness of Beverton–Holt stock recruitment relationship	$h$	0.75
Age of first selectivity	$A_{sel}$	8
Age of maturity	$A_{mat}$	8
von Bertalanffy growth parameters	$L_{\infty}$	125 cm
	$k$	0.152
	$t_0$	1.552
Length–weight parameters	$a$	2e-6
	$b$	3.15

#### D. Short-Term Projection

No short-term predictions are carried out for this stock.

#### E. Medium-Term Projections

None.

#### F. Long-Term Projections

None.

#### G. Biological Reference Points

Reference points below were defined by WKMSYref4 and published in an ICES advice (ICES, 2015, 2016).

REFERENCE POINT	VALUE	SOURCE	RATIONALE
MSY $F_{lower}$	0.08	ICES, 2015	
$F_{MSY}$	0.12	ICES, 2015	
MSY $F_{upper}$ with Advice Rule	0.17	ICES, 2015	
MSY $B_{trigger}$ (tonnes)	75 000	ICES, 2015	Set to $B_{pa}$
MSY $F_{upper}$ with no Advice Rule	0.14	ICES, 2015	
$F_{lim}$	0.17	ICES, 2015	Simulated SSB to $B_{lim}$
$F_{pa}$	0.12	ICES, 2015	$F_{lim} * \exp(-1.645 * 0.2)$
$B_{lim}$ (tonnes)	54 000	ICES, 2015	Bloss (lowest estimated SSB in the time-series)
$B_{pa}$ (tonnes)	75 000	ICES, 2015	$1.4 * B_{lim}$

The advice rule (AR) is the rule used by ICES to provide catch advice where  $F_{MSY}$  is applied to the projected stock biomass to derived the maximum catch recommended



when the SSB is above  $MSY B_{trigger}$  and  $F$  is reduced linearly when the SSB is below the biomass reference point  $MSY B_{trigger}$ .

## H. Other Issues

The stock identity of blue ling is uncertain. The only area where juvenile are known to occur in high number is the Icelandic shelf (Division 5.a). No juvenile are known to occur in Subareas 6 and 7 and number observed in the Faroese survey (about one fish smaller than 80 cm per hour) do not seem sufficient to supply the abundance for adult blue ling. Fish smaller than 40 cm are almost not caught in the Faroese surveys and are not known to occur elsewhere in Division 5.b and Subareas 6 and 7 while they are caught in survey in Division 5.a. Fish in Division 5.b and Subareas 6 and 7 start recruiting to the fishery at age 7. They are considered 50% recruited at age 8 and fully recruited at age 9. As no younger fish are found in scientific surveys and fisheries in Division 5.b and Subareas 6 and 7, they could come from outside the assessment unit area and possibly from ICES Division 5.a

### H.1. Historical overview of previous assessment methods

Exploratory assessment carried out before the benchmarked assessment are summarised below (synthesis carried out as part of the DEEPFISHMAN project). Assessment types are "Exploratory", "Benchmark" (to identify best practise), Update (repeat of previous years' assessment using same method and settings but with the addition of data for another year)

YEAR	ASSESSMENT TYPE	METHOD	ASSESSMENT PACKAGE/ PROGRAM USED	USED FOR ADVICE?	IF NOT, WHAT WAS LATEST SCIENTIFIC ADVICE BASED ON?
1998	Exploratory	Schaefer& DeLury depletion model	CEDA (1)	No	French OTB and Faroese longline lpue
2000	Exploratory	Schaefer& DeLury depletion model	CEDA (1)	No	French OTB unstandardised lpue
2004	Exploratory	Schaefer, Pella-Tomlinson and Fox production models & DeLury depletion model	CEDA (1)	No	Trend in French commercial otter trawl lpue
	Exploratory	Stock reduction	PMOD	No	Trend in French commercial otter trawl lpue
2006	Exploratory	Catch Survey analysis	CSA (Mesnil, 2003)	No	Trend in French commercial otter trawl lpue
2014	Benchmark	Multi-year Catch Curve Stock reduction analysis	MYCC (R code) SRA (FLR package)	Yes	
2014-2018	Update	Multi-year Catch Curve Stock reduction analysis	MYCC (R code) SRA (FLR package)	Yes	

(1) MRAG (UK) software.

## Summary of data ranges used in recent assessments:

DATA	2007 ASSESSMENT	2008 ASSESSMENT	2009 ASSESSMENT	2010 ASSESSMENT
Landings	Years: 1988–2006	Years: 1988–2007	Years: 1966–2008	Years: 1966–2009
Quarterly length dist. of French landings	Years: 1989–2006	Years: 1984–2007	Years: 1984–2008	Years: 1984–2010
Quarterly length dist. of Faroese landings	Years: 1995–2006	Years: 1995–2007	Years: 1995–2008	Years: 1995–2009
Quarterly age dist.				Year: 2009
Survey: Scottish deep-water			Years: 1998–2008 N° per hour	Years: 1998–2009 N° per hour
Survey: Irish				Years: 2006–2009 N° per hour
Survey: spring and autumn Faroese				Years: 1994–2009 N° per hour Size
Haul-by-haul lpues from French trawlers	Not used	Not used	Years: 2000–2008	Years: 2000–2009
Aggregated unstandardised French lpue	Years: 1989–2006	Years: 1989–2007	Years: 1989–2008	Not used

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## Appendix 1. Landings from the stock from 1966 to 1999

### Appendix 1.1. Landings of blue ling in Subdivision 5.b.1. from 1966 to 1999

YEAR	FAROEES	FRANCE(1)	GERMANY(1)	NORWAY(2)	E & W(1)	RUSSIA(1)	TOTAL
1966		839		430			1269
1967			1006	238			1244
1968			1838	823			2661
1969			303	798			1101
1970			348	2718			3066
1971			1367	557			1924
1972			2730	1203			3933
1973	51	80	3009	4003	4		7147
1974	43	390	1808	1554	3		3798
1975	17	2147	1528	2492	1		6185
1976	42	10475	896	1482			12 895
1977	23	6977	870	858	4	12 500	21 232
1978	423	3369	744	237	35		4808
1979	1072	2683	691	331			4777
1980	1187	2427	5905	304			9823
1981	1481	371	2867	167			4886
1982	2761	843	2538	121			6263
1983	3933	668	222	256			5079
1984	6453	515	214	105			7287
1985	4038	1193	217	140			5588
1986	4830	2578	197	94			7699
1987	3361	3246	152	81			6840
1988	3487	3036	49	94			6666
1989	2468	1802	51	228			4549
1990	946	3073	71	450			4540
1991	1573	1013	36	196	1		2819
1992	1918	407	21	390	4		2740
1993	2088	192	24	218	19		2541
1994	1065	147	3	173			1388
1995	1606	588	2	38	4		2238
1996	1100	301	3	82			1486
1997	778	1656		65	11		2510
1998	1026	1411	0	24	1		2462
1999	1730	1067	4	38	4		2843

(1) Includes 5.b.2; (2) includes 5.b.2 up to 1974.

## Appendix 1.2.. Landings of blue ling in Subdivision 5.b.2. from 1966 to 1999.

YEAR	FAROEES	NORWAY	SCOTLAND	FRANCE	TOTAL
1966					0
1967					0
1968					0
1969					0
1970					0
1971					0
1972					0
1973					0
1974					0
1975	1				1
1976	6	37			43
1977		86			86
1978	7	83			90
1979	14	87			101
1980	36	159	1		196
1981	48	93			141
1982	128	66			194
1983	463	182			645
1984	757	50			807
1985	396	70			466
1986	81	41			122
1987	209	90			299
1988	2788	72			2860
1989	622	95			717
1990	68	191			259
1991	71	51	21		143
1992	1705	256	1		1962
1993	182	22	91		295
1994	239	16	1		256
1995	162	36	4		202
1996	42	62	12		116
1997	229	48	11		288
1998	64	29	29		122
1999	15	49	24		88

**Appendix 1.3. Landings of blue ling in Division 6.a. from 1966 to 1999 (includes 6.b for all countries up to 1974 included).**

YE R	FAROE S	FRANC E	GERMAN Y	IRELAN D	NORWA Y	SPAIN( 1)	E & W	SCOTLAN D	TOTA L
1966					20				20
1967			37		35				72
1968					126				126
1969			6		112				118
1970					176				176
1971					15				15
1972		696			14				710
1973		18 000			25				18 025
1974	33	15 000	1218		362		164		16 777
1975		5000	2941		20		8		7969
1976		5462	818		10		1		6291
1977		7940	470		16		556		8982
1978		5495	2498		19		21		8033
1979		3064	993		2		279		4338
1980		2124	773		10				2907
1981		3338	335		11			1	3685
1982		3430	79		16		99		3624
1983		5233	11		118		13		5375
1984		3653	183		45		5		3886
1985	56	5670	5		75		2		5808
1986		8254	7		47		2	1	8311
1987		9389	45		51		1		9486
1988	14	6645	2		29		2	1	6693
1989	6	7797	2		143				7948
1990		6114	44		54			1	6213
1991	8	6165	18		63		1	35	6290
1992	4	7742	4		129			24	7903
1993		6793	48	3	27		13	42	6926
1994		3363	24	73	90	433	1	91	4075
1995	0	3073		11	96	392	34	738	4344
1996	0	4116	4		50	681	9	1407	6267
1997	0	4053		1	29	190	789	1021	6083
1998	0	4735	3	1	21	142	11	1416	6329
1999	0	3731		10	55	119	5	1105	5025

. <sup>(1)</sup> Includes 5.b.

**Appendix 1.4. Landings of blue ling in Division 6.b. from 1975 to 1999 (no landings reported before 1975).**

YE AR	FARO ES	FRAN CE	GERM ANY	NORW AY	E & W	SCOTLA ND	ICELA ND	IRELA ND	TOT AL
1975	1			37					38
1976	13			6					19
1977	6	36		7					49
1978	3	58		8					69
1979	4	652	187	28					871
1980		3827	5526	8					9361
1981		534	3944	5					4483
1982		263	554	13		1			831
1983		243	38	50		2			333
1984	133	3281		43					3457
1985	11	7263	31	38					7343
1986	1845	2928	39	66	7	1			4886
1987	350	10	356	76	3	10			805
1988	2000	499	37	42	9	14			2601
1989	1292	61	22	217		16			1608
1990	360	703		127		2			1192
1991	111	2482	6	102	5	15			2721
1992	231	348	2	50	2	14			647
1993	51	373	109	50	66	57			706
1994	5	89	104	33	3	25			259
1995	1	305	189	12	11	38			556
1996	0	87	92	7	37	74			297
1997	138	331		6	65	562	1		1103
1998	76	469		13	190	287	122	11	1168
1999	204	654		9	168	2411	610	4	4060



**Appendix 1.5. Landings of blue ling in Subarea 7 from 1988 to 1999 (no landings reported before 1998).**

YEAR	FRANCE	GERMANY	SPAIN	NORWAY	E & W	SCOTLAND	IRELAND	TOTAL
1988	21	1	0	0	0	0	0	22
1989	292	0	0	2	0	0	0	294
1990	223	0	0	0	0	0	0	223
1991	211	0	0	0	0	1	0	212
1992	398	0	0	3	0	6	0	407
1993	273	0	0	2	16	30	0	321
1994	298	0	4	1	9	26	1	339
1995	155	0	13	0	43	16	3	230
1996	189	0	21	1	57	97	0	365
1997	179	8	0	2	170	15	9	383
1998	252	3	22	1	283	30	10	601
1999	115	2	59	1	168	18	27	390

**Appendix 1.6. Summary of blue ling landings in Division 5.b and Subareas 6 and 7 from 1966 to 1999.**

YEAR	5.B	6	7	TOTAL
1966	1269	20		1289
1967	1244	72		1316
1968	2661	126		2787
1969	1101	118		1219
1970	3066	176		3242
1971	1924	15		1939
1972	3933	710		4643
1973	7147	18 025		25 172
1974	3798	16 777		20 575
1975	6186	8007		14 193
1976	12 938	6310		19 248
1977	21 318	9031		30 349
1978	4898	8102		13 000
1979	4878	5209		10 087
1980	10 019	12 268		22 287
1981	5027	8168		13 195
1982	6457	4455		10 912
1983	5724	5708		11 432
1984	8094	7343		15 437
1985	6054	13 151		19 205
1986	7821	13 197		21 018
1987	7139	10 291		17 430
1988	9526	9294	22	18 842
1989	5266	9556	294	15 116
1990	4799	7405	223	12 427
1991	2962	9011	212	12 185

YEAR	5.B	6	7	TOTAL
1992	4702	8550	407	13 659
1993	2836	7632	321	10 789
1994	1644	4334	339	6317
1995	2440	4900	230	7570
1996	1602	6564	365	8531
1997	2798	7186	383	10 367
1998	2584	7497	601	10 682
1999	2931	9085	390	12 406