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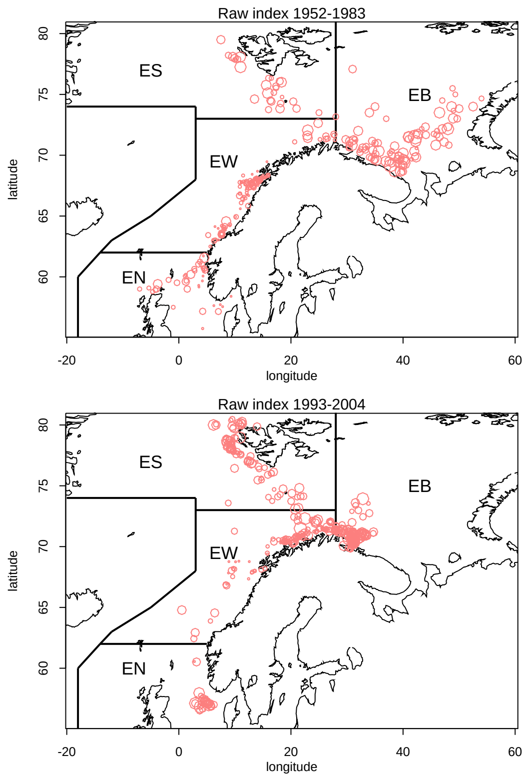
Note

Standardized catch per unit effort in minke whaling in Norwegian waters, 1952-1983 and 1993-2004



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Abstract

We construct a catch per unit effort (CPUE) index for minke whales caught in the E-areas of north-eastern Atlantic, adjusted for boat efficiency and spatial effects. The index is interpreted as an unsmoothed relative index of abundance, also including variation in catch conditions due to weather, migration and local clustering of minke whales. Norwegian minke whaling was interrupted from 1984 to 1992. Two series are therefore constructed, one for the period 1952-1983 and another for the period 1993-2004. The estimated index value for 1983 is 63% of the value in 1952, while the estimated index value for 2004 is 186% of the value in 1993.

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Contents

1 Introduction

Our aim is to construct relative abundance series of minke whales in the E-areas of north-eastern Atlantic, consisting of the small areas ES, EB, EW and EN (Figure 1). As argued below, we are only able to estimate an annual relative index, here called the standardized catch per unit effort (CPUE) index, whose values in addition to the abundance also depend on catching conditions due to weather and temporal variations in the spatial distribution of minke whales both locally and over the whole area. The CPUE index can, in combination with absolute abundance estimates and a model for the population dynamics, be used to estimate important recruitment parameters, see for instance Cooke (1993).

The data consist of information on each caught whale from 1952 to 2004, with date and year, position and boat characteristics. The regulations have changed over time, which may have affected the catch efficiency. However, we assume that the catch regime has been sufficiently stable from 1952 to 1983 to allow a meaningful consecutive series of standardized CPUE index to be constructed for this period. This assumption is discussed in more detail in for instance Schweder and Volden (1994). From 1984 onwards the quotas were substantially reduced and individual boat quotas were introduced, with a seemingly negative effect on the catch efficiency.

Commercial whaling was suspended from 1988 to 1992 due to the moratorium of all commercial whaling imposed by IWC. Due to changes in the regulations from 1984 and the general uncertainty in the industry due to the moratorium decision, we have excluded the period 1984-1987 from the series. Norway lodged an objection to the moratorium decision and thus was not legally bound to stop whaling. Based on results from rather intensive marine mammal research, whaling was started again in 1993. The regulations and also other catch conditions in the period from 1993 onwards have differed from those in the 1952-1883 period. Hence, we construct two series of standardized CPUE index, one from 1952 to 1983 and another from 1993 to 2004.

The basic idea is that increasing abundance will tend to give increased catch per unit effort and vice versa. Hence, yearly variations in catch per unit effort could be interpreted as corresponding changes in the abundance. This is correct only if other conditions that could affect the catch efficiency are constant. However, there has been several important changes over time. The catcher boats increase in average lengths and engine power. This has increased catch efficiency, also by allowing effort to be more easily shifted to areas with higher whale density and better weather conditions. The CPUE index we construct is therefore adjusted for individual boat efficiency and also spatial effects. This is done by fitting a regression model with spatial covariates to the data regarded as a panel of individual boat histories. However, since we have not adjusted for year-specific variations in catch conditions, changes in the standardized CPUE series cannot be interpreted as changes in abundance alone.

Our statistical model is based on a variant of the so called net catcher days method (Cooke 1984). Let N be the net catcher days, i.e. the number of days with at least one catch for a boat in a year, and let C be the corresponding total catch. Disregarding the first catch in a day of catch, $C - N$ is the number of extra whales caught in the N days of catch. The ratio $(C - N)/N$ will then reflect how easy it is to find extra whales when a whale is caught, and is used as an unadjusted index for catch efficiency. Similar analyses have been performed by Cooke (1993) and Schweder and Volden (1994) for the Barents Sea.

Schweder, Ulltang and Volden (1991) and Schweder and Volden (1994) used data from 1976 to 1983 to estimate the gross catcher days in the years 1952 to 1975 with their so called ACD and COMP methods. However, in Schweder and Volden (1994) these methods gave similar results to the net catcher days method, differing by less than one standard error. Furthermore, they found that the methods, which were based on extrapolation of the gross catcher days, were only appropriate in the Barents sea, but could not be used in the North Sea. It is desirable to develop a relative series for the whole north-eastern stock of minke whales. The North Sea and the Norwegian Sea should therefore be covered together with the Barents Sea. Since the net catcher days method is more reliable for the North Sea, and since this method largely yields similar results to those of the slightly more powerful ACD method (Schweder and Volden, 1994) in the Barents Sea, we will use the net catcher days method.

Skaug, Øien, Schweder and Bøthun (2004) found the spatial distribution of minke whales in the northeastern Atlantic to vary from year to year. This might cause an interaction between time and spatial covariates in the CPUE series. We have subsumed this possible interaction in the the over-dispersion in the model to be developed below. This is partly supported by Schweder, Ulltang and Volden (1991) who found no interaction between area and time in CPUE in the model they considered, where they assumed the interaction to be carried by the distribution of herring in time and space.

In the following we first present the data and the statistical model in Section 2 and then give the main results in Section 3. Finally, a discussion and some conclusions are given, including some alternative analyzes that confirm the main results.

2 Material and methods

2.1 Data

The data are made available by the Norwegian Institute of Marine Research (IMR). The same data are reported to the International Whaling Commission (IWC). The data consist of information on all minke whales caught in the four small E-areas between 1952 and 2004 as well as information on the catcher boats. The boat information consists of a registration number and the home county of the boat as well as its length and engine power.

>From 1976 whalers have been requested to hand in a journal with information recorded for every day on effort. The compliance has varied over the years and the quality of these more detailed data is unfortunately insufficient for our purpose (Nils Øien, personal communication). An additional reason to only use the reduced data with information on each whale caught (together with boat data), is that they are reported to IWC and thus made available to members of its scientific committee.

The whales are usually caught in the period from 15th of March to 15th of September, with a summer closure between the 1st of July and 21st of July. Most of the catcher dates and catcher positions are recorded. However, there are a few observations (0.15% of the data) where only month is recorded, but day is missing.

For each year t and boat i, the total catch C_{it} is the number of whales caught, while N_{it} is the number of days with at least one catch for the boat that year. In the case of missing days days, we impute an estimate of N_{it} as shown in appendix A.

The whales are caught at different positions, but usually a boat catches all its whales within the same region. For each boat i and year t, a common position lon_{it} and lat_{it} is allocated to C_{it} and N_{it}. Here lon_{it} and lat_{it} denotes the longitude and the latitude, respectively. The corresponding catch is sorted according to date, and a common position is defined as the position at the middle or the first of the two middle numbered catches, according to the total catches being an odd or even number respectively.

In total there are 4152 observations of the raw index $(C_{it} - N_{it})/N_{it}$ from 1952 to 1983. A random sample of these is shown in the upper panel of Figure 1. Each catch position is plotted as a circle with radius proportional to the raw index, which tend to be higher in the Barents Sea than further south. The lower panel of Figure 1 shows all the 377 values of the raw index from 1993 to 2004.

Figure 2 shows time plots of various statistics. The catch has decreased from 3-4000 animals per year in the fifties to around 500 animals in 2004. This is obviously related to the decrease in effort, measured as number of net catcher days or number of boats involved in the catch. The average raw index is quite stable over time. Over the years, more of the catch effort has been allocated to the Barents Sea where whale density is higher than further south. The catcher boats have increased in length and engine power. In summary, the efficiency has increased and effort has been better allocated over the years while the mean raw index of CPUE has been relatively stable. Statistical models are thus called for to construct series of standardized CPUE to account for the increased catch efficiency.

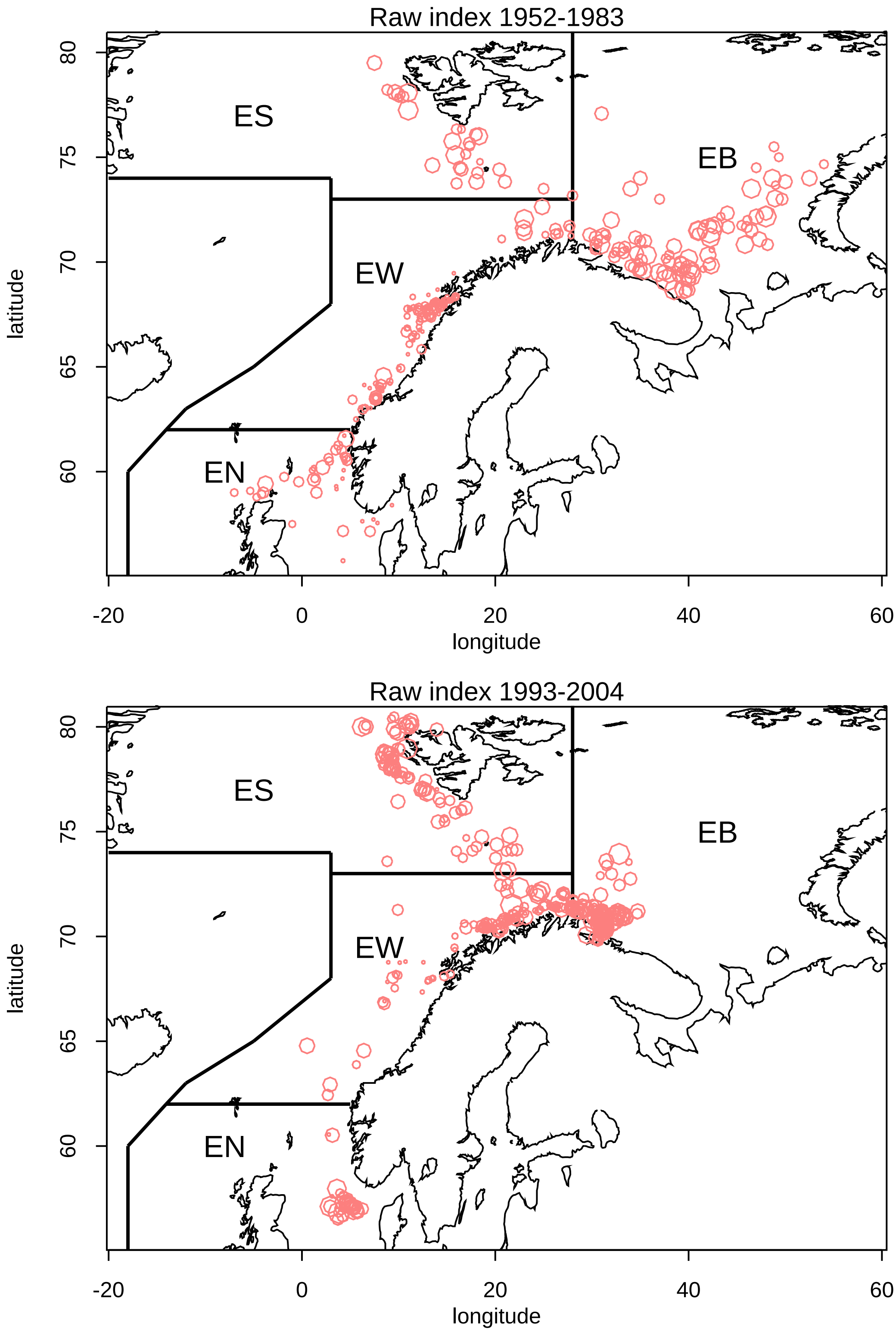

Figure 1. Values of $(C_{it} - N_{it})/N_{it}$ at position of catch. Upper panel: 300 random samples from 1952-1983. Lower panel: All values from 1993-2004. The areas of the circles are proportional to the value of $(C_{it} - N_{it})/N_{it}$, except that values less than 0.05 are plotted as if they had a value of 0.05.

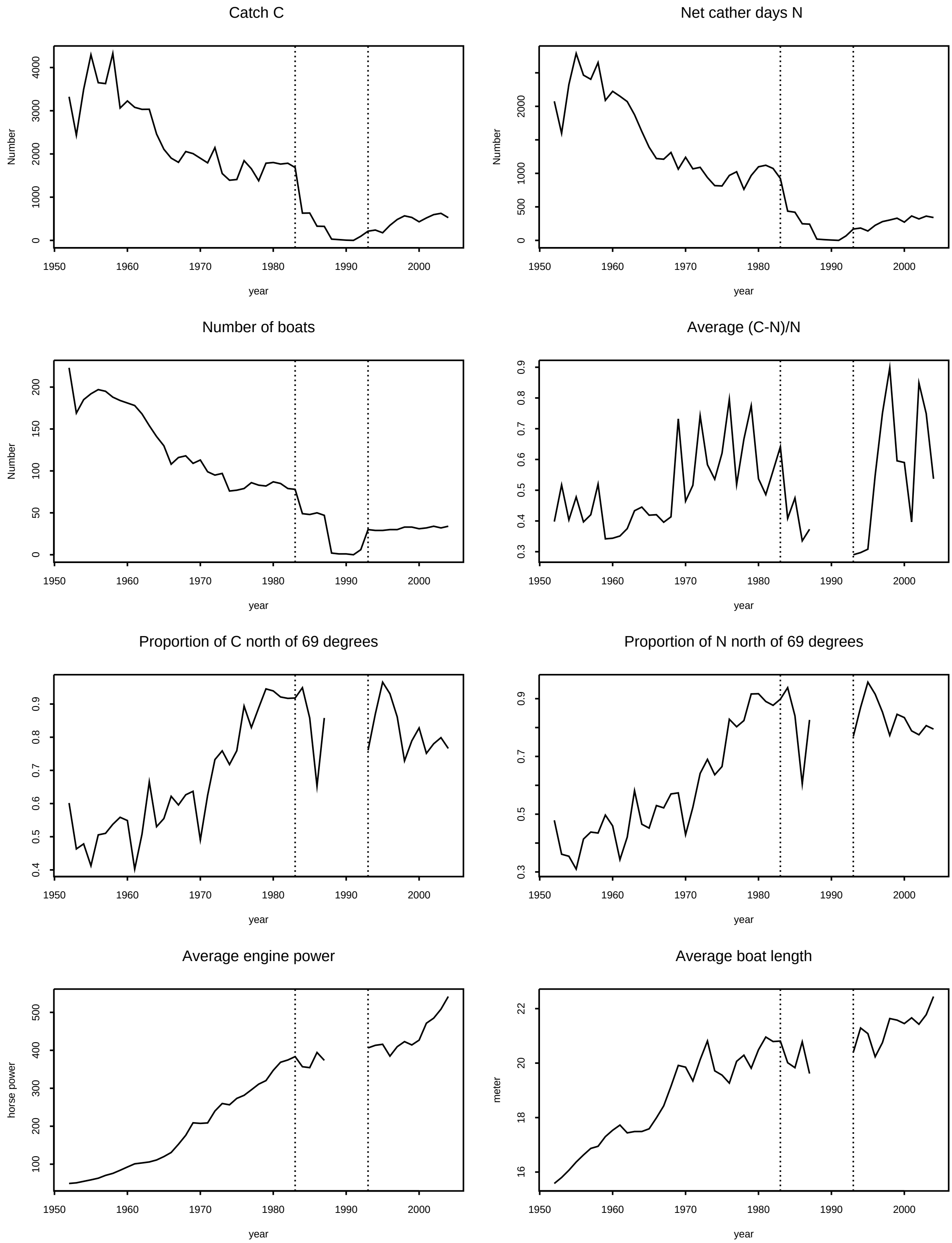

Figure 2. Time plots of various statistics. Averages and proportions between 1988 and 1992 are not shown, since they are based on very few data and hence are unstable.

2.2 Data handling

One could use boat lengths and engine power as proxies for boat efficiency, as in for instance Schweder, Ulltang and Volden (1991), but there are obviously differences among boats that can not be explained by the size alone. Instead we regard the data as a set of boat histories, and control for boat efficiency by fixed effects in an additive model.

Schweder and Volden (1994) defined a boat period as a period for which a vessel can be assumed to have constant catch efficiency. We take the same approach and use the term “boat” as short hand for boat period. Operationally, a vessel is regarded as a new boat when its registration number or home county is changed, or when its length is increased by more than 2.5 meters or its engine power is changed by more than 20%. The rational is as follows. A change in registration occurs usually when the vessel is taken over by another skipper (and owner) and a new crew. The skills of the skipper and crew influence catch efficiency strongly. With the same skipper and crew, boat efficiency is changed when the vessel is improved by being extended in length or is powered by a stronger engine. Small changes in instrumentation and engine power might also increase efficiency, but data on minor changes are scanty. Inconsistencies in 50 boat lengths and engine powers are manually corrected for by us, after correspondence with Siri Hartveit at IMR. These corrections are available at the web adress
`http://www.nr.no/~aldrin/whales/CorrectedLengthAndPower.txt`.

Only boat years where at least 90% of the catch dates are recorded are used in the analysis. Further, only boats with data of at least two years are used in the analysis. Finally, boats with the number of catches C_{it} equal to the number of net catcher days N_{it} for all years t contain no information and are therefore excluded from the analysis as well. These exclusions result in a data set with 3862 observations from 609 different “boats” in the period 1952-1983 and a separate data set with 343 observations from 61 different “boats” in the period 1993-2004.

2.3 Statistical modeling

The difference between total catch and net catcher days, $C_{it} - N_{it}$ is used as a response variable in a regression model, where the expected value of $C_{it} - N_{it}$ is assumed to be the following multiplicative function of relevant explanatory variables

$$E(C_{it} - N_{it}) \quad = \quad \mu_{it} = N_{it} \cdot F(lon_{it}, lat_{it}) \cdot G_i \cdot D_t. \tag{1}$$

Here F is a data-driven, smooth spatial function of the catch positions (lon_{it}, lat_{it}), representing a spatial trend in catch conditions (weather, whale density etc.). Furthermore, G_i is the catch efficiency for boat i. The year effect D_t is interpreted as the standardized CPUE index reflecting relative abundance of minke whales and also year-specific catch conditions such as weather and temporal changes in the spatial distribution of minke whales.

Since D_t is a relative index, it is subject to an arbitrary scaling factor, and has to be normalised to be unique. We have chosen to set the first D_t in the data period to 1, and the subsequent values of D_t is then relative to the first year. Thus, $D_{1952} = 1$ in the period 1952-1983, and $D_{1993} = 1$ in the period 1993-2004. This standardization is one of many possible standardizations for a relative index. Since we supply the full covariance matrix for our relative index, other linear indexes can be computed along with their covariance matrices.

Taking the (natural) logarithm of equation (1) gives the additive relationship

$$\log(\mu_{it}) \quad = \quad \log(N_{it}) + f(lon_{it}, lat_{it}) + \gamma_i + \delta_t, \tag{2}$$

where $\log(N_{it})$ is an offset (i.e. an explanatory variable with a fixed regression coefficient equal to 1), $f = \log(F)$, $\gamma = \log(G)$, and $\delta = \log(D)$.

The function f is modelled by smoothing splines using the methodology of generalised additive models (Hastie and Tibshirani, 1990). For simplicity, the spherical coordinates (lon_{it}, lat_{it}) are transformed into planar coordinate (x_{it}, y_{it}). This is done by projecting the (lon_{it}, lat_{it}) position on the sphere onto a plane that tangentiates the sphere (orthographic projection) at latitude 19 degrees east and longitude 69 degrees north, which is roughly in the centre of the data. This transformation roughly preserves the distances among two positions. Then the spatial function f is formulated as an additive function of x_{it}, y_{it}, and $x_{it}y_{it}$ by

$$f(lon_{it}, lat_{it}) \quad = \quad s_x(x_{it}) + s_y(y_{it}) + s_{xy}(x_{it}y_{it}), \tag{3}$$

where s_x, s_y, and s_{xy} are (smoothing) spline functions to be estimated from the data. The smoothness of the functions can be controlled by adjusting the number of effective parameters. A higher number of effective parameters gives a better fit to the data on the cost of less smooth functions and possible higher estimation variability. About 4 effective parameters are chosen for each of the s-functions in the model in the 1952-1983 period and only about 2 effective parameters for each of the s-functions in the model in the 1993-2004 period with considerable less observations. These choices are based on Akaike's criterion. See further details in appendix B.

The model is estimated by maximising the Poisson-likelihood, but allowing for over-dispersion. The variance is therefore modelled as

$$Var(C_{it} - Nit) \;=\; \Phi\mu_{it},$$

where the over-dispersion factor Φ is larger than 1. It is estimated from the data by the Pearson statistic, and all the reported standard errors are adjusted accordingly.

3 Results and discussion

Figure 3 plots the estimated standardized CPUE index D_t with 95% point-wise confidence intervals in the period 1952-1983 (with $D_{1952} = 1$) and for the period 1993-2004 (with $D_{1993} = 1$). The estimated values of D_t are also found in Table 1, with corresponding estimates of $\delta_t = \log(D_t)$ and their standard errors. There is a clear decreasing trend from 1952 to 1983, which suggests a corresponding decrease in abundance. The estimate in 1983 is 63% of the level in 1952. The picture is reversed in the second period, where the index is markedly and significantly higher after 1996 than before.

Some of this apparent temporal variation might be due to positive autocorrelation in the catching condition. The long series from 1952 to 1983 certainly shows a pattern compatible with positive autocorrelation. Perhaps the conditions by chance were slightly unfavorable in the first few years of the later rather short series. Also, the regulation has changed a bit over the years. Since 2001 for example, there has been an element of competition since some 10% of the total quota has been redistributing between the boats to those with the highest catches in the first part of the season. This has probably increased the efficiency. The buyers of minke whale meat have on the other hand recently asked their suppliers to stop temporarily when supply exceeds capacity and demand. This might have decreased efficiency in the last few years. Market conditions have also changed over the first period, with a reduced demand on whale meat as other read meat became more affordable during the period of economic growth in Norway in the post-war period. An analysis taking these economic mechanisms into account would be quite demanding. We have not done anything of that. Nor have we modelled the autocorrelation in the variability in excess of Poisson variability that we have regarded as over-dispersion.

Separate analyses were conducted by Cooke (1993) and Schweder and Volden (1994) in the Barents Sea, i.e. the whole EB small area, and the parts of the ES and EW small areas that are east of 3 degrees east and north of 69 degrees. To compare the results from those studies to the results from the methodology used here, we performed a separate analysis based on the data in this area in the period 1952-1983. This analysis gave an standardized CPUE index of 66% in 1983 compared to the level in 1952 which is the same as (read by eye from a figure in the paper) of what Schweder and Volden (1994) got with a net catcher days method. The alternative ACD and COMP methods in Schweder and Volden (1994) methods gave 70% and 78% respectively, whereas Cooke (1993) got 52% (read by eye from a figure).

Figure 4 shows the estimated spatial effect on the CPUE on logarithmic scale, adjusted only for boat efficiency, i.e. the f-function. In the period 1952-1983 CPUE is generally higher in the north than in the south when adjusting for boat efficiency. In the period 1993-2004 CPUE is higher in both north and south than in the middle of Norway, but in this period there are few boats that operate in the southern areas.

The over-dispersion parameter Φ is estimated to 1.62 in the period 1952-1983 and 1.12 in the period 1993-2004.

Schweder and Volden (1994) considered the first year of a boat period (i.e. the period where a vessel is assumed to have constant catch efficiency as defined in Section 2.2) as a learning year, and discarded these observations from their analysis. We have done the same, and re-estimated model (2). The new estimates of the standardized CPUE index are very similar to the original ones presented in Figure figs/relest. As an alternative way to treat possible learning, we have kept all the data, but extended our main model (2) with a common learning effect from the first to the second year for all boats. The coefficients are not significant for any of the two periods, and the standardized CPUE series are almost unchanged.

The Vestfjord area, or area 7 in Schweder and Volden (1994), has been an important catch area, with a different mode of operation than in the Barents Sea, due to its closeness to the cost. To explore if this catch area differs from what can be modelled by the smooth spatial surface f, we add an extra explanatory to the main model (2), which is 1 for catch positions within the area and 0 elsewhere. The coefficients are not significant, and once more the standardized CPUE index remain almost unchanged.

The purpose of this work has been to summarize catch and effort data into standardized CPUE series for use in the estimation of the productivity and other aspects of the population dynamics of the north-eastern Atlantic minke whale population. The standardized CPUE series on the logarithmic scale, and their nominal variance/covariance matrices, are available at the web address http://www.nr.no/~aldrin/whales/estcov.txt . When these series together with other data are used to estimate productivity and other population dynamic parameters, the extra variability in the standardized CPUE series should be properly modelled.

The series reflect changes in relative abundance, in addition to variability in catching conditions due to weather, local clustering of whales, market conditions, small changes in regulations, and possibly other factors. Without having conducted a formal statistical test taking autocorrelation in the latent variability into account, we regard the series from 1953 to 1983 to be long enough to safely conclude that the nominally significant drop reflects a real decrease in abundance. The data are however weaker and the series is shorter from 1993 to 2004, and our finding of a significant increase in abundance in recent years should be regarded as a less reliable conclusion.

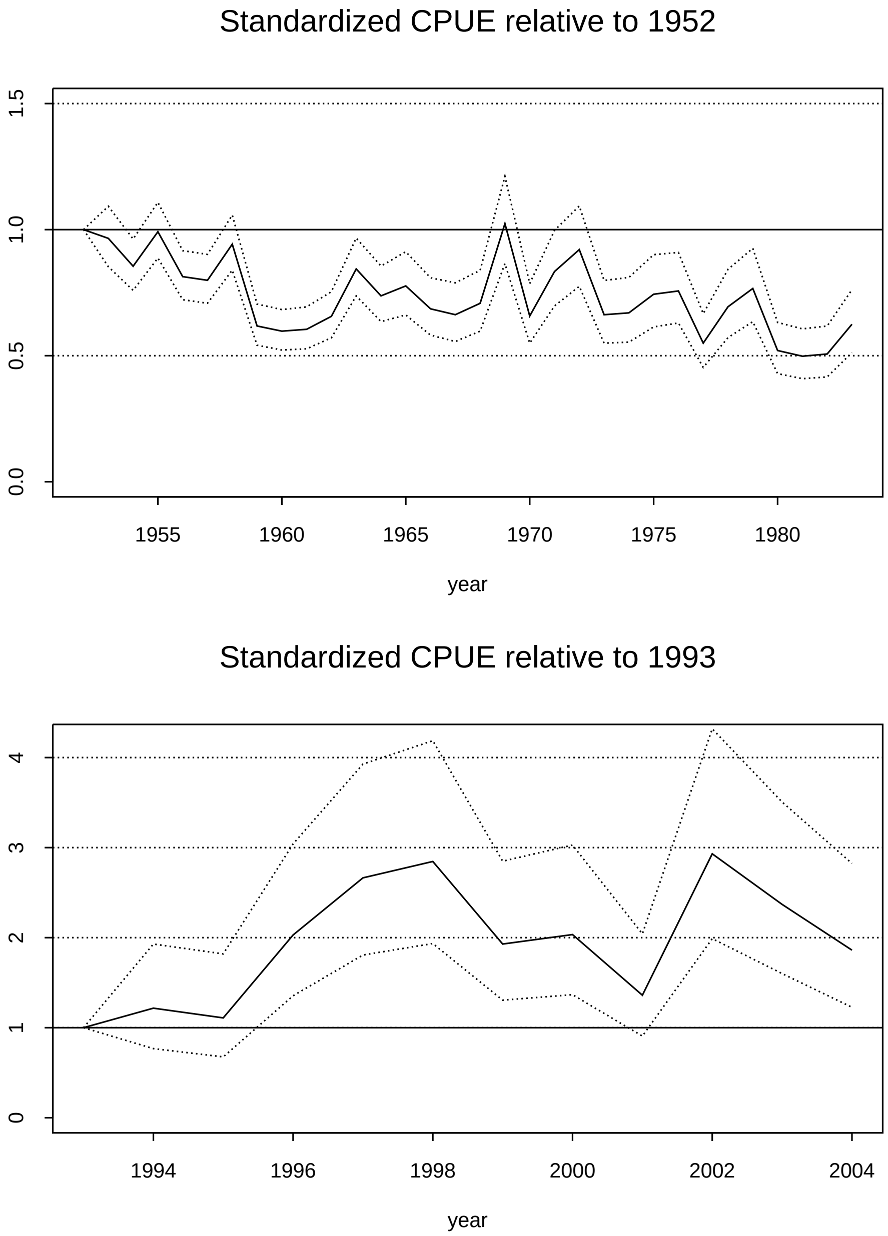

Figure 3. Estimates of standardized CPUE indexes (D_t) relative to 1952 and 1993 with 95% confidence intervals.

year	$\hat{D}_t$	$\hat{\delta}_t$	standard error of $\hat{\delta}_t$	year	$\hat{D}_t$	$\hat{\delta}_t$	standard error of $\hat{\delta}_t$
1953	0.965	-0.035	0.063	1994	1.217	0.196	0.235
1954	0.855	-0.157	0.061	1995	1.109	0.103	0.253
1955	0.992	-0.008	0.057	1996	2.030	0.708	0.206
1956	0.814	-0.206	0.061	1997	2.664	0.980	0.198
1957	0.799	-0.224	0.062	1998	2.846	1.046	0.197
1958	0.942	-0.059	0.059	1999	1.929	0.657	0.199
1959	0.618	-0.482	0.067	2000	2.034	0.710	0.203
1960	0.597	-0.515	0.068	2002	2.931	1.075	0.198
1961	0.605	-0.503	0.070	2003	2.369	0.863	0.200
1962	0.656	-0.421	0.071	2004	1.861	0.621	0.213
1963	0.844	-0.170	0.069				
1964	0.737	-0.305	0.076				
1965	0.777	-0.253	0.082				
1966	0.686	-0.377	0.084				
1967	0.663	-0.412	0.089				
1968	0.708	-0.346	0.087				
1969	1.024	0.024	0.086				
1970	0.657	-0.420	0.091				
1971	0.834	-0.182	0.091				
1972	0.921	-0.083	0.088				
1973	0.662	-0.412	0.095				
1974	0.670	-0.401	0.097				
1975	0.744	-0.296	0.098				
1976	0.757	-0.279	0.094				
1977	0.550	-0.598	0.098				
1978	0.694	-0.365	0.099				
1979	0.767	-0.266	0.096				
1980	0.520	-0.653	0.099				
1981	0.498	-0.697	0.101				
1982	0.507	-0.680	0.101				
1983	0.625	-0.471	0.101				

Table 1. Estimates of standardized CPUE indexes on relative and logarithmic scale, with standard errors on logarithmic scale.

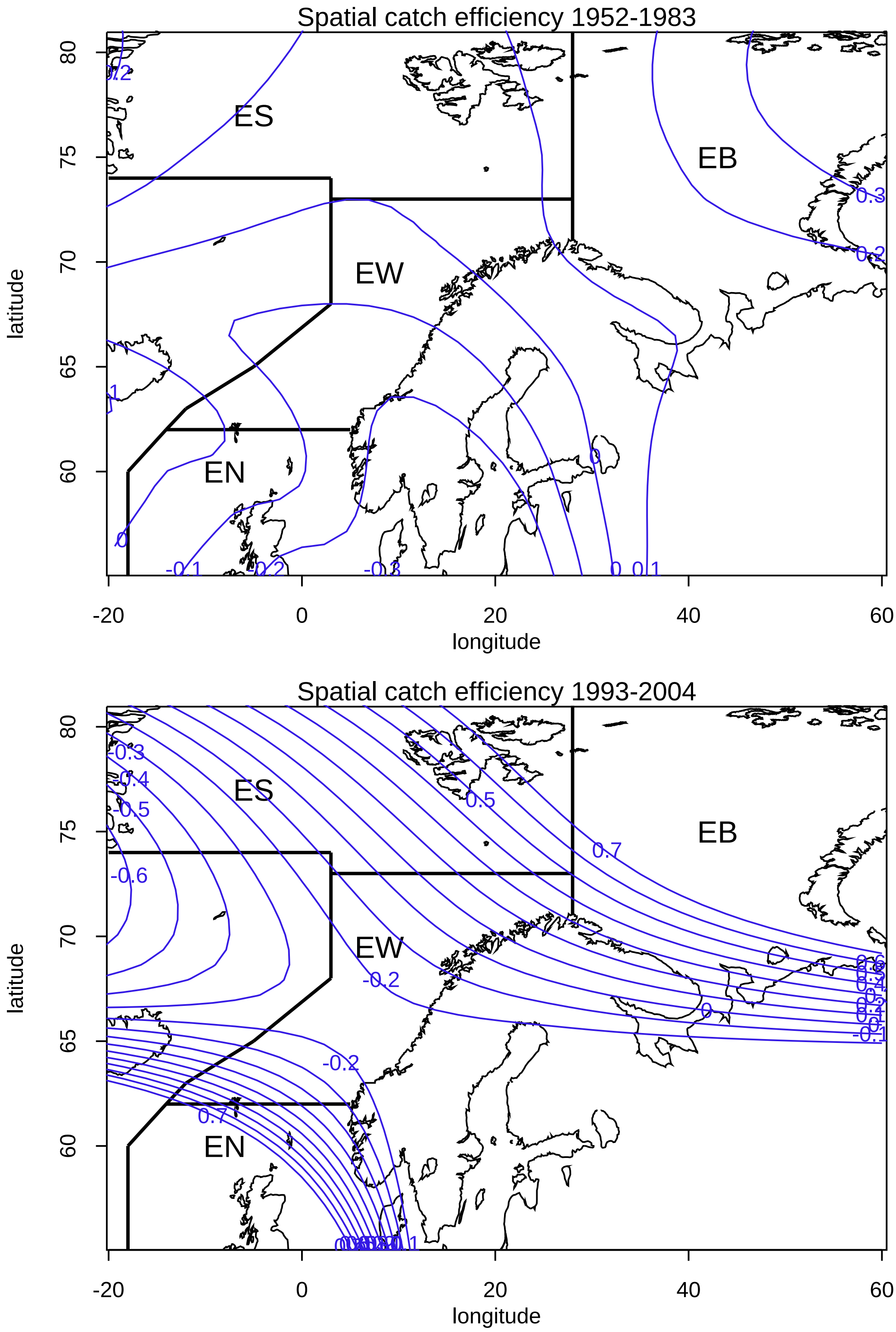

Figure 4. Estimates of spatial catch efficiency on logarithmic scale. Equidistance is 0.1. In the lower panel (1993-2004); the contours outside the areas with data in the upper, right corner and the lower, left corner are not plotted.

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A Calculation of expected net catcher days in case of missing days

The net catcher days for boat i year t can be calculated as the sum of net catcher days within each month m, i.e. $N_{it} = \sum_{m=1}^{12} N_{itm}$, where N_{itm} is the number of net catcher days in month m. For 0.15% of the catches, only month and year recorded, whereas the day in month is missing. We assume that the catches with missing days are uniformly distributed over the days in a month. Then N_{itm}, and hence also N_{it}, is replaced by its expected value as shown below.

Suppose there are r catches with registered days and q catches with missing days for the boat and month in question. Now, the true number of net catcher days N in the month, both registered and missing, could be any number between r and $r+q$, but not larger than the number of days d in the month. Number the missing days from 1 to n. Define an index I_k, $k = 1, ..., n$, which is one if the k'th missing day is not a registered day or among the first $k-1$ missing days, zero elsewhere.

The expected net catcher days in the month in question is then $E(N) = r + \sum_{k=1}^{q} E(I_k)$ Since we assume that the missing days are uniformly distributed, the first missing day has a probability $(d-r)/d$ to be on an unregistered day, and hence $E(I_k) = (d-r)/d$. By recursion one can show that

$$E(N_{itm}) \quad = \quad E(N) = r + \sum_{k=1}^{q} E(I_k) = r + (1 - r/d) \sum_{k=0}^{q-1} (1 - 1/d)^k.$$

B Choice of effective number of parameters in the spatial catch efficiency

The smoothness of the spline functions s_x, s_y and s_{xy} in (3) can be controlled by adjusting the number of effective parameters. A higher number of effective parameters give better fit to the data on the cost of less smooth functions and possible higher estimation variability. We have used the Splus package to fit the generalised additive models. In Splus, a pilot number of effective parameters is specified for each spline function. Based on the model fit, the real numbers of effective parameters are estimated and reported, and these may differ slightly from the pilot numbers.

We have chosen the number of effective parameters by minimising an Akaikes type criterion adjusted for over dispersion (Burnham and Anderson, 1998), defined as

$$AIC_{adj} = -2(log\ likelihood)/\Phi + 2p,$$

where Φ is the dispersion parameter and p is the estimated number of effective parameters.

The pilot number of effective parameters is restricted to the same number in the three spline functions s_x, s_y and s_{xy}. Furthermore, the pilot number is varied from 0 to 6, or from 0 to 18 in total for the spatial function $f = s_x + s_y + s_{xy}$. Table B.1 shows the results, reported as the difference in effective number of parameters and in AIC_{adj} compared to a model without the spatial function. There is an obvious gain by including a spatial function, but the results are not very sensitive to the number of effective parameters. The optimal pilot numbers are 4 per s-function in the period 1952-1983, and 1 for in period 1983-2004.

	1952-1983		1993-2004	
pilot number of effective parameters	estimated number of effective parameters	AIC_{adj}	estimated number of effective parameters	AIC_{adj}
0	0.0	0.0	0.0	0.0
3	7.6	-35.8	5.4	**-25.8**
6	8.7	-34.9	6.4	-23.8
9	10.7	-35.9	9.0	-20.5
12	12.7	**-36.7**	12.0	-16.6
15	15.0	-36.3	15.0	-12.7
18	18.0	-34.8	18.0	-8.7

Table B.1. Number of effective parameters and adjusted AIC for the spatial part of the models compared to a model without a spatial part.