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VESSEL AND DAY/NIGHT EFFECTS IN THE ESTIMATION OF HERRING ABUNDANCE AND DISTRIBUTION FROM THE IBTS SURVEYS IN NORTH SEA

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ABSTRACT

Data from the 1983 to 1998 IBTS surveys were examined for evidence of vessel effects (including trawl rigging, working practices) and day/night differences in catch. Paired observations from different vessels were used to examine the differences in catch of herring among vessels. Kriging with external drift was used to show differences in spatial distribution resulting from differences in catch rate between daylight and darkness. This method is able to account for a day/night effect even when this is scarcely evident. The results of kriging the abundance with external drift are compared to ordinary kriging without compensation for time of day and to the IBTS standard abundance indices. Important effects have been observed, both with time of day and with vessel. The effects of vessel are particularly important as these effect not just the variability but the long-term stability of the time series. Significant improvements in the IBTS index are possible when correction factors for all vessels are applied as two independent age dependant factors for 1 ring and 2+ ring herring.

INTRODUCTION

The IBTS 1st quarter surveys, which were coordinated as the young fish surveys since 1971, have, with only minor exceptions, been standardised since 1983/4. The data from 1983 onwards has been used to estimate an index of abundance at age of a number of important commercial species in the North Sea. This paper addresses two issues of catch rate consistency within the time series, vessel-related effects, and time of day. Here we consider only the index of herring ages 1 to 5+ which have been used in the assessments of North Sea herring since 1989, although the 1 ring index has been used as an index of recruitment in earlier assessments. A total of 17 different vessels have been used over the period, with only one vessel operating over the whole study period. Operating procedures have drifted over time and the proportion of day and night hauls changes with time. These two aspects of the survey are potential sources of bias and it would be advantageous if their effects could be removed.

METHODS

General

The catch data used is the standardised hourly catch rate of herring at ages 1 to 5+ winter ring from IBTS 1st quarter survey 1983 to 1997. The studies carried out here used herring catch per hour at age, trawl location, latitude, longitude, time of day, date and vessel. The number of winter rings observed in otoliths defines ages of autumn spawned herring. Herring spawned in the autumn matures from the larval stage over winter is 0 group for the next 12 months and forms its first winter ring over its second winter. The data were obtained from the ICES database and examined for consistent dates, times and locations by checking between station sailing distances and times, station sequences and cross-referencing times and locations with the ICES hydrographic database that contains data collected on the same surveys. About 100 errors in location date and time in both IBTS and hydrographic databases were detected and corrected. The station times dates and locations used are now thought to be accurate to within one hour and located to better than 10 nmi. The vessels and years of operation are given in Table 1. The hauls were carried out preferentially during the day but the proportion of hauls carried out at night changes slightly during the period of the survey, rising from a mean of around 14% over the first few years to 20% over the last few years. The fraction of hauls taken at night for each year is shown in Figure 1.

Day Night

The exact relationship between catch rate and time of day is difficult to establish. However, inspection of the data suggests that there are no strong relationships between spatial sampling and time of day, though there are more night hauls in the north. There are some differences in mean abundance over years, and the number of hauls per year varies, but the number of stations was not related to abundance. So all the data may be analysed together, for time of day effects, without significant effects due to none representative sampling. Figures 2a-e show the mean catch rate at age by two hour periods in the 1st quarter in the North Sea for the period 1983 to 1997. The data has been examined with a bootstrap (Efron and Tibshirani 1993) to give 95 percentiles on the estimates of mean catch for each two hour period (Figs 2a-e). In order to incorporate changes in catch between day and night, the technique of kriging with external drift (Rivoirard *et al.*, 2000) is used. Kriging with external drift is a geostatistical method, which allows the estimation of a spatial variable when this is driven by a known external parameter. The great flexibility of the method lies in the fact that the response function to this parameter needs only be known in general terms, the coefficients in any expression are not required. This is advantageous when the effect of the parameter exists or is postulated, but without being known precisely. A postulated day/night effect on catch rates in trawl survey data can thus be handled, even when the exact influence of day and night levels is poorly known. The methods are described in detail and illustrated on studies of juvenile gadoid catches in North Sea (Rivoirard and Wieland 2000).

Here two functions of time of day have been tested:

> Firstly an indicator variable for day and night, used as external drift in kriging. Kriging was carried out for both conditions day and night and a new index independent of time of day calculated as the equally weighted mean of the two series.
>
> Secondly a function of time of day was selected. A 24 hour period cosine function centred on midday giving a symmetrical and continuous factor related to time of day was used. Again kriging with external drift was carried out, this time at two specific times of

day, mid-day and mid-night. The new index independent of time of day is calculated as the mean of these two estimates.

In addition, the arithmetic mean of the stations and an estimate by ordinary kriging were calculated for comparison. The arithmetic mean is equivalent to the assessment index. This provides four estimates of the time-series of catch at age from the IBTS 1st quarter survey: 1) the assessment index or the arithmetic mean (Index); 2) ordinary kriging (OK), 3) kriging with external drift with the day night indicator variable (D/N); and 4) kriging with external drift with a the cosine time of day function (ToD).

The variogram models required for kriging are given in Table 2.

To assess the performance of these functions it is necessary to compare them to a standard, ideally to the population under study, however, we do not know the population well so two methods are selected. We compared the performance of these functions: firstly by comparison of cohort estimation, and secondly comparison with an assessment excluding the IBTS survey. In the first case, the catch at age by the survey is assumed to be age selective but consistent over time. Estimates of relative year class strength are obtained for each of five ages by normalising each age of each series over a standard period, a set of years that contain the same year classes. Comparing the standard deviation of the five estimates of year class strength gives a criterion for comparison of the performance of the four series. A series with a lower standard deviation in the estimates of year class strength is providing more similar estimates of the cohorts and is therefore thought to be more reliable. Secondly, comparison with the assessment. An assessment of the North Sea herring stock was carried out excluding the IBTS 1st quarter survey data, but using the all the other data in all respects as carried out by the ICES Herring Assessment WG in 2000 (ICES 2000). In this assessment the method used is Integrated Catch at Age (ICA, Patterson and Melvin 1996) and the tuning series are fitted by minimising the log ratios between population and indices. So the same method was used to compare the four series. The sums of the absolute log ratios by age between the new assessment and the four test series were calculated and compared.

Vessel Effects

A total of 17 were vessels involved with the 1st quarter IBTS survey from 1983 to 1997. The spatial distribution of sampling by vessel is non-representative. Traditionally vessels carry out surveys in areas that cover only 1/4 to 1/3 of the total area and the allocation changes only a little from year to year. However, the areas overlap and in most cases two or more vessels fish in each ICES statistical rectangle (approximately 30 by 30 nmi). The distribution of herring at age is thought to be non-stationary with the younger fish occupying the south and east of the area and the older herring the north and west. Thus both catch and vessel is thought to be particularly dependent on location and an analysis of catch by vessel using the complete data set would confound location and vessel. Sparholt (1990) used a GLM analysis of the complete IBTS dataset and his results were hard to interpret because he compounded spatial and vessel effects. To avoid this problem trawl station pairs were selected from the data set according to the following rules:

Selecting the closest haul by distance and quarter and for each different vessel pair.
Hauls separated by greater than 20 nmi or more than a quarter were excluded.
Multiple use of hauls with the same vessel pairs was excluded by selecting the closest spatial pairing only.

This provided 3117 pairs of hauls linking 17 vessels. The numbers of vessel pairs is shown in Table 3. Figure 3 shows the spatial distribution of the selected pairs and Figure 4 shows a scatter plot (on a log scale) of the paired catch rates for 1 group herring. In this plot the zero values have been included along the axes of the figure. This figure illustrates the high variability in catch rate, catch rate ratios of up to 6 orders of magnitude are observed and 14% of ratios exceed two orders of magnitude. Initially, the vessel pairs were analysed, by examining individual vessel pairings, for significant differences in mean catch rate using a Student t test, which assumes the difference in catch rate is normally distributed. Secondly, to remove the required parametric amplitude distributional restriction, the differences in mean catch between pairs were examined using a bootstrap of the vessel pairs. Thirdly, to make use of all the cross links between vessels simultaneously and provide a complete and consistent estimate of catch rate by vessel, a generalised linear model (GLM) was fitted to the data. The selected data set of 3117 observation pairs was bootstrapped to estimate the precision of the vessel factors from the model. To model the process the catch C at a location j by vessel k was assumed to be:

$$C_{jk} = \lambda_k \beta_j$$

where β_j is the density of herring at a location j and λ_k is the catch rate of vessel k.

Then the relative catch rate of vessel 1 at a location j fished by vessels 1 and 2 is:

$$C_{j1} / (C_{j1} + C_{j2}) = \lambda_1 \beta_j / (\lambda_1 \beta j + \lambda_2 \beta_j) = \lambda_1 / (\lambda_1 + \lambda_2);$$

As this provide a series of estimates of catch proportions it therefore should approximate to the properties of a binomial distribution, the values of λ may be estimated by minimising the binomial log likelyhood estimator:

$$-\Sigma\, [C_{j1} \log (\lambda_1 / (\lambda_1 + \lambda_2)) + C_{j2} \log (\lambda_2 / (\lambda_1 + \lambda_2))]$$

There are many sets values of λ which satisfy this minimisation and to stabilise the estimated values one vessel may be given a value of unity. However, this has two problems, first there is no objective criteria for choosing the vessel so the choice becomes arbitrary. Secondly, and more importantly, this method moves all the variability for the chosen vessel into the values for the other 16 vessels, making it difficult to assign precision to the factor associated with that vessel. An alternative is to require that the mean catch rate remains constant. To do this an additional factor was included in the minimisation to ensure that the λ were all positive and the mean λ was equal to unity. The precision of each of the factors (the λ) could then be estimated by bootstrap. However, for some ages of herring some vessels had zero catch, or a probability of zero catch within the bootstrap, the λ for this vessel was then unconstrained and the additional constraint on mean λ then allowed the unconstrained λ to affected the others. This only occurred for vessels with small numbers of hauls and these four vessels were excluded from the calculation of mean λ (Table 1). This procedure effects only the value of mean λ; the relative difference in λ_k is not influenced by this choice. In practice 2957 of the 3117 catch rate pairs were used to set mean λ. In constraining the mean λ it is necessary to define how this value is calculated, two methods were applied, firstly, equal weight for each of the 13 vessels included and secondly, weighted by the number of hauls per vessel. Again the spread of factors and the precision of the factors is not affected by the decision, only the mean value which is affected by less than 4% for ages 1 to 3 and for combined two to five ring age groups. The effect is about 13% for four and five ring herring.

The GLM model was fitted for each age class separately, however, for five ring (and to some extent four ring) the data was more sparse, giving rise to concerns about the usefulness of the factors. The catch rates were checked for correlation in catch at age (Table 4). The correlation coefficient between age 1 ring and all other ages was less than 0.1. The mean correlation coefficient between adjacent ages two ring to five ring was 0.7. As the catch at these ages are so highly correlated it was thought that the λ would also be correlated. Catches from age two ring to five ring were combined as 2+ and mean 2-5 normalised by mean selection. 1,001 bootstrap replicate samples of the 3,117 pairs were taken with replacement and the GLM catch rate model fitted and the λs estimated. Within the bootstrap a very small number of model fits failed. There were no model fit failures for 1, 2 and two to five ring herring, two fits failed for the three ring herring, four fits failed at four and five ring and one fit failed for 2+ herring. In estimating the confidence intervals it was assumed that these failures would effectively lie outside the 95% intervals and the estimates were treated accordingly, this assumption gives a conservative estimate of the precision. The 95% intervals were estimated from the 1,001 replicates by ordering and taking the 26^{th} and 976^{th} values. The point estimates for the factors were taken from the GLM fitted to the full data set.

The model results from the GLM fit can be used to correct for differences in vessel performance. The correction factor is the inverse of the catch probability. For the small number of ages and vessels where there was insufficient data to obtain values of λ reliably in the bootstrap the estimated factors have been removed and replaced as unity. The catch by vessel has been corrected using six methods:

a) Correction for ages and vessels with significant deviation from unity using individual factors;

b) Correction for ages and vessels with significant deviation from unity for age 1 using age 1 factor and ages 2-5 using 2+ factor;

c) Correction for ages and vessels with significant deviation from unity for age 1 using age 1 factor and ages 2-5 using mean 2 to 5 factor;

d) Correction for all ages and vessels using individual factors;

e) Correction for all ages and vessels using age 1 factor and ages 2-5 using 2+ factor;

f) Correction for all ages and vessels using age 1 factor and ages 2-5 using mean 2 to 5 factor.

The IBTS index used in the assessment were calculated for these six conditions. These modified indices have then been compared for consistency of cohort estimation and comparison with an independent assessment as described above for day night effects.

RESULTS

Day Night

Figures 2a-e illustrate both the fluctuation in catch due to time of day and the 95% intervals derived from the bootstrap. Some kind of time of day effect in catch rate of herring is well supported for the younger herring (1 and 2 ring) but is not clear for four and five ring where a small number of large catches influence both the mean and the precision from the period between 1800 and midnight. For these ages there is evidence of predictable lower catches in the dark period of the early morning but not during the evening darkness.

Examples of the changes in index values can be seen in Figures 5a and b for two and three ring herring. In both these cases a single outlier from the 1988 survey is suppressed by both external drift kriging methods. However, this is only one point albeit a large outlier. Overall estimates of the influence of day night effects on the indices can be seen in the consistency of estimates of cohort strength. Table 5 shows the CV by cohort estimated at 1 to 5 ring, the overall mean for the assessment index, and for two variables used with kriging with external drift D/N and ToD. Table 6 shows the same measure but using only estimates of cohort strength from ages 1 to 3. There is no change in the precision of the cohort estimates when the cohort is observed over five years. The original index and the day night indicator are similar but the time of day function performs poorly. However, there is improvements for all but one cohort for the day night indicator when estimated at ages one, two and three ring.

The estimated log residuals between an assessment of herring (excluding the IBTS data) and the indices can be seen in Table 7. Again there are indications that improvements are possible for ages 1 to 3 when the day night indicator variable is used but not at older ages.

Vessel Effects

The results from the vessel by vessel pair wise comparisons are given Tables 8 and 9 for Student t and Bootstrap methods respectively. Both methods show a small proportion of the catch rates at age are significantly different among the vessel pairs. The bootstrap method indicates greater numbers of significant differences. The Student’s t method requires an assumption of normality in the distribution of the differences between the mean catch rate of each vessel. This statistic is generally robust to some deviation from normality and should hold in all cases, except possibly for catches of the oldest herring where there are a small number of high catch rates. The bootstrap method should be a more reliable method given the type of data involved. A small proportion (5%) of significant tests might be expected just by chance but there are 14% significant differences for the Student test and 30% for the bootstrap. All significant comparisons by the Student t test are significant for the bootstrap. These methods indicate that there are some significant differences, particularly between *Thalassa* and *Walter Herwig II* or *Tridens* or *Isis* or *Dana II* or *Cirolana* at for age 1 herring and between *Eldjarn* and *Walter Herwig II* or *Scotia II* or *Dana II* for older herring. These results are interesting but difficult to use.

The significant departures from unity catch rates determined from the bootstrapped fitted GLM are given in Table 10 and the estimated factors with 95% intervals are shown in Figures 6a-e for herring at ages 1 to 5 ring respectively. The results for 2+ and for two to five ring combined are shown in Figures 7a and b. These results show significantly low catch rates for 1 group herring by *Eldjarn*, *Solea*, *Thalassa* and *Tridens II*, and significantly high catch rates for *Isis*, *Tridens* and *Walter Herwig II*. For older herring (2+) there are no vessels with catch rates significantly above unity but *Eldjarn*, *GO Sars* and *Explorer* show significantly low catches.

The estimated relative catch rates are given in Table 11. Where the factor is marked with * and is exactly unity the estimated value has been removed as it is regarded as unreliable due to shortage of non zero catches. Performance of the corrected indices can be seen in Tables 12 and 13. Here the correction obtained by applying factors at 1 ring and 2+ using all the vessel correction factors, irrespective of whether they are significant or not, performs best. This method reduces the standard deviation of cohort estimation from 0.44 to 0.32 and when compared with the assessment the mean absolute difference in log ratio reduces from 0.45 to 0.34.

DISCUSSION

The examination of two sources of variability, time of day and vessel effects in the calculation of the IBTS index for herring show that there is evidence that both influence the catch rate. The time of day effect has the most impact on the measurement of catch rate at one and two ring, with less evidence for older herring. Correcting for this makes a small improvement in the index for these ages (relative to the assessment) in addition to this general improvement a single known large deviation in estimates of two and three ring herring in the 1988 survey is removed. This index if used at the time might have eliminated a short-term management problem. The vessel effect is more important and shows that useful catch rate corrections as large as a factor of six need to be applied. Correcting for vessel shows a much greater improvement in the index when compared with both cohort estimation and to the assessment. The best results are obtained when correcting for all observed vessel effects even when these are not significant, reducing the log deviation by about 25%. These studies of vessel effects are subject to the assumptions that the data treated as catch proportions follow a binomial distribution. It is more likely that the data gives rise to an over dispersed binomial, but the between pair variance is still very much larger than the within pair variance. It is not anticipated the factors would be effected much by this assumption.

The exact causes of the effects are not known. Vessel effects include (small) deployment and rigging practices as well as obvious differences such as vessel noise. Indeed, it is possible that time of day may also be interacting as a vessel effect due to different working practices influencing the timing of trawls and thus the catch rates. Clearly it would be useful to investigate these effects in a single analysis, but the non-representative nature of the survey design gives rise to analytical problems reducing the number of hauls that can be included and thus the power of the analysis.

CONCLUSIONS

Important effects have been observed, both with time of day and with vessel. The effects of vessel are particularly important as these effect not just the variability but the long-term stability of the time series. These effects need to be taken into account and this study shows that this is possible and that it should improve the performance and usefulness of the survey. While causal relationships can be postulated obtaining sufficient precision to apportion the effects observed will be difficult. It is important to use the work here to include useful factors with sufficient precision to give improvements in performance rather than attempting to explain all the effects in detail. However, more work is required in particular to determine the best method for incorporating the vessel effects observed, particularly where the factors are poorly defined. Methods that use not just the point estimates but the range of correction factors might give more robust results.

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TABLE 1

Vessels, period of use and number of paired observations for IBTS 1st quarter survey. Vessel pairings that are included (Y) and excluded (N) for calculating mean l in the GLM

Vessel	Short Code	Ist year	last year	Number of Station Pairs	Included in mean λ constraint (Y/N)
Anton Dohrn 2	AND2	1983	1986	556	Y
Argos	ARG	1984	1996	25	N
Cirolana	CIR	1983	1990	488	Y
Dana 2	DAN2	1983	1997	658	Y
Eldjarn	ELD	1983	1990	379	Y
Explorer	EXP	1983	1984	138	Y
G O Sars	GOS	1994	1994	70	N
Isis	ISI	1984	1993	308	Y
Michael Sars	MIC	1995	1997	157	Y
Scotia 2	SCO2	1985	1997	756	Y
Solea	SOL	1992	1996	26	N
Thalassa	THA	1983	1996	877	Y
Thalassa 2	THA2	1997	1997	39	N
Tridens	TRI	1983	1990	620	Y
Tridens 2	TRI2	1991	1997	273	Y
Walter Herwig 2	WAH2	1987	1993	611	Y
Walter Herwig 3	WAH3	1995	1997	253	Y

TABLE 2

Variogram models used for kriging. Fits were made on the classical variogram estimate with lag 15 nmi and nlag = 20 distance classes. Where indicated, a sample weighted variogram or a lower number of lags had to be used

Year of survey/Age of herring	Model	Comments
Herring 1 ring		
83	1.06*nugget(h) + 0.00033*h	nlag = 17
84	0.64*nugget(h)+ 0.78*spheric(h/93)	nlag = 11
85	0.85*nugget(h) + 0.00083*h	sample weighted
86	0.26*nugget(h)+ 0.18*spheric(h/54)	sample weighted
87	0.73*nugget(h) + 0.17*spheric(h/95)	sample weighted
88	0.58*nugget(h) + 0.0019*h	sample weighted
89	0.32*nugget(h) + 0.00058*h	sample weighted
90	1.06*nugget(h)	
91	0.37*nugget(h) + 0.58*spheric(h/86)	
92	0.7*nugget(h) + 0.38*spheric(h/100)	sample weighted
93	0.3*nugget(h) + 0.34*spheric(h/82)	sample weighted
94	0.65*nugget(h)+ 0.45*spheric(h/120)	
95	0.68*nugget(h) + 0.32*spheric(h/150)	nlag= 17
96	0.51*nugget(h) + 0.002*h	
97	0.61*nugget(h) + 0.5*spheric(h/130)	although weighted variograms are pure nugget
Herring 2 ring		
83	0.31*nugget(h) + 0.92*spheric(h/97)	
84	0.72*nugget(h) + 0.16*spheric(h/190)	
85	0.53*nugget(h) + 0.33*spheric(h/56)	
86	0.4*nugget(h) + 0.85*spheric(h/180)	
87	0.77*nugget(h) + 0.4*spheric(h/250)	
88	0.98*nugget(h) + 0.00051*h	
89	0.81*nugget(h) + 0.31*spheric(h/85)	
90	0.81*nugget(h) + 0.27*spheric(h/120)	
91	0.51*nugget(h) + 0.55*spheric(h/260)	
92	0.45*nugget(h) + 0.0037*h	

93	0.84*nugget(h) + 0.58*spheric(h/230)	
94	0.70*nugget(h) + 0.66*spheric(h/68)	
95	0.86*nugget(h) + 0.0025*h	
96	1.26*nugget(h) + 0.00057*h	
97	0.43*nugget(h) + 0.0017*h	
Herring 3 ring		
83	0.66*nugget(h) + 0.61*spheric(h/180)	
84	0.63*nugget(h) + 0.00057*h	
85	0.78*nugget(h)	
86	0.2*nugget(h) + 1.08*spheric(h/150)	
87	0.74*nugget(h) + 0.00025*h	
88	0.93*nugget(h) + 0.00075*h	
89	0.48*nugget(h) + 0.58*spheric(h/120)	
90	0.61*nugget(h) + 0.38*spheric(h/72)	
91	0.59*nugget(h) + 0.34*spheric(h/61)	nlag = 9
92	0.27*nugget(h) + 0.0043*h	
93	0.92*nugget(h)	
94	1.06*nugget(h)	
95	0.86*nugget(h) + 0.002*h	
96	1.14*nugget(h)	
97	0.47*nugget(h) + 0.0023*h	
Herring 4 ring		
83	0.11*nugget(h) + 1.10*spheric(h/79)	although nugget is lower than in weighted variograms
84	0.62*nugget(h) + 0.0005*h	
85	0.79*nugget(h)	
86	0.38*nugget(h) + 0.66*spheric(h/110)	
87	0.76*nugget(h)	
88	0.89*nugget(h) + 0.00066*h	
89	0.47*nugget(h) + 0.74*spheric(h/190)	
90	0.46*nugget(h) + 0.002*h	
91	0.88*nugget(h)	
92	0.33*nugget(h) + 0.0025*h	
93	0.32*nugget(h) + 0.0022*h	
94	0.11*nugget(h) + 0.003*h	
95	1.02*nugget(h) + 0.001*h	nlag = 18
96	1.09*nugget(h)	
97	0.73*nugget(h) + 0.00088*h	
Herring 5 ring		
83	0.77*nugget(h)	
84	0.64*nugget(h) + 0.00058*h	
85	0.76*nugget(h)	

86	0.13*nugget(h) + 1.00*spheric(h/120)	
87	0.76*nugget(h)	
88	0.65*nugget(h) + 0.00022*h	
89	0.47*nugget(h) + 0.74*spheric(h/190)	
90	0.43*nugget(h) + 0.0021*h	
91	0.89*nugget(h)	
92	0.45*nugget(h) + 0.0023*h	
93	0.2*nugget(h) + 0.72*spheric(h/300)	
94	0.33*nugget(h) + 0.0022*h	
95	0.47*nugget(h) + 0.002*h	
96	0.4*nugget(h) + 0.0021*h	
97	0.72*nugget(h) + 0.00096*h	

TABLE 3

Number of selected paired stations in the same quarter separated by less than 20 nmi by vessel

Vessel	*WAH3*	*WAH2*	*TRI2*	*TRI*	*THA2*	*THA*	*SOL*	*SCO2*	*MIC*	*ISI*	*GOS*	*EXP*	*ELD*	*DAN2*	*CIR*	*ARG*	**Total**
AND2	0	0	0	117	0	73	0	74	0	6	0	54	98	60	74	0	**557**
ARG	0	7	0	1	0	0	0	0	0	9	0	0	4	4	0	**25**	
CIR	0	38	0	73	0	133	0	18	0	40	0	6	18	88	**488**		
DAN2	24	59	53	37	16	141	8	41	0	37	0	13	77	**658**			
ELD	0	84	0	20	0	17	0	47	0	5	0	9	**379**				
EXP	0	0	0	43	0	11	0	0	0	2	0	**138**					
GOS	24	29	0	0	0	0	0	17	0	0	**70**						
ISI	0	42	7	53	0	88	0	19	0	**308**							
MIC	88	26	0	0	0	1	0	42	**157**								
SCO2	105	164	67	78	0	83	1	**756**									
SOL	0	0	7	0	0	10	**26**										
THA	5	84	99	132	0	**877**											
THA2	1	0	22	0	**39**												
TRI	0	66	0	**620**													
TRI2	6	12	**273**														
WAH2	0	**611**															
Total	**253**																

TABLE 4

Correlation coefficient of catch rate at age from full dataset. Showing the close correlation in catch two ring and older and the low correlation between one ring and older

	1 ring	2 ring	3 ring	4 ring	5 ring
1 ring	1.00				
2 ring	0.10	1.00			
3 ring	0.04	0.80	1.00		
4 ring	0.02	0.30	0.47	1.00	
5 ring	-0.01	0.11	0.34	0.82	1.00

TABLE 5

Precision of estimates of yearclass strength from one to five ring herring comparing the usual assessment index, and two indices obtained by kriging with external drift, first with a Day/Night Indicator variable and secondly with cosine Time of Day function

Year class	Assessment Index	Day/Night Indicator	Time of Day
1981	0.49	0.46	0.76
1982	0.12	0.61	1.20
1983	0.45	0.60	0.76
1984	0.59	0.22	0.40
1985	0.45	0.48	0.54
1986	0.57	0.58	0.63
1987	0.33	0.43	0.77
1988	0.30	0.35	0.54
1989	0.46	0.54	0.62
1990	0.33	0.32	0.67
1991	0.52	0.46	1.05
Mean	**0.42**	**0.46**	**0.72**

TABLE 6

Precision of estimates of yearclass strength from one, two and three ring herring comparing the usual assessment index, and two indices obtained by kriging with external drift, first with a Day/Night Indicator variable and secondly with cosine Time of Day function

Year class	Assessment Index	Day/Night Indicator	Time of Day
1981	0.69	0.62	0.69
1982	0.13	0.50	0.53
1983	0.42	0.45	0.79
1984	0.64	0.15	0.30
1985	0.62	0.28	0.38
1986	0.20	0.36	0.58
1987	0.29	0.16	0.51
1988	0.06	0.07	0.31
1989	0.34	0.23	0.38
1990	0.21	0.19	0.65
1991	0.43	0.28	0.85
Mean	**0.37**	**0.30**	**0.54**

TABLE 7

Mean absolute log residual between a year 2000 assessment of herring excluding the IBTS and the usual assessment index, and two indices obtained by kriging with external drift first with a Day/Night Indicator variable and secondly with cosine Time of Day function. Improvements can be seen for one, two and three ring when time of day is taken into account using an indicator variable

Age/w ring	1	2	3	4	5	**mean**
Assessment Index	0.29	0.58	0.44	0.40	0.53	**0.45**
Day/Night Indicator	0.26	0.43	0.40	0.57	0.60	**0.45**
Time of Day	0.46	0.59	0.68	0.92	0.99	**0.73**

TABLE 8

Student t test for significant differences in mean catch rate by vessel from pair wise comparisons, * indicates there is data for comparison, a numeral indicates significant differences at the age (ring) indicated. Vessels are indicated by IBTS vessel codes, full names are given in Table 1

	WAH 3	*WAH 2*	*TRI2*	*TRI*	*THA2*	*THA*	*SOL*	*SCO2*	*MIC*	*ISI*	*SOS*	*EXP*	*ELD*	*DAN2*	*CIR*
AND2				*****		***4*		**3**				*2***	**345	*****	*****
ARG															
CIR		1****		****		1****				1*				*****	
DAN2		*****	***	*****		1****		*****		****			12***		
ELD		*2345						12***							
EXP				*****											
SOS															
ISI		*****		****		1****									
MIC	*****							*****							
SCO2	*****	*****	*****	*****		*23**									
SOL															
THA		1****	**3**	1****											
THA2															
TRI		*****													

TABLE 9

Bootstrap estimates of significant differences in mean catch rate by vessel from pair wise comparisons, * indicates there is data for comparison, a numeral indicates significant differences at the age (ring) indicated. Vessels are indicated by IBTS vessel codes, full names are given in Table 1

	WAH 3	WAH 2	TRI2	TRI	THA2	THA	SOL	SCO2	MIC	ISI	SOS	EXP	ELD	DAN2	CIR
AND2				*****		*2345		123**				*2***	**345	*2***	*2***
ARG															
CIR		123**		*234		1****				12				*2***	
DAN2		*****	***	*****		1****		*****		****			12345		
ELD		*2345						12**5							
EXP				*2***											
SOS															
ISI		*****		**34		12***									
MIC	*****							*2345							
SCO2	*****	*****	***4*	***4*		*23**									
SOL															
THA		1****	**345	1****											
THA2															
TRI		****5													

TABLE 10

Results of bootstrap generalised linear model estimates of relative catch rate. Catch rates showing significant deviation from 1 for herring by age, catches are either high or low relative to unity catch. ** indicates significant deviation, X indicates significant deviation for bootstrap evaluations but with some unresolved evaluations where all catches in the pairs were zero. N indicates that there was a chance of all zero catches so the vessel factors were excluded from the normalisation criteria for overall catch rate factor of one. The total number of non-zero catch pairs by ring is given at the base of the table

Vessel	Code	1 ring		2 ring		3 ring		4 ring		5 ring		2+ ring		2+ ring Weighted	
		Lo	hi	Lo	hi	Lo	hi	Lo	hi	Lo	hi	Lo	hi	Lo	Hi
Anton Dohrn 2	AND2														
Argos	ARG														
Cirolana	CIR														
Dana 2	DAN2														
Eldjarn	ELD	**		**		**		**		**		**		**	
Explorer	EXP			**		**		**		**		**		**	
G O Sars	SOS					X		X		X		**		**	
Isis	ISI		**												
Michael Sars	MIC														
Scotia 2	SCO2														
Solea	SOL	**		**					X			**			
Thalassa	THA	**		**		**						**			
Thalassa 2	THA2						X				X				
Tridens	TRI		**							**					
Tridens 2	TRI2	**						**		X					
Walter Herwig 2	WAH2		**												
Walter Herwig 3	WAH3														
Non-zero catch pairs		2461		2706		2114		1638		1213		2810		2810	

TABLE 11

Estimated catch rates at age for herring 1st quarter IBTS survey in the North Sea. Factors are estimated for ages one to 5 independently, and for 2+ and for two to five ring with equal weight at age. The values 1.00* are not estimated, they are where the data is insufficient to obtain estimates

Vessel/age	1 ring	2 ring	3 ring	4 ring	5 ring	2+ ring	mean 2-5
AND2	0.95	0.84	1.52	1.35	2.30	1.13	1.51
ARG	2.13	1.40	1.00*	1.00*	1.00*	1.03	0.39
CIR	0.98	0.57	1.38	1.20	1.71	0.76	1.14
DAN2	1.20	1.34	1.46	2.58	2.03	1.51	1.86
ELD	0.24	0.26	0.14	0.08	0.08	0.21	0.13
EXP	0.51	0.43	0.11	0.05	0.08	0.37	0.18
GOS	1.01	1.00*	1.00*	0.23	0.15	0.15	0.17
ISI	2.35	1.53	1.46	0.55	0.43	1.23	0.62
MIC	1.24	0.32	1.29	1.43	0.96	0.63	1.08
SCO2	0.92	1.34	1.36	1.74	2.05	1.56	1.82
SOL	0.37	0.37	2.88	1.00*	1.00*	0.40	0.55
THA	0.32	0.44	0.48	1.10	0.96	0.55	0.77
THA2	2.25	4.45	1.00*	2.30	1.00*	4.29	4.90
TRI	1.51	0.75	0.88	0.77	0.20	0.85	0.76
TRI2	0.35	2.68	1.00*	1.00*	1.00*	1.57	0.52
WAH2	1.62	1.14	1.46	1.39	0.97	1.37	1.53
WAH3	0.82	1.37	0.75	0.65	1.03	1.27	1.07

TABLE 12

Precision of estimates of yearclass strength from 1-5 w ring herring comparing the usual assessment index, and six levels of correction for vessel factor. The method using all estimated vessel correction factors at ages one ring and 2+ ring performs best

Year class	Assessment Index	Significant Factors Individual Ages	Significant Factors Ages 1 and 2+	Significant Factors Ages 1 and 2-5	All Factors Individual Ages	All Factors Ages 1 and 2+	All Factors Ages 1 and 2-5
1981	0.49	0.41	0.44	0.42	0.38	0.41	0.31
1982	0.21	0.11	0.20	0.16	0.08	0.21	0.26
1983	0.51	0.30	0.29	0.28	0.26	0.31	0.24
1984	0.54	0.60	0.53	0.54	0.42	0.41	0.36
1985	0.46	0.41	0.41	0.41	0.40	0.34	0.27
1986	0.44	0.48	0.43	0.43	0.42	0.36	0.34
1987	0.36	0.19	0.22	0.22	0.17	0.11	0.19
1988	0.24	0.29	0.36	0.35	0.30	0.32	0.45
1989	0.51	0.48	0.46	0.46	0.44	0.33	0.51
1990	0.49	0.27	0.20	0.23	0.26	0.17	0.31
1991	0.63	0.69	0.69	0.69	0.54	0.52	0.48
Mean	**0.44**	**0.39**	**0.38**	**0.38**	**0.33**	**0.32**	**0.34**

TABLE 13

Mean absolute log ratio of index and assessment, for six types of correction. The method using all estimated vessel correction factors at ages one ring and 2+ ring performs best. Although the differences between this and the separate age factors is not large

Age/w ring	1	2	3	4	5	**mean**
Assessment Index	0.29	0.58	0.44	0.40	0.53	**0.45**
Significant ages Individually	0.33	0.38	0.34	0.37	0.56	**0.40**
Significant one ring and 2+	0.33	0.40	0.37	0.33	0.50	**0.39**
Significant one ring and 2-5	0.33	0.41	0.37	0.36	0.50	**0.40**
All factors ages Individually	0.24	0.36	0.32	0.38	0.45	**0.35**
All factors one ring and 2+	0.24	0.34	0.31	0.32	0.47	**0.34**
All factors one ring and 2-5	0.24	0.40	0.42	0.39	0.49	**0.39**

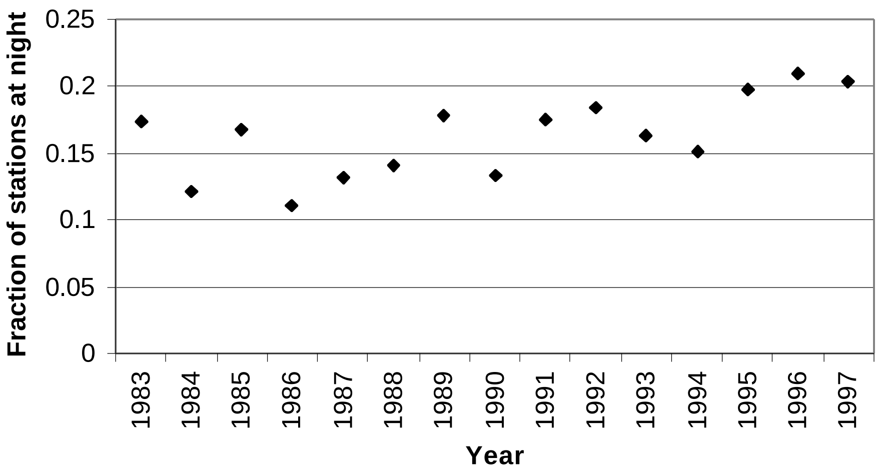

Figure 1. Fraction of hauls carried out at night on the 1st Quarter IBTS survey in the North Sea from 1983 – 1997

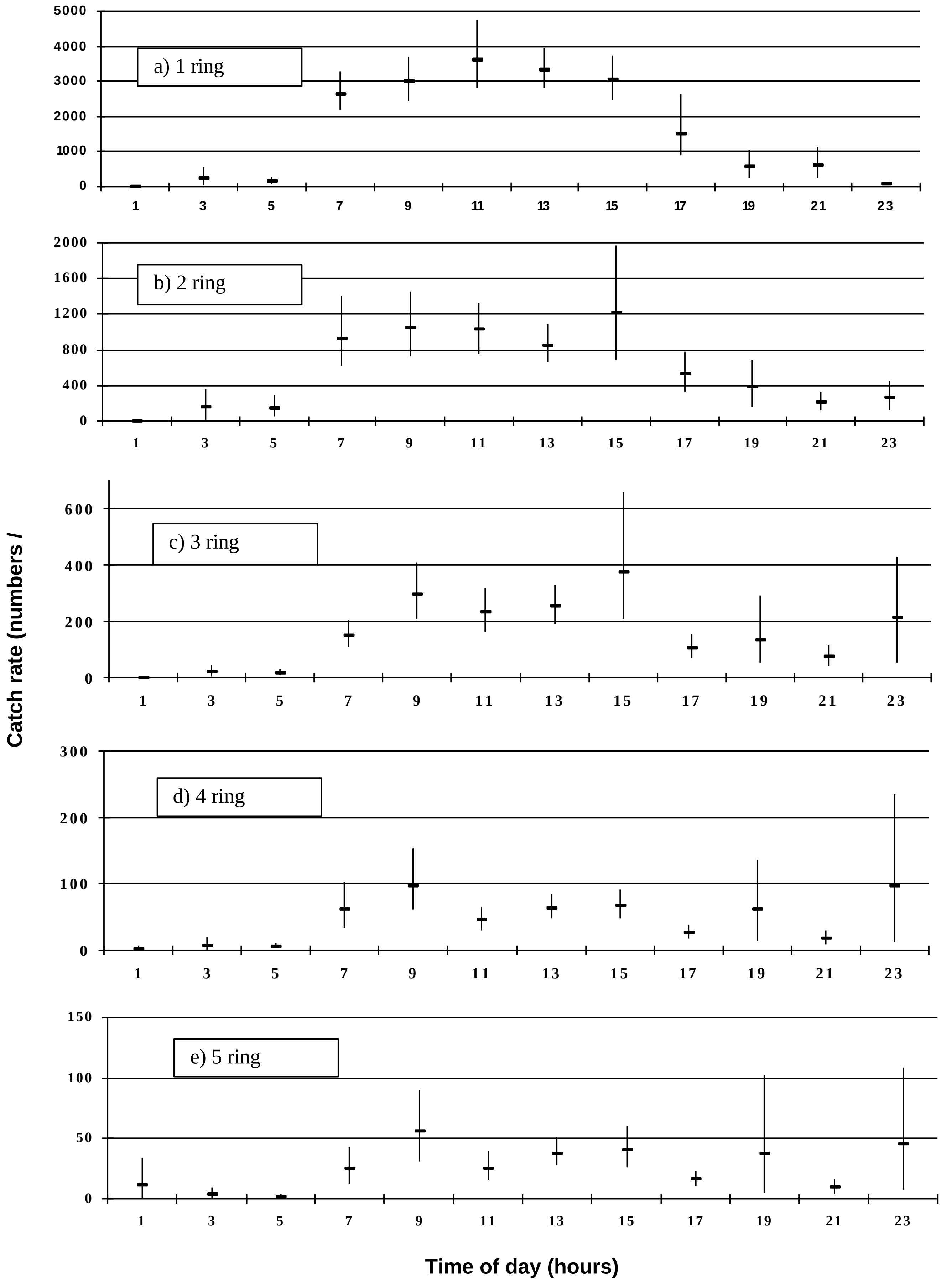

Figure 2. Mean catch rate for a standard hour tow and 95% intervals of herring at age for 2 hour periods (centred on 1 to 23 hours) from 1st quarter IBTS survey 1983 to 1997 . Mean rates are estimated from all hauls, 95% intervals are estimated by bootstrap. Note the significantly lower mean catch rates at night., particularly for 1 and 2 ring herring. The estimated catch rates of 3 ring and older are affected by a small number of large values between 1800 and midnight.

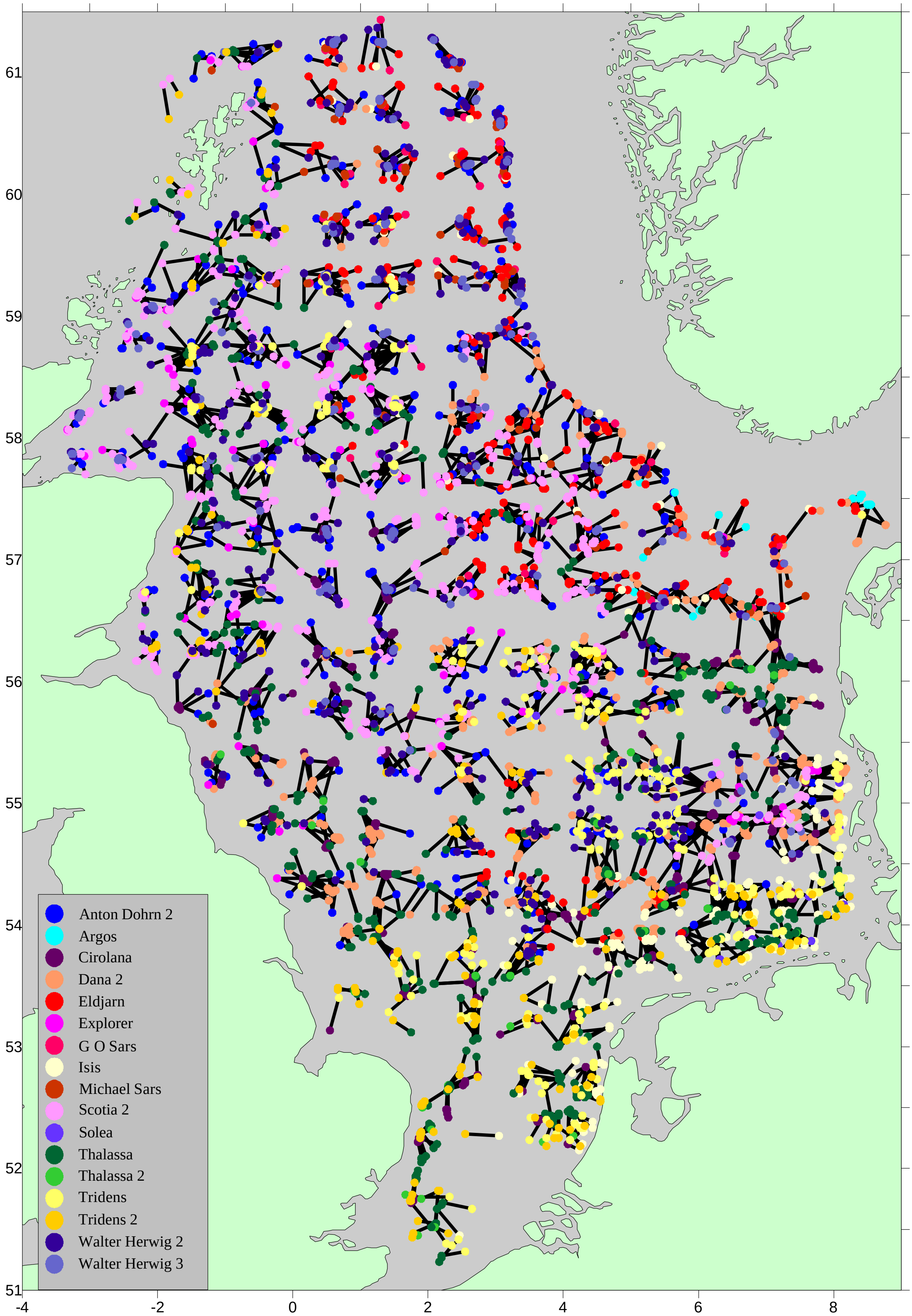

Figure 3. The spatial distribution and links between pairs of trawls by 17 different vessels from 1st quarter IBTS survey 1983 to 1997. The coloured dots represent the trawl locations and vessels, the linking lines shows the link for pairs from the same year and quarter with less than 20 n.mi separation. (Note the good area coverage but the non representative spatial distribution of individual vessels).

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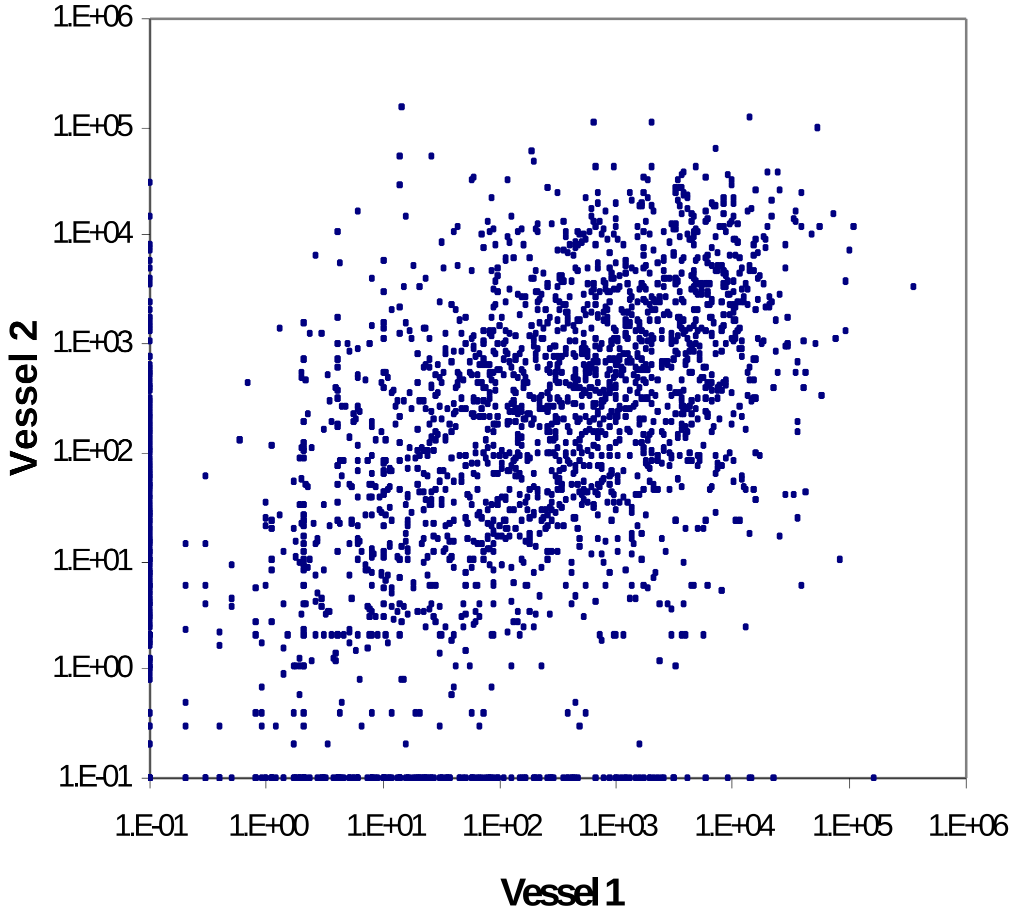

Figure 4. Log log scatter plot of catch rate of 1 ring herring for paired standardised 1 hour hauls from 1st quarter IBTS survey. Zero catch rates are included on the axes of the plot. All pairings used in the analysis of vessel effects are included, the designation of order of vessel in the pairs is arbitrary. The plot showes the huge variability in the catch rates for paired hauls.

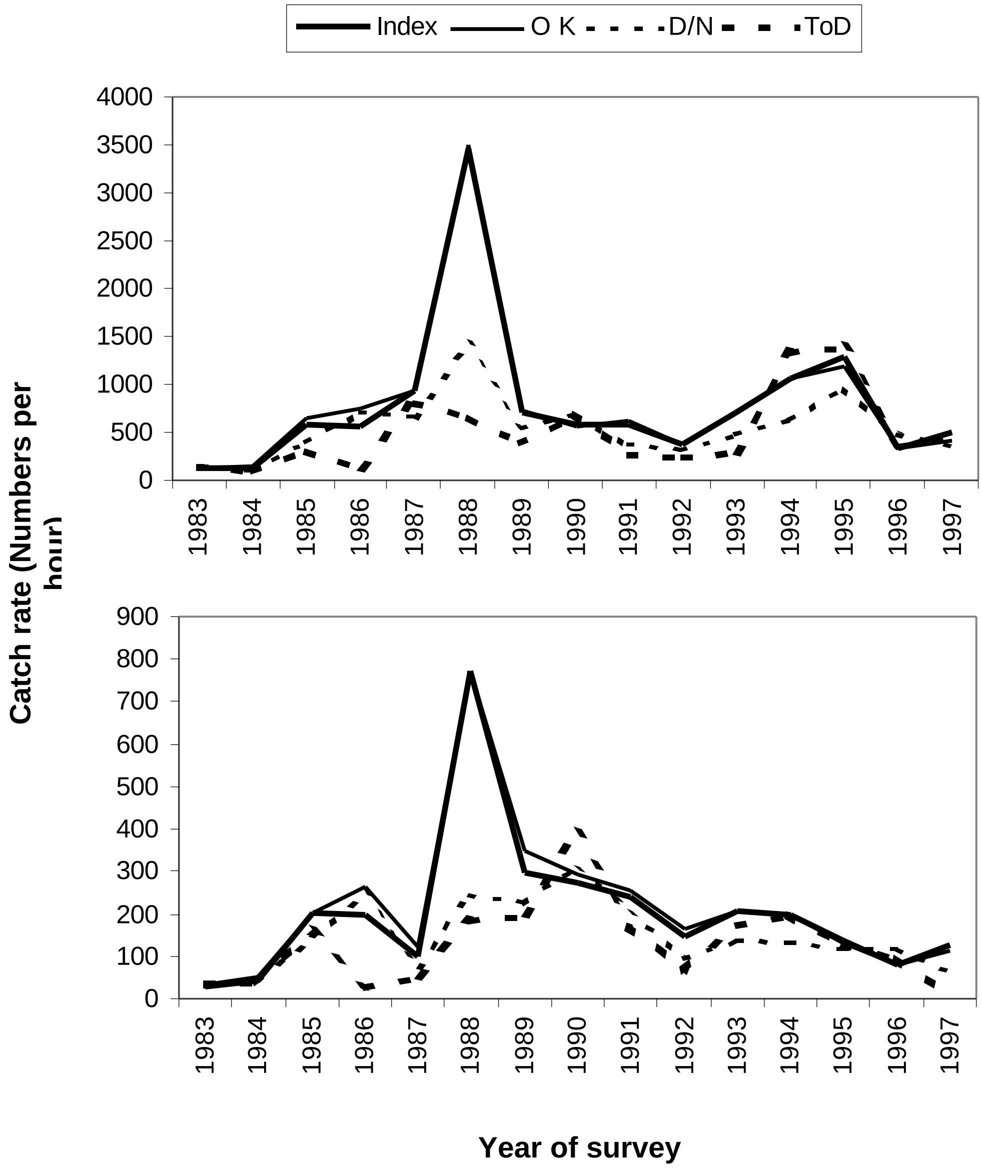

Figure 5. Catch rate of 2 ring and 3 ring herring. A comparison of indices for herring, working group index (Index), ordinary kriging (O K), kriging with external drift with day / night indicator variable (D/N) and kriging with external drift with cosine time of day variable (ToD). Note the suppression of outliers at both ages in 1988 when unusually high estimates of herring abundance occur in the working group index and the ordinary kriging but are removed when either method for including time of day is used.

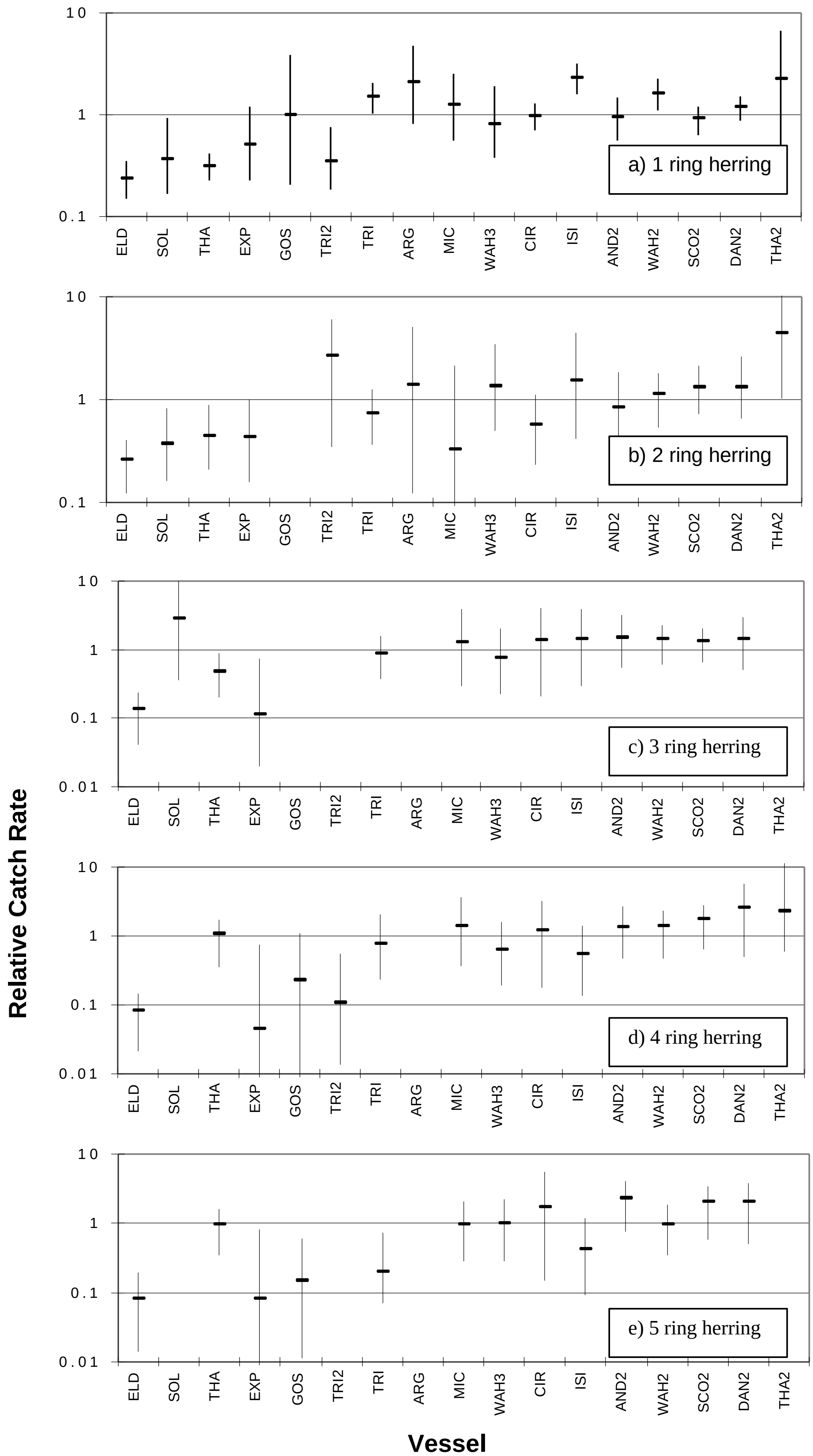

Figure 6. Relative catch rate at ages 1 to 5 ring for herring North Sea IBTS survey 1983 to 1997, a) 1 ring, b) 2 ring, c) 3 ring, d) 4 ring, and e) 5 ring herring. Relative catch rates and 95% intervals estimated from a generalised linear model of paired hauls. The overall catch rate at age is maintained equal to unity for all estimates (excluding vessels with small numbers of paired hauls (see Table 1).

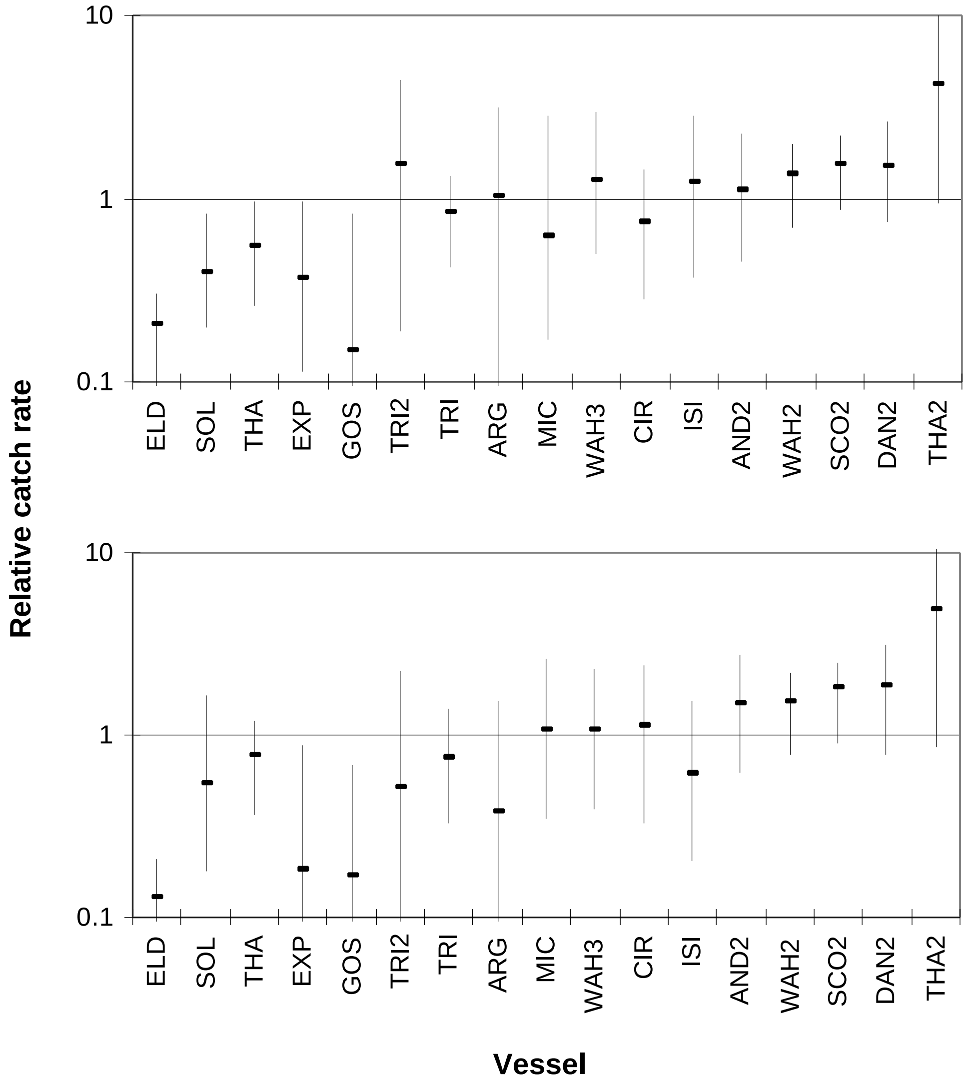

Figure 7. Relative catch rate at ages 2 to 5 ring for herring North Sea IBTS survey 1983 to 1997. Relative catch rates and 95% intervals estimated from a generalised linear model of paired hauls. a) 2+ herring; sum of all catches 2 ring and older, b) 2 – 5 ring herring; catches of herring ages 2 to 5 giving equal weight to each age group. The overall catch rate at age is maintained equal to unity for all estimates (excluding vessels with small numbers of paired hauls (see Table 1).