Spatial distribution pattern generating processes in the International Bottom Trawl Survey in the North Sea

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ISBN: 87-88047-90-3

DFU-Rapport nr. 60-98

Introduction

Recruitment indices based on surveys are regaining increasing attention as fisheries-independent estimates because it is assumed that the conventional assessments obtained from Virtual Population Analyses (VPA) have become increasingly biased during recent years due to mis- and non-reporting of landings and discards. For 1- and 2-group roundfish (cod, haddock, whiting) in the North Sea, however, considerable discrepancies of recruit abundance indices from surveys and the VPA estimates are observed (ICES 1998a,b).

The International Bottom Trawl Survey (IBTS; formerly International Young Fish Survey) in the North Sea conducted in February each year started in the beginning of the 1960s and aimed at first exclusively at juvenile herring. Over the years the objectives of this survey were broadened to include the sampling of young gadoids, and the survey area was extended in the 1980s to include the northern North Sea and the Skagerrak/Kattegat. From 1991 onwards, sampling has also been conducted in the second, third and fourth quarters of each year, in addition to the traditional first quarter survey in February.

Standard abundance indices are presently computed by taking the arithmetic mean per hour trawling for all hauls within a statistical rectangle and subsequently the arithmetic mean for all rectangles within a species-specific standard area. This procedure does not consider aspects of the frequency distribution of the catches, or the spatial distribution of the fish. Based on the analysis of abundance estimates for North Sea herring (age 1, years 1981-1992) it was concluded that more sophisticated methods for the calculation of the indices would not generally produce significantly better result (ICES 1992a). However, as the arithmetic mean is not necessarily a meaningful estimator of central tendency, the application of more realistic statistical models (e.g., using Poisson, Delta, Beta distributions) can lead to less variable estimates for a specific species, age group or area (Pennington 1986, Myers & Pepin 1990, Gröger & Ehrich 1992, Stefánsson 1996). In particular for the 1990s, when a large amount of effort was put into standardising the survey design (Heessen et al. 1997) and gear (ICES 1992b,c), an improvement of the recruitment indices by applying realistic statistical distributions would in itself represent an important progress.

Recent years have seen increasing interest in the application of spatial statistics to fisheries survey data (Petitgas 1993, 1996). The potential of geostatistics is to detect the structual pattern of spatial data, as demonstrated by Stensholt & Sunnanå (1996). Their contribution demonstrated kriging as an appropriate tool to concurrently study the possible influence of environmental factors like temperature, salinity and bottom type, as well as the composition of the fish community, on the distribution of 0-group cod in the Barents Sea. Such an approach may lead to a species-specific post-stratification of the survey data in order to reduce the variance in the estimation of recruitment indices.

Annual abundance estimates from trawl surveys often change rapidly between years, which are referred to as year-effects. It has been shown for cod in the Northwest Atlantic that these sudden changes reflect changes in the distribution or catchability of the fish which can be related in turn to environmental factors, i.e. a distinct combination of temperature and salinity (Smith & Page 1996). Considering age specific environmental preferences, as documentated for North Sea cod in respect to depth and temperature (Riley & Parnell 1984, ICES 1992a, Heessen & Daan 1994), the concurrent analysis of spatial structures in the fish distribution and the ancillary variables may serve as a sound basis to provide more consistent estimates of recruitment.

The IBTS data have been analyzed here and there with different aspects. For example, IBTS data were used for studying the distribution of individual age groups of cod (Riley & Parnell 1984, Heessen & Daan 1994) and standard statistical analysis was performed for herring (Sparholt 1990). So far, however, the data set has not yet been analysed with state-of-the-art spatial statistical methods focusing on the improvement of recruitment indices of gadoids (age 1 and 2 cod, haddock and whiting).

Concerning an improvement of the IBTS abundance indices, three levels of variation were considered in the present project:

- Random variation
- Within-square variability (random if the specific square is homogeneous)
- Variability in the entire study area.

Target species were whiting and cod (age groups 1 and 2), and the work conducted is described in detail in three papers (see Appendices 1 – 3) from which a summary is given in the following sections.

Material and Methods

Statistical methodology

Two major statistical tools were used in the present project: Generalized linear models (GLM's) and kriging. A GLM is specified by describing a) the connection between a linear predictor and the expected value of the response, and b) the distribution of the response around the mean (McCullagh & Nelder 1989). The primary potential of GLM's (as opposed to simple averages or regressions) lies in the possibility of explicitly specifying the distribution of the response z around its mean using a link function that relates the expected value to the linear predictor (Foote & Stefánsson 1993). The basis for kriging is a spatial model of the entire observed surface, z (x,y). The observed surface is interpreted as a realisation of a random process possessing certain spatial characteristics. If basic assumptionsinre met, the technique produces the best (= minimum variance) linear unbiased estimator, and also is an exact interpolator, i.e. the estimator at a location which has been sampled is returned as the sample value (Cressie 1993). GLM's and kriging are two extreme models of the same phenomenon. If we write $z = \mu + \varepsilon$, with $E(z) = \mu$, then GLM's typically assume that all of the structural information is in the mean function μ, and that ε is simply random error. Ordinary kriging, on the other hand, treats μ as a constant and assumes that all of the structural information is in the correlation structure of ε (Foote & Stefánsson 1993).

Variables

The variability of bottom trawl catches of age 1 and 2 whiting and cod was studied on three spatial scales: at fixed stations, within statistical rectangles and within the species-specific standard areas used in the IBTS. Daylight period, temperature, salinity, water depth and bottom type were considered as potential environmental variables influencing the catches.

Fixed locations

Basic data for the analysis of variability of bottom trawl catches at fixed locations were available from four cruises carried out by the Danish Institute for Fisheries Research. Catches and length frequencies of whiting and cod by haul, as well as corresponding haul information (e.g. position, date, time of day), were extracted from the institute's database, but age disaggregated data were not available from that source. Therefore, at first the length frequencies were raised and standardized to one hour trawling using the weight of the subsample measured, the total catch of the species in question and the trawl duration. The standardized length frequency distributions were then decomposed into age groups either by applying Bhattacharya's method (Bhattacharya 1967) or by using age-length-keys constructed from Scottish and IBTS data (Table 1). Subsequently, daylight period, bottom depth and towing speed were studied as potential covariates affecting the catch rates of age 1 and 2 whiting and cod using GLM's (see Appendix 1).

Statistical rectangles

Information on the variability of catches for whiting and cod from different stations located within a statistical rectangle was derived from the Danish part of the first quarter IBTS. Here, only rectangles were considered, in which at least 4 different stations were covered during the same survey. A total of 11 series of samples with 4 to 6 individual hauls for each specific year/square combination were available, together with mean depth of the trawl track and observations on the bottom type. Length frequencies were raised and standardized to 1 hour trawling time as described above. Area specific age-length-keys were constructed according to the different sampling sites based on age data from the first quarter IBTS (international data set; Table 1) and used to disaggregate the length distributions into numbers at age by haul. Temperature and salinity data were obtained from the ICES Hydrographic Database, and GLM's were used to study the effects of the environmental factors in detail (see Appendix 1).

IBTS standard areas

For the entire study area, catches of whiting and cod in numbers per hour trawling (CPUE) by age group and trawling depths were received from the ICES IBTS Database for the first and the third quarter 1991 to 1996. Following the IBTS Working Group's procedure, arithmetic means from all hauls within a statistical rectangle were calculated for catches of age 1 and 2 whiting and cod. Average trawling depth was obtained in the same way. Temperature and salinity data recorded during the IBTS were obtained from the ICES Hydrographic Database for the first quarter. There was no reliable link in the two databases between the catch data and the hydrographic information, which allow relating them by haul or station. Thus, average bottom temperatures by rectangle were calculated for comparison with the average catches.

Abundance indices for age 1 and 2 whiting and cod were computed both by the standard technique and by methods that accounted for the error structure of the data. The standard abundance indices were calculated as the arithmetic mean for all rectangles within the species-specific standard areas, which consist of 144 squares for whiting and 139 squares for cod (ICES 1996a). The new abundance indices were calculated using GLM's which consider the probability distribution of the catches and which include either depth or temperature as covariates (see Appendix 1).

Doubts existed on how far the first quarter IBTS standard indices are representative for the 1-group because negative mortalities had been reported for several year classes of cod comparing the index for the 1-group with that of the 2-group one year later (ICES 1996a). This may indicate that either the area considered in the calculation of the index did not cover an important part of the nursery area or that the maximum catchability of the 1-group is yet not established in the first quarter, or both. Hence, indices were calculated which were based on an extended area and results from the first and the third quarter were compared (see Appendix 2).

A geostatistical analysis was conducted for whiting age 2 using first quarter IBTS data from 1991 to 1996. The estimation of the variogram is widely regarded as the most critical step in a geostatistical analysis (Cressie 1993). Hence, at first different methods of calculating experimental variograms were tested. Subsequently, distribution maps and global abundance estimates for a predefined area, the domain, were derived using ordinary kriging. Here, the domain was specified as the IBTS standard area for whiting with an extension towards the eastern Skagerrak (see Appendix 3).

The usefulness of the different abundance indices established during the project was evaluated by comparing them with results from recent assessment (ICES 1998a). In this context, it must be noted that the IBTS standard indices were used among data from other surveys in the assessment for VPA tuning and recruitment estimation and hence the VPA results are not fully independent from the IBTS.

Results

Fixed locations

The daylight period was the dominant factor influencing the catches of age 1 and 2 whiting and cod at fixed stations. In general, daylight catches of the 1- and the 2-group were substantially higher than night catches (Fig. 1). This was in particular the case for the 1-group of cod for which the night catches amounted only to about 60 % of the day catches on average. GLM analysis revealed further that depth and towing speed did not contribute significantly to the variability of the catches and the high importance of the daylight period made it difficult to identify a general background level of random variation (Fig. 2).

Statistical rectangles

The variability of whiting and cod catches within statistical rectangles increased in relation to the heterogeneity in the physical environment (Fig. 2). This was in particular the case for age 1 cod for which a significant ($p < 0.05$) relationship between the coefficient of variation and the number heterogeneous variables, i.e. temperature, salinity, depth and bottom type, was found. Such a trend was much less pronounced for the 2-group of both species. The level of variability in homogeneous squares was similar to that observed at fixed stations on average (Fig. 2). High levels of variability occurred always when the gradient in temperature or depth within a statistical rectangle exceeded 0.5°C and 5 m, respectively. GLM analyses revealed that both covariates contributed significantly to the variability of the catches.

IBTS standard area – GLM's

Frequency distributions of the average catches of age 1 and 2 whiting and cod by statistical rectangle pooled for the years 1991 to 1996 were highly skewed, deviating considerably from normal distributions (see Fig. 7 in Appendix 1). Furthermore, high numbers of zero catches were recorded for cod age 1 and 2 in almost all of the years. A log-transformation of the catches (with 1 added to the average CPUE by square) yielded frequency distributions that could be approximated by normal distributions for whiting age 1 and 2, but not for cod. Hence, for whiting new abundance indices could be calculated directly from the arithmetic mean and the standard deviation of log-transformed catches by square (CPUE + 1). Furthermore, lognormal based GLM's were appropriate for age 1 and 2 whiting. This was not the case for cod where the numerous zero catches became clearly isolated from the positive values when a low constant (0.01) was added (see Fig. 7 in Appendix 1). Therefore, a delta approach was used in the cod case, in which the zero values were modelled separately from positive ones. A usual delta-lognormal model according to Pennington (1983) was applied instead of a delta-gamma model as proposed by Stefánsson (1996) because the latter did not fit our data well. Both, the lognormal based GLM's for whiting age 1 and 2 and the delta-lognormal models for cod age 1 and 2 indicated that depth contributed to significantly to the variability of the catches within the species specific standard areas.

IBTS standard area – area and quarter effects

There was only little difference between IBTS indices calculated with the conventional method for the species-specific standard areas and the extended areas concerning whiting age 1 and 2 and cod age 2. In contrast, the indices for age 1 cod increased substantially in some years when the 'Wadden Sea' (1st quarter 1991, 3rd quarter 1993) and the eastern Skagerrak (1st quarter 1992 and 1995) were included. There, the influence of high catches in the four rectangles adjacent to the Wadden Sea was most pronounced, resulting in an 2-3 fold increase of the abundance indices. Mortality estimates for whiting based on the first quarter indices were quite low and did not change very much regardless of whether the standard or the extended area were considered. For cod, the mortality rates based on the first quarter indices were highly variable and negative values occurred in some years irrespective of an inclusion of the 'Wadden Sea' and the eastern Skagerrak. Using the third quarter indices the area effect was smaller for both species, and the obtained mortality rates were much closer to VPA values (Average total mortality rates from VPA for year classes 1990-1995: approximately 1.1 year $^{-1}$ for whiting and 0.9 year $^{-1}$ for cod).

IBTS standard area: spatial structure

Some problems were observed when analysing the spatial structure of age 2 whiting data from the first quarter IBTS. The various methods for the calculation of experimental varigrams yielded quite different results. Finally, omnidirectional log backtransformed variograms with a lag increment of 15 nm were found to describe the data adequately. These variograms showed some consistency between the years, and spherical models could be fitted in all cases. The spherical variogram models had large ranges amounting to 144 – 231 nm and high nugget components ranging between 40 and 69 % of the total sill. Despite of a high small variation of the catches kriged maps that were produced based on the log backtransformed variograms gave a good overview of the distribution pattern. Areas of high fish density were always found south from the Shetland Isles and east off the English coast, but the location of maximum density varied between the two areas in the different years. The German Bight and the Skagerrak were much less important, and in the central North Sea the density of age 2 whiting was low in all years.

Comparison with assessment

A comparison of the various abundance indices established in the present project with most recent assessment of stock size at age is presented in Table 2. The first quarter IBTS standard index was significantly related with the assessment only for age 2 cod, whereas the third quarter IBTS standard indices yielded significant results in all cases except for age 2 whiting. The indices estimated directly from log-transformed catches of age 1 and 2 whiting for both quarters and the geostatistical index for age 2 whiting in the first quarter showed little or no correlation with the assessment. For age 2 whiting the first quarter GLM indices showed the best agreement with the asessessment, and in the case of cod, the GLM indices yielded significant results for both age groups. The GLM indices were much less variable than the standard ones in all cases (Fig. 2).

Conclusions

Implications for IBTS design

The results concerning the influence of the daylight period on the catches of age 1 and 2 whiting and cod are well in accordance with findings for cod and haddock in the Barents Sea (Engås & Soldal 1992) and the North Sea (Ehrich & Gröger 1989). In contrast, Ehrich & Gröger (1989) found no significant difference between day and night catches for whiting in the North Sea. The latter observation, however, was not based on age disaggregated data, and diurnal migration of whiting might be more pronounced for the early age groups than for the older ones, as observed for other gadoids, i.e. cod and haddock (Engås & Soldal 1992). About 20 % of the catches used for the calculation of abundance indices for whiting and cod from the first quarter IBTS originate from night hauls according to the coding in the IBTS database. This coding very strictly attributes hauls started at or close to twilight to night hauls and only a minority of these hauls was really conducted during darkness. However, it appears advisable to follow the recommendation of the IBTS Working Group for daytime trawling (ICES 1992, 1996b) more closely in spite of the problem of achieving full area coverage during the first quarter IBTS with the short daylight period during that time of the year.

High coefficients of variation for catches taken within a statistical rectangle were observed when either solely the gradient in temperature was high or when temperature was among the set of heterogeneous variables. It has been shown for the Northwest Atlantic that the distribution of cod is associated with specific ranges of temperature and salinity, and that changes in these environmental variables effects the catchability of cod and thus the survey estimates of abundance (Smith & Page 1996). Hence, the performance of the IBTS abundance indices for whiting and cod might be improved if more hauls would be allocated to squares in which high gradients in the environmental variables are regularly found. These are, in terms of temperature, salinity and depth, the coastal regions of the German Bight with the gradients in temperatures being most pronounced after severe winters (Knijn et al. 1993).

The unrealistic mortality rates obtained for age 1 whiting and cod using the first quarter IBTS indices indicate that the maximum catchability of the 1-group is not established in that time of the year. This may be caused by a combination of behaviour and gear selection. In particular in the case of cod the mortality rates varied considerably between the years and the large between year variation in catchability severely hamper the use of the 1-group index from the first quarter IBTS and may also have distorted the distribution pattern derived from this survey. This problem vanished for the third quarter IBTS and hence the corresponding indices for the 1-group appeared to be much more reliable estimators of year class strength. This conclusion was also accepted by the Study Group on the Evaluation of the Quarterly IBTS surveys (ICES 1998b).

The coastal areas of the German Bight and at times also the Skagerrak are important nursery areas for whiting and cod (Munk et al. 1995). It therefore appears worthwhile to include these regions in the area on which the IBTS indices are based despite of the effect that occasionally high catches from the coastal region of the German Bight and the eastern Skagerrak could result in more variable indices. The area effect was most pronounced for age 1 cod, but the Study Group on the Evaluation of the Quarterly IBTS survey has recommended that the IBTS Working Group should consider a redefinition of the species-specific standard areas also for other species than cod (ICES 998b).

Importance of covariates and spatial structure

GLM analyses showed that 'temperature' models generally performed less well than 'depth' models explaining the variability of catches of age 1 and 2 whiting and cod between statistical rectangles, i.e. within the species specific standard areas. Salinity was not considered here because the results on the 'within square' variability did not indicate that this variable could be important, and further because salinity is relative uniform in the central North Sea (Knijn et al. 1993). Heessen & Daan (1994) reported differences in the temperature at which the different age groups of cod live in the North Sea but specific preferences were not found, at least not for the juveniles. This is in line with observations from the present study. Marked interannual differences in the ambient temperature at which high catches occurred were only found for age 1 whiting and specific temperature preferences could not be detected at all. However, the range of bottom water temperatures was small in most of the years, and this could have been a reason that the use of depth as a covariate yielded better results. Besides, there is probably an energy-dependent effect of depth related to diurnal vertical feeding migration for the juveniles which might explain decreasing catch rates at depths of more 100 to 150 m for the 1- and the 2-group, respectively.

Skewed density distributions are often encountered in surveys of fish abundance, which makes it difficult to determine an underlying spatial structure in the data (Maravelias et al. 1996). This was also the case in the present study. The analysis was restricted to first quarter IBTS data for age 2 whiting because catches of other species/age groups considered in the project showed a higher level of variability. For age 2 whiting, the spatial structure was largely persistent over the years and no indication was found that the low catches obtained in the German Bight were related to the adverse temperature condition observed there in two out of the six years considered. Future geostatistical analyses of whiting and cod age 1 catches should focus on the third quarter IBTS due to the problems described above.

Outlook

The present project yielded a sound basis for a recently started started EU-CFP study ("The use of multivariate data for improving the quality of survey-based stock estimation in the North Sea", MIQES). Future work, however, may further aim to analyse the IBTS data on haul by haul basis instead of using mean values by statistical rectangle. This, however, would invoke new problems as in that case, for example, vessel effects are likely to become more important. Moreover, a reliable link between the trawl data and the hydrographic information, which does not exist to date, has to be established. Such an approach, as it will be performed under MIQES, would allow to examine the importance of temperature and salinity more explicitly, and would also enable to assess potential effects of other covariates like gear parameters, e.g. towing speed, and, in particular, the daylight period.

Lognormal-based GLM's for whiting and delta-lognormal GLM's for cod yielded first quarter abundance indices for age 1 and 2 that are less variable than the standard IBTS indices, and which showed a significant correlation with assessment results of the 2-group for both species. Such an improvement could not be obtained when either considering the frequency description of the catches or the spatial structure of the data alone. This clearly indicated the potential of including environmental variables as covariates in the estimation procedure.

Acknowledgements

Dr. Harry Dooley and Else Juul Nielsen, ICES Headquarters Copenhagen, are thanked for providing temperature and salinity data from the ICES Hydrographic Database. I further thank Dr. Andrew Newton, SOAEFD Marine Laboratory Aberdeen, for age/length information from the Scottish Groundfish Survey, as well as Dr. Henrik Sparholt and Arne Facius, ICES Headquarters Copenhagen, for extracting age/length and catch data from the ICES IBTS Database. The productive cooperation with Leslie Foldager and René Holst, ConStat Hirtshals, on the application of Generalized Linear Models is gratefully acknowledged. Above all, sincere thanks to the staff of the Danish Institute for Fisheries Research in Hirtshals for their hospitality and support, in particular to Poul Degnbol and to Dr. Astrid Jarre-Teichmann.

The study was funded by an EU TMR grant (FAIR GT-97-3498).

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Table 1: Sampling periods and number of length measurements or age readings available for age length keys.

	Sampling period	Statistical rectangle	Sampling area*	Roundfish area**	Cod (< 60 cm) number	Cod (< 60 cm) total	Whiting (< 40 cm) number	Whiting (< 40 cm) total	Remarks and data source
1)	Sept. '88	37F5			49	2042	3860	7468	ALK's based on length frequency de-
	(31.08.-07.09.)	39F5			1993		3608		composition using Battacharya's method
	Sept. '89	40F2			181		4302		
	(30.8.-09.09.)	40F5			99	576	9107	18046	ALK's based on length frequency de-
		44F0			296		4637		composition using Battacharya's method
	April '92	42F0		2	541		622		
	(03.04.-06.04)			3	150	876	536	1158	ALK's from 2nd quarter IBTS
				4	185		-		(ICES)
	May/April '93	42F0		2	348		466		
	(28.04.-03.05.)	43F0		3	127	768	483	949	ALK's from 2nd quarter IBTS
				4	293		-		(ICES)
2)	1975	41F7	605		47		40		
	(05.02.-27.02.)		606		0		0		
			607		0		0		
			704		141	234	98	202	
			705		0		0		
			706		46		64		
			707		0		0		
		39F3	605		47		40		
			606		0		0		ALK's
			607		0		0		
			704		141		98		from
			705		0	279	0	236	
			706		46		64		1st quarter IBTS
			707		0		0		
			804		45		34		(ICES)
		37F5	603		118		129		
			604		37	296	60	287	
			704		141		98		
		36F3	402-404		0		0		
			502-504		0		0		
			602		49	204	62	251	
			603		118		60		
			604		37		129		
	1976	41F7	606		43		-		
	(05.05.-11.02.)		705		107		-		ALK's
			706		106	286	308	308	
			707		30		-		from
		37F7	603		113		54		
			604		52		336		1st quarter IBTS
			703		97		0		
			704		18	387	59	449	(ICES)
			705		107		-		
			804		0		0		
	1977	41F7	705		141		0		
	(05.02.-20.02.)		706		265	306	409	409	
		36F3	402		0		0		
			403		1		35		
			404		92		0		ALK's
			502		6		52		
			503		5	368	226	527	from
			504		80		214		
			602		75		0		1st quarter IBTS
			603		53		0		
			604		56		0		(ICES)
		40E8	206		66		121		
			304		64		148		
			305		31	236	1050	1979	
			306		75		660		
	1983	38F6		6	280	350	303		ALK's from
	(22.02.-25.02.)	38F7		7	70		-		1st quarter IBTS
		37F5							(ICES
	1988	42F6		2	135		225		ALK's from 1 st quarter
	(29.01.-28.02.)			7	8	143	101	326	IBTS (ICES)

1) fixed stations, 2) within statistical rectagles; *: used until 1980 for sampling of roundfish otoliths, **: used since 1980 (ICES 1992b, 1996b)

Table 2: Correlation (r^2) between VPA and different abundance indices for age 1 and 2 whiting and cod 1991-1996.

Index		Whiting age 1		Whiting age 2		Cod age 1		Cod age 2	
IBTS standard	1st quarter	0.42	(n.s.)	0.04	(n.s.)	0.48	(n.s.)	0.85	($p < 0.01$)
	3rd quarter	0.82	($p < 0.01$)	0.38	(n.s.)	0.64	($p < 0.05$)	0.80	($p < 0.01$)
Log - transf.	1st quarter	0.13	(n.s.)	0.24	(n.s.)	-		-	
	3rd quarter	0.48	(n.s.)	0.23	(n.s.)	-		-	
GLM - Depth	1st quarter	0.08	(n.s.)	0.58	(n.s.)	0.77	($p < 0.05$)	0.71	($p < 0.05$)
Geostat.	1st quarter	-		0.04	(n.s.)	-		-	

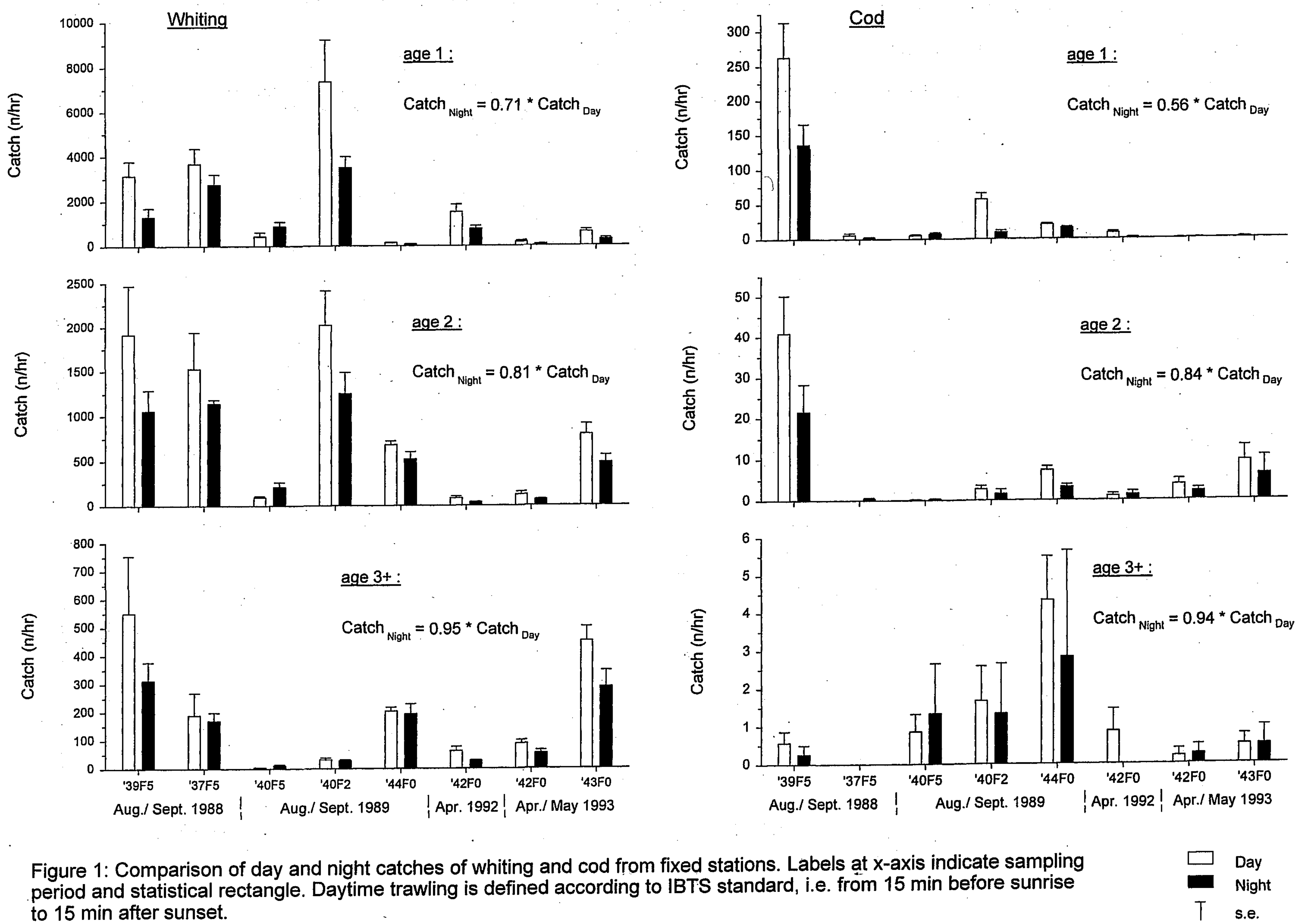

Figure 1: Comparison of day and night catches of whiting and cod from fixed stations. Labels at x-axis indicate sampling period and statistical rectangle. Daytime trawling is defined according to IBTS standard, i.e. from 15 min before sunrise to 15 min after sunset.

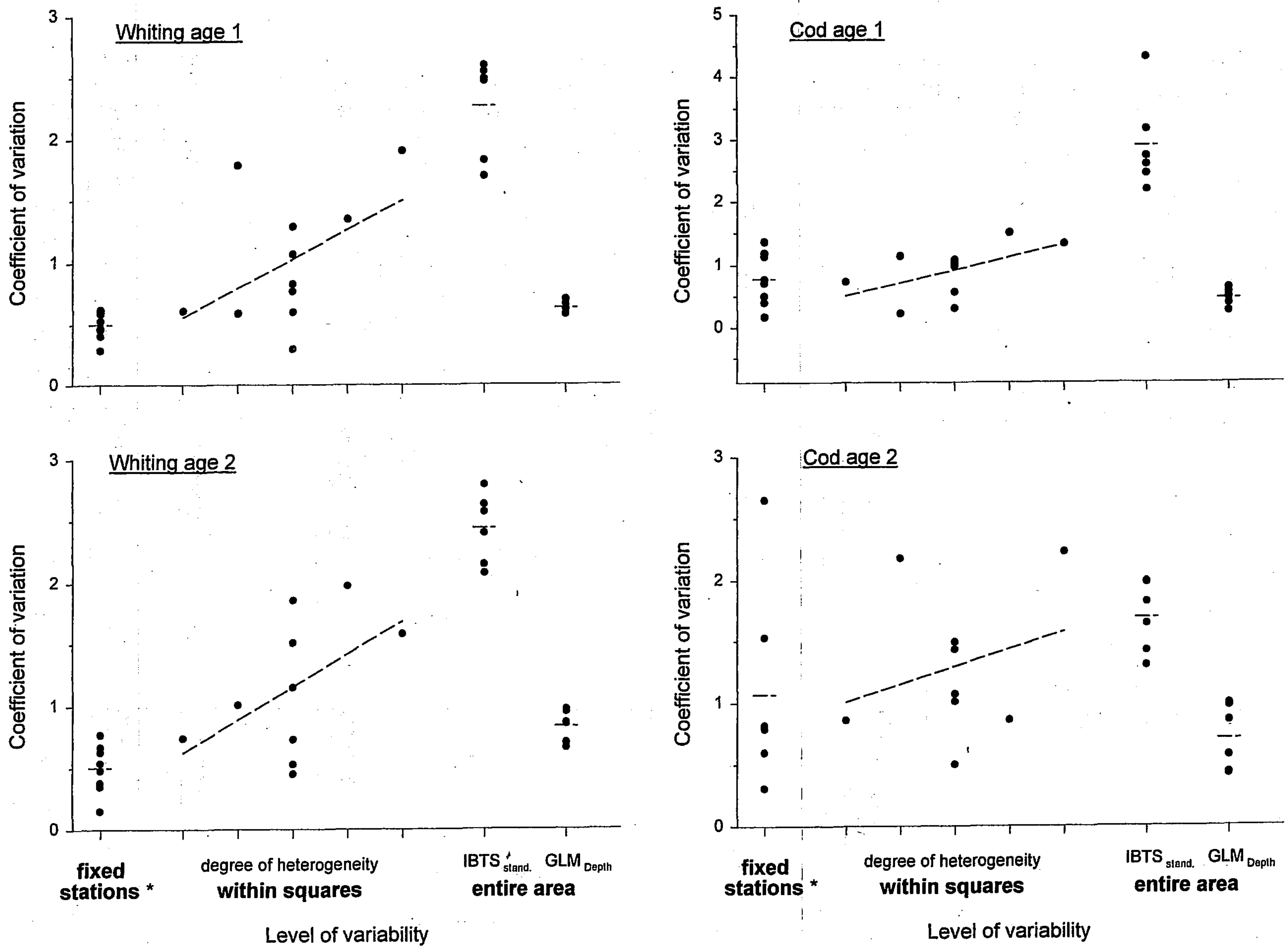

Figure 2: Coefficients of variation versus spatial scale for catches of age 1 and 2 whiting and cod. *: daylight catches only.

Appendices

Appendix 1:

Wieland, K., L. Foldager, R. Holst & A. Jarre-Teichmann (1998): Spatial distribution and variability of abundance estimates of juvenile (age 1 and 2) whiting and cod in the North Sea. ICES CM 1998 / J:7. 31 p.

Appendix 2:

Wieland, K. (1998): Comparison of first and third quarter IBTS abundance indices for age 1 and 2 whiting and cod. Working paper 1. ICES Study Group on the Evaluation of the Quarterly IBTS Surveys. 12 p.

Appendix 3:

Wieland, K. (1998): Spatial structures in the distribution of age 2 whiting in the North Sea – a geostatistical analysis of the 1st quarter IBTS data 1991-1996. Internal report. 18 p.

Appendix 1 Theme Session J: Variation in the pattern of fish aggregation: Measurement and analysis at different spatial and temporal scales and implications

ICES CM 1998 / J:7

Spatial distribution and variability of abundance estimates of juvenile (age 1 and 2) whiting and cod in the North Sea

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Abstract

Abundance indices of young fish in the North Sea derived from the International Bottom Trawl Survey (IBTS) show large interannual fluctuations, which are not in accordance with ICES assessments in every case. The standard estimation of the abundance indices, however, does not explicitly account for potential influences of environmental variables on the spatial aggregation of juvenile fish and the probability distribution of the catches. The present study aims at improving the analysis and the estimation procedures for IBTS abundance indices. Variability of bottom trawl catches of age 1 and 2 whiting and cod was studied on three spatial scales: at fixed stations, within statistical rectangles and within the species-specific standard areas used in the IBTS. Daylight period, temperature, salinity, water depth and bottom type were considered as potential environmental variables influencing the catches. At fixed stations significant differences between day and night catches were found. Variability within rectangles increased with the degree of heterogeneity in the environment, where the effects of temperature and depth were most pronounced. Frequency distributions of the average catch by rectangle always deviate substantially from normal distributions. Lognormal-based Generalized Linear Models for whiting and Delta-lognormal models for cod revealed that temperature and, in particular, depth contribute significantly to the variability also between rectangles. It is further demonstrated that depth can be used as a covariate in the estimation of abundance indices for the species-specific standard areas.

Introduction

The International Bottom Trawl Survey (IBTS) in the North Sea conducted in February each year started in the beginning of the 1960's and aimed in the start exclusively at juvenile herring. Over the years the objectives of this survey were broadened to provide recruitment indices also for cod *Gadus morhua*, haddock *Melanogrammus aeglefinus* and whiting *Merlangius merlangus*, and the survey area was extended in the 1980's to include the northern North Sea and the Skagerrak/Kattegat (Heessen et al. 1997). At the same time the GOV (Grand Ouverture Verticale) trawl was introduced as standard gear and in the early 1990's a large amount of effort was put into standardizing the sampling design (ICES 1992, 1996a). The survey is stratified based on a grid of statistical rectangles ("squares") of 1 ° longitude and 0.5 ° latitude (≈ 30 * 30 nm; Fig. 1). Ships of two different countries usually fish each square so that at least two hauls are made per square, and the tows conducted from one vessel in adjacent squares are normally separated by at least 10 nm. The survey provides abundance indices that are calculated by taking the average catch per hour trawling of all hauls within a square, and then the average of all squares within species-specific standard areas. Although it is recommended that trawling should be limited to daylight hours, some hauls are made during twilight or night due to a short daylight period, and night catches are only excluded from the index calculation for herring (Heessen et al. 1997).

The first quarter IBTS abundance indices show large interannual fluctuations, which do not coincide with VPA estimates in every case. For gadoids where multiple survey information is available, the first quarter IBTS performs less well for cod than other surveys (ICES 1996b, Wieland 1998), and there is an inconsistency between the surveys and the assessment for whiting in general (Cook 1997, ICES 1998). However, the present procedure of calculating the abundance indices does not consider the error structure of the catches. The use of a rigorous statistical approach can potentially improve the performance of the survey indices (e.g. Pennington 1983, Stefánsson 1996).

There are numerous technical aspects of trawling which affect survey catches, and similarly the behaviour and the distribution of the fish in relation to environmental conditions influence catch efficiency. For example, diurnal variations in bottom trawl catches have been observed for different fish species including gadoids (Ehrich & Gröger 1989, Engås & Soldal 1992, Michalsen et al. 1996), and interannual differences in catchability due to changes in the distribution related to water temperature and salinity were found for cod (Smith & Page 1996).

In the present study, the variability of bottom trawl catches for age 1 and 2 whiting and cod is analyzed on three spatial scales with different aspects. These are: 1) the effect of the daylight period on catches from fixed stations, 2) influences of environmental variables on catches obtained within a statistical square, and 3) the application of statistical methods which account for the frequency distribution of the catches, and which also consider environmental variables as covariates in the calculation of abundance indices for the IBTS species-specific standard areas.

Material and Methods

Variability at fixed stations

Basic data for the analysis of variability of bottom trawl catches at fixed locations were available from investigations carried out by the Danish Institute for Fisheries Research. The surveys were originally designed to sample whiting stomachs (Degnbol 1992, Pedersen 1996, Pedersen submitted). The sampling was conducted in autumn 1988 and 1989 and in spring 1992 and 1993 with R/V Dana. Hauls were made in about 4 hour time intervals over a 72-hour period each at a single station. In 1988 and 1989 the tracks of the hauls were laid out in a star pattern crossing through the same center, and are thus only exact replicates concerning their central position. In 1992 and 1993 parallel tracks close to each other in a box of 5 * 7 nm were used. In some cases fishing was conducted at some distance from the bottom during night, but these tows were discarded from our analysis. In total 93 hauls were selected for analysis which were all carried out with an EXPO trawl. Sampling periods and statistical rectangles (Fig. 1) in which the sampling was performed are given in Table 1. Towing time was 60 min in most cases, towing speed amounted to 3.4 kn on average, and vertical net opening ranged between 5 and 10 m.

Catches and length frequencies of whiting and cod, as well as corresponding haul information, were extracted from the institute's database, but age data were not available from that source. In order to obtain catches of age 1 and 2 fish, the length frequency distributions from the sampling dates in autumn 1988 and 1989 were decomposed into age groups applying Bhattacharya's method (Bhattacharya 1967). The calculations were made with the FiSAT Software (FAO 1996). The length frequencies and their age decomposition are given in Figure 2 for whiting and in Figure 4 for cod. The resulting age length keys compare fairly well with those from the Scottish Groundfish Survey for the 3rd quarter 1989 (Figs. 3 and 5), in particular for whiting. Such a comparison was not possible for 1988, as the area coverage of the Scottish Groundfish Survey did not match the sampling locations used here. For the age decomposition of the catches from spring 1992 and 1993, which originated from sampling sites in the westernmost part of roundfish area 2, age length keys from the 2nd quarter IBTS were used. Here, age data from roundfish areas 2 and 3 (Fig. 1) were combined for whiting and from areas 2 to 4 for cod to include a sufficient number of age readings.

Daylight period and towing speed were studied as potential covariates affecting the catch rates using a Generalized Linear Model (GLM, McCullagh & Nelder 1989) approach. Bottom depth was also included in the analysis despite of its narrow range for the different hauls made at the single locations (Tab. 1). The influence of other factors like towing direction in relation to wind direction and wind speed could not be studied, as too many observations of the meteorological conditions were missing. We assume that the systematic component is multiplicative and that the errors are lognormal distributed. Log-log plots of variance versus average catch, for which the slope of the regression line should be close to 2 if a lognormal (or Gamma) model is appropriate (Hoffmann-Jørgensen 1994), were used to assess the error structure. The data were too sparse to analyze the effect of more than one covariate at the same time, and hence GLM's of the following form were analyzed subsequently for whiting:

$$\text{Log}_e \text{CPUE} = A + DL + D + A * DL + A * D + D * DL + A * DL * D + \varepsilon \qquad (1)$$

$$\text{Log}_e \text{CPUE} = A + DL + T + A * DL + A * T + T * DL + A * DL * T + \varepsilon \qquad (2)$$

where

CPUE = Catch per unit effort (in numbers per hour trawling)
A = Age (1 or 2)
DL = Daylight period (day or night)
D = Depth (continuous)
T = Towing speed (continuous)
ε = Error term,

and where * denotes interaction.

In the case of cod, catches for age 1 and 2 were summed up, and 1 was added to the combined CPUE due to the occurrence of zero catches in a few cases. The full models applied for the two combined age groups of cod were:

$$\text{Log}_e (\text{CPUE} + 1) = DL + D + D * DL + \varepsilon \qquad (1\,*)$$

$$\text{Log}_e (\text{CPUE} + 1) = DL + T + T * DL + \varepsilon \qquad (2\,*)$$

The covariates were nested according to sampling date and location, i.e. within year and square (Tab. 1), in all cases.

Removing insignificant terms sequentially reduced the full models. The following F-statistic was used to test the significance of the reduction under consideration (Chambers & Hastie 1993):

$$F = (\text{Deviance}_{new} - \text{Deviance}_{old}) \;/\; ((\text{Df}_{new} - \text{Df}_{old}) * \varphi_{old})$$

Here, Df denotes the degrees of freedom and φ is the dispersion parameter in the GLM. Since we used the Gaussian family, the dispersion parameter is equal to the variance term in the normal distribution, i.e. $\varphi = \sigma^2$. The assumption that the residuals originate from a normal distribution was checked by normplots, in which slope and intercept are equal to the standard deviation and the average of the residuals, respectively, as well as by scatterplots of the residuals versus fitted values (McCullagh & Nelder 1989). The statistical analyses were carried out with S-PLUS 4.0 (Mathsoft 1997).

Within square variability

Information on the variability of catches for whiting and cod from different stations located within a statistical rectangle was derived from the Danish part of the 1st quarter IBTS. Here, only squares were considered, in which at least 4 different stations were covered during the same survey. A total of 11 series of samples with 4 to 6 individual hauls for each specific year/square combination were available, together with mean depth of the trawl track and observations on the bottom type (Tab. 2). Catches were standardized to 60 min trawling time. Area specific age length keys were constructed according to the different sampling sites based on age data from the 1st quarter IBTS (international data set) and used to disaggregate the length distributions into numbers at age by haul. Temperature and salinity data were obtained from the ICES Hydrographic Database. For studying the influence of the degree of heterogeneity within a given square on the variability of the catch temperature, salinity and depth were defined as homogeneous when they did not differ by more than 0.5 °C, 0.5 psu and 5 m, respectively. Lognormal-based GLM's were used to study the effects of the environmental factors in detail. Here, the covariates were nested into series of samples, i.e. year and square (Tab. 2), and only one covariate could be analyzed at the time due to the low number of observations in each cell:

$$\text{Log}_e(\text{CPUE} + 1) = A + T + A*T + \varepsilon \tag{3}$$

$$\text{Log}_e(\text{CPUE} + 1) = A + S + A*S + \varepsilon \tag{4}$$

$$\text{Log}_e(\text{CPUE} + 1) = A + D + A*D + \varepsilon \tag{5}$$

$$\text{Log}_e(\text{CPUE} + 1) = A + B + \varepsilon \tag{6}$$

where

CPUE = Catch per unit effort (in numbers per hour trawling)
A = Age (1 or 2)
T = Temperature (continuous)
S = Salinity (continuous)
D = Depth (continuous)
B = Bottom type (mud, fine sand, sand and coarse sand; no interaction term included due to insufficient number of observations)
ε = Error term.

Variability within species-specific standard areas

Catches of whiting and cod in numbers per hour trawling (CPUE) by age group and trawling depths were received from the ICES IBTS Database for the first quarter in 1991 to 1996. Following the IBTS Working Group's procedure, arithmetic means from all hauls within a statistical rectangle were calculated for catches of age 1 and 2 whiting and cod. Average trawling depth was obtained in the same way. Average bottom temperature by square was calculated from data recorded during the first quarter IBTS and stored in the ICES Hydrographic Database.

Abundance indices for age 1 and 2 whiting and cod were computed both by the standard technique and by methods that accounted for the error structure of the data. The standard abundance indices were calculated as the arithmetic mean for all rectangles within the species-specific standard areas (Fig. 6), which consist of 144 squares for whiting and 139 squares for cod (ICES 1996). The new abundance indices were calculated using methods which consider the probability distribution of the catches and which include either depth or temperature as covariates. The usefulness of the different indices was evaluated by comparing them with results from recent assessment (ICES 1998).

Frequency distributions of the catches of age 1 and 2 whiting and cod are given in Figure 7. They deviate considerably from normal distributions in all cases, and high numbers of zero catches were recorded for cod age 1 and 2 (Tab. 3) in almost all of the years. A log-transformation of the catches (with 1 added to the average CPUE by square) yielded frequency distributions which could be approximated by normal distributions for whiting age 1 and 2, but not for cod. For cod, the zero catches became clearly isolated from the positive catches when a low constant (0.01) was added. This was much less pronounced for whiting (Fig. 7), and allowed to compute mean abundance (Mean) and variance (Var) from the arithmetic mean (μ) and the standard deviation (σ) of log-transformed catches by square (CPUE + 1) according to Hoffmann-Jørgensen (1994):

$$\text{Mean} = \exp(\mu + 0.5 * \sigma^2) - 1 ,$$

$$\text{Var} = (\exp(\sigma^2) - 1) * \text{Mean}^2 ,$$

and where the coefficient of variation (CV) is given by:

$$\text{CV} = (\exp(\sigma^2) - 1)^{1/2} .$$

Lognormal-based GLM's were used to study potential effects of temperature (T) and depth (D) in addition to year (Y; 1991 to 1996) on catches of age 1 and 2 whiting separately:

$$\text{Log}_e(\text{CPUE} + 1) = Y + T + Y * T + T^2 + \varepsilon \qquad (7)$$

$$\text{Log}_e(\text{CPUE} + 1) = Y + D + Y * D + D^2 + \varepsilon \qquad (8)$$

For age 1 and 2 cod, Delta-lognormal approaches were applied as only the frequency distributions of the log-transformed positive values could be approximated by normal distributions (Fig. 7). The full models used for the positive values were:

$$\text{Log}_e \text{CPUE} = Y + T + Y * T + T^2 + \varepsilon \qquad (7*)$$

$$\text{Log}_e \text{CPUE} = Y + D + Y * D + D^2 + \varepsilon \qquad (8*)$$

And, similar to the approach outlined by Stefánsson (1996), the presence - absence of age 1 and 2 cod was modelled as Bernoulli random variables with probabilities (p) using the logit function as the link function:

$$\text{Logit}(p) = \text{Log}_e(p / (1 - p)),$$

where either temperature (model 9) or depth (model 10) were used as covariates in addition to the year factor in the GLM analysis. For the Bernoulli models, χ^2-tests were used to check the significance of the change in deviance when removing single model terms.

To select the best models for the calculation of abundance indices, i.e. using either temperature or depth as a covariate, a modified version of Akaike's Information Criterion (AIC) was used as defined by Chambers & Hastie (1993):

$$AIC = D + 2 * df * \varphi,$$

where D is the residual deviance, df the degrees of freedom in the fit, and φ an estimate of the dispersion parameter ($\varphi = \sigma^2$ for lognormal-based GLM's and $\varphi = 1$ for binomial GLM's). The AIC can be used to compare competing models that are not constraints or reduced versions of each other (Jones 1993) selecting the model with the lowest AIC value as the best one.

New annual abundance indices for the species-specific standard areas were then calculated taking the arithmetic mean of the GLM estimates for each square. For whiting age 1 and 2, these estimates were obtained from the lognormal-based GLM´s by back-transformation according to Hoffmann-Jørgensen (1994) as:

$$CPUE_{est.} = \exp(\log_e(CPUE + 1)_{fitted} + 0.5 * \sigma^2_{GLM}) - 1,$$

where σ^2_{GLM} is the common variance of the lognormal-based GLM's, which depends on the model under consideration. For cod age 1 and 2, the predicted values were obtained from the probabilities for presence/absence (p) given by the binomial GLM's and the fitted Log_e CPUE from the lognormal-based GLM's for the positive values after back-transformation as:

$$CPUE_{est.} = p * \exp(\log_e(CPUE)_{fitted} + 0.5 * \sigma^2_{GLM}).$$

Results

Variability at fixed stations

Tables 4a and 4b present mean values of day and night catches together with corresponding coefficients of variation by sampling period, species and age group. Daylight catches were substantially higher than night catches for whiting age 1 and 2 and for cod age 1 except for one sampling date (1989 square 40F5). Daylight catches of cod age 2 were slightly lower than night catches also for two other sampling dates (1988 square 37F5 and 1992 square 42F0). Including all observations, the night catches amounted to about 60 % (cod age 1), 70 % (whiting age 1) and 80 % (whiting and cod age 2) of the daylight catches on average. The coefficients of variation for day and night catches were quite similar within a single species and age group. However, the coefficients of variation for cod exceeded those for whiting considerably, which was probably due to the low abundance of cod age 1 and 2.

For further analysis, cod age 1 and 2 were combined, and results from 1988 (square 37F5), 1992 (square 42F0) and 1993 (square 43F0) were discarded due to the low numbers caught. As still a few zero catches were left (4 out of 57 hauls), 1 was added to the CPUE of cod for the remaining sampling dates to include them as a part of the whole model.

Log-log plots of variance versus average catch by sampling period are given in Figure 8 for whiting and cod. The slopes of the regression lines were close to 2 indicating that lognormal-based models were appropriate for both species.

The results of the analysis of deviance for different lognormal-based GLM's are given in Table 5a for whiting. All interactions with age were insignificant, which means that the abundance of both age groups responded in a similar manner to the covariates considered here. In model 1 the interaction between daylight period and depth was at the edge of significance at the level of 5 %. If this term was removed, depth was not significant whereas daylight period was. In model 2 the interaction between daylight period and towing speed was also at the edge of significance, and if this term was removed, towing speed became insignificant whereas daylight period was again significant. Corresponding Normplots and scatterplots of the residuals versus the fitted values (Fig. 9) indicate that the GLM reduced to the effect of the daylight period described the data appropriately, and it was concluded that the daylight period was the only important covariate.

Table 5b gives the corresponding results for cod. All interactions and depth (model 1*) were insignificant whereas daylight period (both models) and towing speed (model 2*) were significant covariates. The Normplots and scatterplots for the daylight term, however, do not support that the residuals originated from a normal distribution (Fig. 9), and hence the results for cod were much less conclusive than those for whiting. It has further to be noted that there might be some interaction between depth and towing speed, which could not be studied here.

Within square variability

Figure 10 shows the coefficients of variation for whiting and cod catches in relation to the number heterogeneous variables in a given statistical rectangle. Significant regressions ($p < 0.05$) were obtained for age 1 whiting and cod omitting one observation which was characterized by an exceptional high temperature gradient (1977 square 41F7, Tab. 2). Age 2 whiting and cod were missing in one (1977 square 41F7) and two (1975 36F3 and 1977 36F3) series of samples, respectively. However, for both species the results for age 2 also indicate a trend towards higher variability at a higher degree of heterogeneity in the environment, but the regressions were not significant. High levels of variability were always found when temperature was heterogeneous (Fig. 11). Heterogeneous depth appeared to have an effect as well when accompanied with differences in the bottom type, or with heterogeneous salinity and bottom type at the same time (Fig. 11).

There were a few individual hauls with zero catches for single ages and species (14 out of 180 values) and hence 1 was added to the individual CPUE's prior to GLM analysis. Log-log plots of variance versus average (CPUE + 1) yielded slopes of 1.85 and 2.04 for whiting and cod, respectively, indicating that lognormal models were appropriate for both (Fig. 12).

The results of the analysis of deviance for different lognormal-based GLM's on the potential influences of environmental variables on the variability of catches of age 1 and 2 whiting and cod within statistical rectangles are given in Table 6. For whiting, the interaction between age and temperature was at the edge of significance at the level of 5 %, and if this term was removed the main effect of temperature was significant. The interactions between age and salinity as well as between age and depth were not significant in contrast to the main effects of salinity and depth. For cod, the interactions between age and temperature and between age and salinity were not significant. The interaction between age and depth as well as the main effect of temperature, but not salinity, was significant. For both species, the bottom type had no influence on the variability of the catches. Normplots having intercepts close to zero as well as scatterplots of the residuals versus fitted values with the residuals scattered equally around the zero line did not give any indication of non-normality (Fig. 13). Therefore, the reduced GLM's for whiting on the effects of temperature, salinity and depth, and the GLM's for cod concerning temperature and depth, were accepted.

Variability within species-specific standard areas

Figure 14 shows log-log plots of variance versus average CPUE by square for age 1 and 2 whiting and cod for the period 1991 to 1996. Here, only those squares were included which were covered in each of the 6 years for whiting, and which yielded non-zero catches for cod in all cases. The slopes of the regression lines were always close to 2 indicating that lognormal-based models were appropriate for the entire data sets for age 1 and 2 whiting as well as for the positive values for age 1 and 2 cod.

Scatterplots of log-transformed catches versus depth and temperature by year and age are given in Figure 15 for whiting and in Figure 16 for cod. These plots indicate that second order polynomials fit better than straight lines in most of the cases. Highest catches of age 1 whiting were recorded at depths of about 80 m in all of the years, except in 1991 where they were most abundant in shallower waters (20 – 60 m). In contrast, the highest catches for age 2 whiting always originated from deeper waters (> 100 m). Similar to whiting, age 1 cod tended to occur shallower than age 2 cod, but the catches, especially those of cod age 1, were less consistently distributed with depth than in the case of whiting. The influence of temperature on the catches appeared to be highly variable between the years except for age 1 whiting which were most abundant at temperatures between 3 and 5 °C in cold years (1991 and 1996) and between 5 and 7 °C in warm years (1992 – 1995).

The results of the analysis of deviance for different GLM's on the effects of temperature and depth on the catches of age 1 and 2 whiting and cod are presented in Tables 7 and 8, respectively. For both age groups of whiting none of the models terms could be removed, and the values of Akaike's Information Criterion (AIC) for the full models were lower when depth was used as a covariate in addition to year than in the case of temperature (Tab. 7). For the positive catches of age 1 and 2 cod, temperature squared was not significant (Tab. 8a). In the 'depth' models only year and depth contribute significantly to the variability of positive catches for cod age 1 whereas all of the model terms were significant for cod age 2 (Tab. 8a). Concerning the presence - absence of cod age 1 and 2 no terms could be removed from the full GLM's except for depth squared in the model for cod age 2 (Tab. 8b). The AIC value of the 'depth' model for the positive catches of cod age 1 was slightly higher than the corresponding one for the 'temperature' model. However, we selected the 'depth' model instead because the difference in AIC values was quite small and the 'depth' model could be reduced to a simpler one than the 'temperature' model.

Normplots and scatterplots of the residuals versus fitted values for the final lognormal-based GLM's using depth as a covariate in the estimation of catches of whiting (CPUE + 1) and cod (CPUE > 0) did not reject the assumption of normally distributed residuals (Fig. 17). A similiar approach could not be applied for checking the Bernoulli GLM's on the presence – absence of age 1 and 2 cod. Residuals from Bernoulli models are not easy to examine (Venables & Ripley 1997) as they have a non-normal distribution, and in particular residuals close to zero do usually not occur (Cox & Snell 1989). The residuals observed here were small ranging between –2.13 and 2.36 for age 1 cod and between –2.81 and 1.46 for age 2 cod with no values around zero in either case.

The different annual abundance indices for age 1 and 2 whiting and cod, i.e. the IBTS standard indices and the new indices estimated directly from log-transformed catches (for whiting only) or obtained from the GLM's using depth as a covariate, are listed in Tables 9a and 9b. Corresponding coefficients of variation are given there as well. Differences in magnitude between the various indices were most pronounced for age 2 whiting while differences in their trends occurred in all cases except for age 2 cod. The coefficients of variations that correspond to the indices for age 1 and 2 whiting which were estimated based on lognormal distributed catches (Fig. 7) became noticeably large (Tab. 9a). In contrast, the coefficients of variation corresponding to the GLM estimates were considerably smaller than those calculated from the original data.

A comparison of the various abundance indices with most recent assessment of stock size at age is presented in Table 10. In this context, it must be noted that the 1st quarter IBTS standard indices were used among data from other surveys in the assessment for VPA tuning and recruitment estimation (ICES 1998). In the case of whiting, highest correlation with the assessment was found for the IBTS standard index at age 1 and the GLM index for age 2, but neither of them was significant. For cod, the standard index was significantly correlated with the assessment only at age 2 while the GLM indices yielded significant results for both age groups.

Discussion

Variability at fixed stations

Daylight catches of age 1 and 2 whiting and cod were on average substantially higher than night catches. This is well in accordance with findings for cod and haddock in the Barents Sea (Engås & Soldal 1992) and the North Sea (Ehrich & Gröger 1989). In contrast, Ehrich & Gröger (1989) found no significant difference between day and night catches for whiting in the North Sea. The latter observation, however, was not based on age disaggregated data, and diurnal migration of whiting might be more pronounced for the early age groups than for the older ones, as observed for other gadoids, i.e. cod and haddock (Engås & Soldal 1992).

About 20 % of the catches used for the calculation of abundance indices for whiting and cod from the first quarter IBTS originate from night hauls according to the coding in the IBTS database (Tab. 11). This coding, however, very strictly attributes hauls started at or close to twilight to night hauls (ICES 1996a) and only a minority of these hauls was really conducted during darkness. Nonetheless, it appears advisable to follow the recommendation of the IBTS Working Group for day time trawling (ICES 1996a) more closely in spite of the problem of achieving full area coverage during the first quarter IBTS with the short daylight period during that time of the year.

Within square variability

The variability of catches within statistical rectangles appeared to increase with increasing heterogeneity in the environment, in particular for the 1-group of both whiting and cod. The GLM analyses gave no clear identification of the most important variable, but the analyses were hampered by a low number of observations in the individual squares. However, high coefficients of variations were always observed when either solely the gradient in temperature was high or when temperature was among the set of heterogeneous variables. It has been shown for the Northwest Atlantic that the distribution of cod is associated with specific ranges of temperature and salinity, and that changes in these environmental variables effects the catchability of cod and thus the survey estimates of abundance (Smith & Page 1996). Hence, the performance of the IBTS abundance indices for whiting and cod might be improved if more hauls would be allocated to squares in which high gradients in the environmental variables are regularly found. These are, in terms of temperature, salinity and depth, the coastal regions of the German Bight with the gradients in temperatures being most pronounced after severe winters (Knijn et al. 1993).

Variability within species-specific standard areas

The frequency distributions of the catches of age 1 and 2 whiting and cod the 1st quarter IBTS 1991 to 1996 were highly skewed. Abundance indices derived from log-transformed catches for whiting, i.e. applying a more realistic probability distribution, yielded a better correlation with the VPA estimates compared to the standard indices, but only for age 2. The poor agreement between the assessment and the indices for age 1 whiting (and cod) could be related to the fact that its maximum catchability is not yet established in the first quarter of the year (ICES 1996, Wieland 1998). The coefficients of variation of the log-transformed data were much higher than those for the standard indices, suggesting that the standard method gives too optimistic an impression of precision. This must not be confused with the accuracy of the resulting abundance indices, which is, of course, difficult to assess. The time series that could be used here were quite short, and the VPA values used as an independent measure for comparison could stem from its non-converged part. However, as the log-transformation described the distribution of the data in a more realistic fashion, we would assume that this result is closer to the truth.

Results of the GLM analyses revealed that temperature and depth significantly affected the variability of catches of age 1 and 2 whiting and cod between squares. Salinity was not considered here because the results on the within square variability did not indicate that this variable could be important, and further because salinity is relative uniform in the central North Sea (Knijn et al. 1993). Heessen & Daan (1994) reported differences in the temperature at which the different age groups of cod live in the North Sea but specific preferences were not found, at least not for the juveniles. This is in line with our observations. Marked interannual differences in the ambient temperature at which high catches occurred were only found for age 1 whiting, and specific temperature preferences could not be detected at all. However, the range of bottom water temperatures was small in most of the years, and this could have been a reason that the 'temperature' models generally performed less well than the 'depth' models as indicated by the values of Akaike's Information Criterion.

The potential of including environmental variables in the analysis of trawl surveys for improving the performance of abundance indices has been demonstrated previously, e.g. for Northwest Atlantic cod by Smith & Page (1996) and for Icelandic cod by Stefánsson (1996). In the present study, lognormal-based GLM's for whiting and Delta-lognormal GLM's for cod yielded abundance estimates for age 1 and 2 that are less variable than the standard IBTS indices. The results of the comparison with VPA estimates should be considered with caution due to the problems mentioned above.

Despite of these difficulties, the approach outlined here appears worthwhile to be applied to an extended data set. Future work may further aim to analyse the IBTS data on haul by haul basis instead of using mean values by square. This, however, would invoke new problems as in that case, for example, vessel effects are likely to become more important. Moreover, a reliable link between the trawl data and the hydrographic information, which does not exist to date, has to be established. Such an approach, as will be performed under a recently started EU-CFP study ("The use of multivariate data for improving the quality of survey-based stock estimation in the North Sea", MIQES), would allow to examine the importance of temperature and salinity more explicitly, and would also enable to assess potential effects of other covariates like gear parameters, e.g. towing speed, and, in particular, the daylight period.

Acknowledgements

We wish to express our sincere thanks to Dr. Harry Dooley and Else Juul Nielsen, ICES Headquarters Copenhagen, who provided us with the temperature and salinity data from the ICES Hydrographic Database. We further thank Dr. Andrew Newton, SOAEFD Marine Laboratory Aberdeen, for age/length information from the Scottish Groundfish Survey, as well as Dr. Henrik Sparholt and Arne Facius, ICES Headquarters Copenhagen, for extracting age/length and catch data from the ICES IBTS Database. This study was partially funded by an EU-TMR scholarship granted to the senior author.

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Table 1: Sampling periods and areas, and numbers of hauls used for the analysis of variation at fixed stations, together with bottom depths and towing speeds.

Period	Square	Number of hauls Day	Night *	Bottom depth (m)	Towing speed (kn)
31.08.-03.09.88	39F5	7	4	41 - 47	3.5
04.09.- 07.09.88	37F5	6	5	42 - 45	2.8 - 3.5
30.08.-02.09.89	40F5	7	6	47 - 56	3.0 - 3.5
03.09.-05.09.89	40F2	6	6	72 - 74	3.0 - 3.6
07.09.-09.09.89	44F0	6	6	136 - 138	2.9 - 3.5
03.04.-07.04.92	42F0	7	6	84 - 96	3.2 - 4.3
28.04.-30.04.93	42F0	5	4	89 - 94	3.2 - 3.6
01.05.-03.05.93	43F0	6	6	85 - 91	3.1 - 3.9

*: including twilight, i.e. 1 hr around sunrise and sunset

Table 2: Sampling areas, number of hauls and environmental variables used for the analysis of variation within squares. Based on Danish data from the 1 st quarter IBTS and ICES Hydrographic database.

Year	Square	Number of hauls	Temperature (°C)	Salinity (psu)	Depth (m)	Bottom type
1975	36F3	4	6.08-6.39	34.69-34.70	38-46	coarse sand
	37F5	4	6.07-6.17	34.47-34.55	42-45	coarse sand
	39F7	4	5.94-6.40	33.49-34.57	25-32	sand
	41F7	4	6.02-6.26	34.36-34.55	28-35	sand
1976	37F7	4	4.07-4.31	32.93-33.36	25-43	fine sand, sand, coarse sand
	41F7	4	3.60-4.36	34.04-34.35	28-35	sand
1977	36F3	6	4.82-5.86	34.65-34.69	38-46	sand
	40E8	4	6.20-6.28	34.95-34.99	68-85	mud, sand
	41F7	6	2.08-4.92	34.58-34.88	30-35	sand
1983	38F7	5	2.71-3.70	31.40-33.28	20-28	fine sand, coarse sand
1988	42F6	4	5.99-6.39	34.45-34.64	36-46	sand, coarse sand

Table 3: Number of observations (mean catch per hour trawling by square) and frequency of zero values in the 1 st quarter IBTS 1991-1996 for whiting and cod at age 1 and 2.

Year	Whiting number of observations	number of zero values age 1	age 2	Cod number of observations	number of zero values age 1	age 2
1991	143	5	1	139	60	23
1992	141	0	2	137	26	18
1993	143	2	3	139	47	21
1994	139	1	9	135	39	36
1995	140	2	5	136	45	32
1996	140	5	9	137	69	24
total	846	15	29	823	286	154

Table 4a: Average catch (number of fish per hour trawling, CPUE) and coefficient of variation (CV) by daylight period for whiting age 1 and 2 at fixed stations.

		Whiting age 1				Whiting age 2			
		Day		Night		Day		Night	
Period	Square	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV
31.08.-03.09.88	39F5	3136	0.53	1297	0.59	1916	0.77	1053	0.45
04.09.- 07.09.88	37F5	3668	0.46	2742	0.37	1525	0.67	1139	0.08
30.08.-02.09.89	40F5	422	0.41	869	0.59	94	0.38	210	0.61
03.09.-05.09.89	40F2	7342	0.62	3477	0.36	2020	0.48	1250	0.46
07.09.-09.09.89	44F0	141	0.29	82	0.27	677	0.15	516	0.40
03.04.-07.04.92	42F0	1504	0.60	747	0.44	81	0.63	35	0.35
28.04.-30.04.93	42F0	195	0.59	64	0.28	137	0.54	55	0.29
01.05.-03.05.93	43F0	671	0.47	307	0.44	885	0.35	483	0.29
		average:	0.50		0.42		0.50		0.37

Table 4b: Average catch (number of fish per hour trawling, CPUE) and coefficient of variation (CV) by daylight period for cod age 1 and 2 at fixed stations.

		Cod age 1				Cod age 2			
		Day		Night		Day		Night	
Period	Square	CPUE	CV	CPUE	CV	CPUE	CV	CPUE	CV
31.08.-03.09.88	39F5	262.6	0.50	136.0	0.44	40.9	0.60	21.5	0.64
04.09.- 07.09.88	37F5	5.5	1.19	1.8	1.14	0.0		0.4	1.37
30.08.-02.09.89	40F5	4.9	0.72	6.6	0.65	0.1	2.65	0.2	2.45
03.09.-05.09.89	40F2	56.7	0.40	9.0	0.73	2.7	0.81	1.5	1.87
07.09.-09.09.89	44F0	20.7	0.17	15.3	0.23	7.3	0.31	3.2	0.54
03.04.-07.04.92	42F0	8.1	0.71	1.2	1.57	1.0	1.53	1.3	1.62
28.04.-30.04.93	42F0	0.4	1.37	0.3	2.00	3.8	0.82	2.5	0.69
01.05.-03.05.93	43F0	1.2	1.14	0.0		12.7	0.79	4.2	1.84
		average:	0.78		0.97	average:	1.07		1.38

Table 5a: Analysis of deviance table for different log-normal based generalized linear models on the effect of daylight period, depth and towing speed on the catches of whiting age 1 and 2 at fixed locations.

Full models and model terms to be reduced from the preceding model	Residual degrees of freedom	Residual deviance	F-value	p
Full model (1)	122	33.7289		
Age * Daylight period * Depth	130	34.4304	0.3172	0.9583
Age * Daylight period	138	34.9249	0.2334	0.9840
Age * Depth	146	35.3309	0.2006	0.9903
Daylight period * Depth	154	39.1548	1.9752	0.0534
Depth	162	40.4205	0.6223	0.7582
Daylight period	170	59.0997	9.3580	0.0000
Full model (2)	128	34.5036		
Age * Daylight period * Towing speed	134	34.6976	0.1200	0.9938
Age * Daylight period	142	35.1776	0.2317	0.9844
Age * Towing speed	149	35.5720	0.2274	0.9782
Daylight period * Towing speed	155	38.6851	2.1733	0.0487
Towing speed	162	40.4205	0.9933	0.4382
Daylight period	170	59.0997	9.3580	0.0000

Table 5b: Analysis of deviance table for different log-normal based generalized linear models on the effect of daylight period, depth and towing speed on the catches of cod (age 1 and 2 combined) at fixed locations.

Full models and model terms to be reduced from the preceding model	Residual degrees of freedom	Residual deviance	F-value	p
Full model (1 *)	37	13.6389		
Daylight period * Depth	42	16.3758	1.4849	0.2182
Depth	47	18.8545	1.2714	0.2942
Daylight period	52	30.8165	5.9637	0.0002
Full model (2 *)	39	12.7223		
Daylight period * Towing speed	43	14.3628	1.2572	0.3032
Towing speed	47	18.8545	3.3618	0.0176
Full model (2 *)			as above	
Daylight period * Towing speed			as above	
Daylight period	48	28.1285	8.2424	0.0000

Table 6: Analysis of deviance table for different log-normal based generalized linear models on the effect of temperature salinity, depth and bottom type on the catches of whiting and cod (age 1 and 2) within squares.

Full models and model terms to be reduced from the previous model	Whiting Residual df	Residual deviance	F-value	p	Cod Residual df	Residual deviance	F-value	p
Full model (3)	50	57.5381			45	58.7573		
Age * Temperature	60	81.2836	2.0635	0.0458	53	69.5585	1.0344	0.4251
Temperature	71	134.8098	3.5919	0.0006	64	98.8986	2.0323	0.0432
Full model (4)	50	72.6398			45	72.6492		
Age * Salinity	60	88.7302	1.1076	0.3752	53	77.9704	0.4120	0.9077
Salinity	71	134.8098	2.8327	0.0048	64	98.8986	1.2933	0.2541
Full model (5)	50	68.7316			45	32.7775		
Age * Depth	60	80.6859	0.8696	0.5667	53	46.2283	2.3083	0.0363
Depth	71	134.8098	3.6589	0.0005				
Full model (6)	66	130.4924			59			
Bottom type	71	134.8098	0.4367	0.8213	64	98.8986	1.6012	0.1739

Table 7: Analysis of deviance table for different log-normal based generalized linear models on the effect of temperature and depth on the catches of whiting age 1 and 2 in the IBTS standard area 1991-1996. AIC: Akaike's Information Criterion.

Full models and model terms to be reduced from the previous model	Whiting Residual df	age 1 Residual deviance	F-value	p	AIC	age 2 Residual deviance	F-value	p	AIC
Full model (7)	827	2555.484			7666	3374.962			10125
Year * Temperature	832	2889.121	21.5942	0.0000		3514.048	6.8163	0.0000	
Full model (7)					as above				
Temperature squared	828	2988.268	140.0564	0.0000		3391.453	4.0410	0.0447	
Full model (8)	831	2056.367			6169	2907.756			8723
Year * Depth	836	2350.525	23.7745	0.0000		2992.862	4.8645	0.0002	
Full model (8)					as above				
Depth squared	832	2842.374	317.6337	0.0000		3446.926	154.0882	0.0000	

Table 8a: Analysis of deviance table for different log-normal based generalized linear models on the effect of temperature and depth on the catches of cod age 1 and 2 (CPUE > 0) in the IBTS standard area 1991-1996. AIC: Akaike's Information Criterion.

Full models and model terms to be reduced from the previous model	Cod age 1 Residual df	Residual deviance	F-value	p	AIC	Cod age 2 Residual df	Residual deviance	F-value	p	AIC
Full model (7 *)	521	1157.119				654	1215.767			
Year * Temperature	526	1188.173	2.7965	0.0167		659	1256.831	4.4179	0.0006	
Full model (7 *)		as	above				as	above		
Temperature squared	522	1163.017	2.6555	0.1038	3489	655	1215.775	0.0044	0.9471	3647
Year * Temperature	527	1213.598	4.5406	0.0005		660	1259.691	4.7320	0.0003	
Full model (8 *)	524	1202.550				656	1117.773			3353
Year * Depth	529	1220.016	1.5221	0.1811		661	1164.675	5.5052	0.0001	
Depth squared	530	1221.164	0.4977	0.4808	3663					
Depth	531	1290.092	29.9159	0.0000						
Full model (8 *)		as	above				as	above		
Depth squared	525	1205.919	1.4681	0.2262		657	1148.726	18.1659	0.0000	
Year * Depth	530	1221.164	1.3274	0.2510						
Year	536	1742.810	37.7335	0.0000						

Table 8b: Analysis of deviance table for different binominal based generalized linear models on the effect of temperature and depth on the presence/absence of cod age 1 and 2 in the squares of the IBTS standard area 1991-1996 (p-values correspond to chi-square tests). AIC: Akaike's Information Criterion.

Full models and model terms to be reduced from the previous model	Cod age 1 Residual df	Residual deviance	p	AIC	Cod age 2 Residual df	Residual deviance	p	AIC
Full model (9)	806	934.146		2546	806	701.831		2314
Year * Temperature	811	960.653	0.0001		811	716.958	0.0098	
Full model (9)		as	above			as	above	
Temperature squared	807	941.108	0.0083		807	707.068	0.0221	
Full model (10)	810	919.176		2539	810	665.016		
Year * Depth	815	966.710	0.0000		815	680.194	0.0096	
Full model (10)		as	above			as	above	
Depth squared	811	943.483	0.0000		811	665.126	0.7401	2287
Year * Depth					816	680.967	0.0073	

Table 9a: Abundance indices (n/hr) and corresponding coefficients of variation for age 1 and 2 whiting, 1st quarter IBTS 1991-1996, standard area.

	Whiting age 1						Whiting age 2					
Year	standard	cv	log-transf.	cv	GLM	cv	standard	cv	log-transf.	cv	GLM	cv
1991	1010.01	2.47	1909.35	10.81	1114.45	0.62	668.43	2.15	1165.52	9.67	984.30	0.66
1992	923.43	1.70	1130.09	3.30	1541.90	0.62	648.06	2.57	851.52	7.57	962.75	0.70
1993	1087.26	2.62	1387.74	8.58	805.95	0.66	523.67	2.13	1155.90	15.90	1000.09	0.97
1994	721.45	2.60	992.55	8.47	614.65	0.58	638.63	2.66	1139.28	24.71	602.56	0.95
1995	644.67	1.83	898.16	4.76	930.23	0.70	437.65	2.79	760.01	12.12	678.04	0.86
1996	502.36	2.49	809.39	9.18	439.49	0.62	485.97	2.38	1116.22	24.66	515.38	0.85

Table 9b: Abundance indices (n/hr) and corresponding coefficients of variation for age 1 and 2 cod, 1st quarter IBTS 1991-1996, standard area.

	Cod age 1				Cod age 2			
Year	standard	cv	GLM	cv	standard	cv	GLM	cv
1991	2.33	2.73	3.35	0.55	4.73	1.64	4.99	0.43
1992	12.29	2.19	16.41	0.45	4.54	1.42	5.83	0.42
1993	13.06	4.31	4.41	0.37	19.50	1.30	30.72	0.97
1994	14.81	3.16	12.81	0.48	4.41	1.99	4.44	0.57
1995	9.59	2.60	10.19	0.25	20.26	1.98	25.15	0.99
1996	3.46	2.45	5.00	0.62	8.04	1.82	9.46	0.85

Table 10: Correlation (r^2) between VPA and different abundance indices for age 1 and 2 whiting and cod from the 1st quarter IBTS 1991-1996, species-specific standard areas.

	Whiting				Cod			
Index	age 1		age 2		age 1		age 2	
standard	0.42	(n.s.)	0.04	(n.s.)	0.48	(n.s.)	0.85	($p < 0.01$)
log-transf.	0.13	(n.s.)	0.24	(n.s.)	-		-	
GLM	0.08	(n.s.)	0.58	(n.s.)	0.77	($p < 0.05$)	0.71	($p < 0.05$)

Table 11: Proportion (%) of night hauls used in the calculation of 1st quarter IBTS abundance indices from the standard areas for whiting and cod in 1991 to 1996 according to the day/night coding in the IBTS database.

	1991	1992	1993	1994	1995	1996
Whiting	19.73	20.65	18.45	16.45	20.07	24.34
Cod	20.22	20.85	18.57	16.56	20.22	24.53

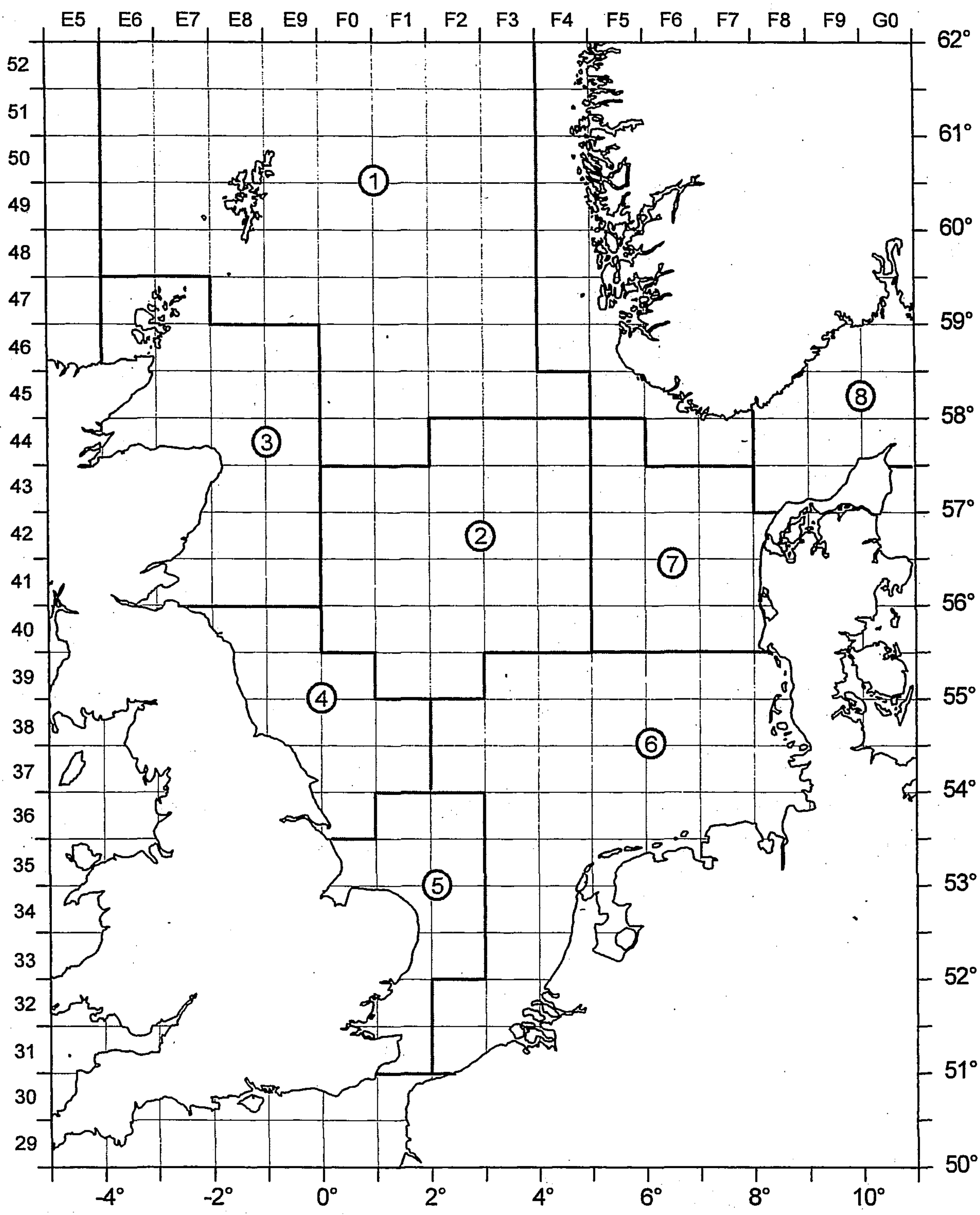


Figure 1: ICES statistical rectangles and roundfish sampling areas in the North Sea.

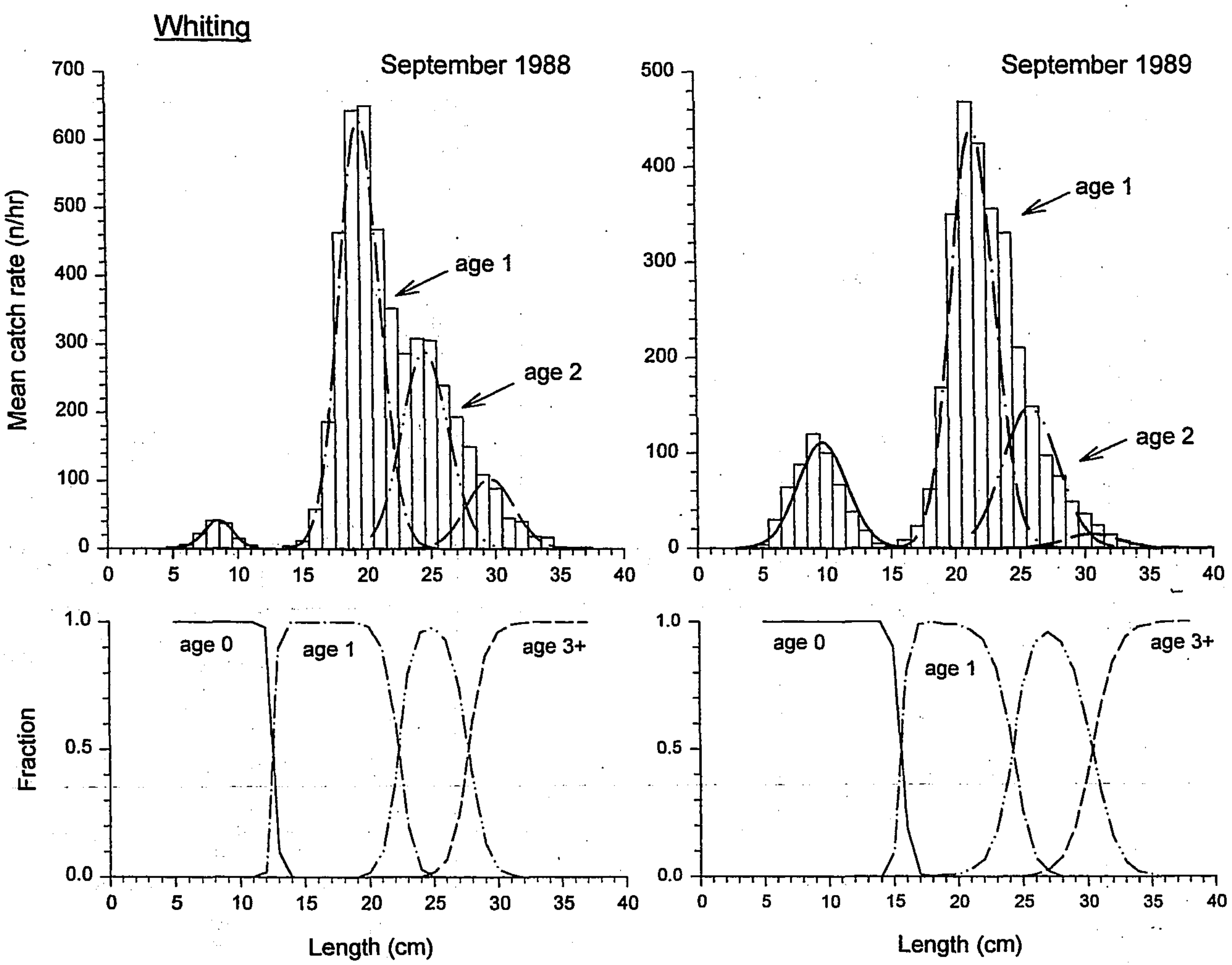
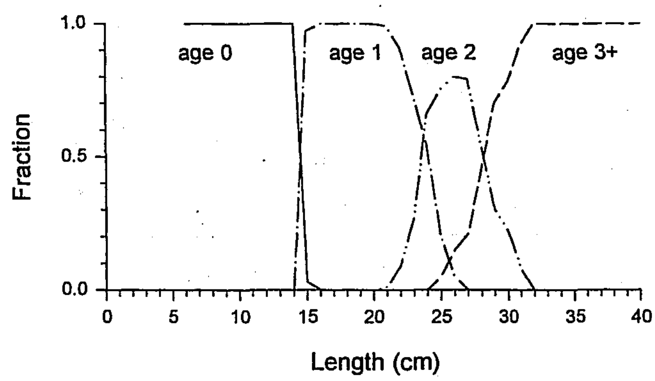


Figure 2: Length frequency distribution and age decomposition of whiting catches for September 1988 and 1989 Catches from different areas were pooled. 1988: squares 37F5 and 39F5 (roundfish area 6); 1989: square 40F2 (roundfish area 2), 40F5 (roundfish area 7) and 44F0 (roundfish area 1).

Figure 3: Age length key for whiting from the 3 rd quarter 1989. Roundfish areas 1 to 4 combined. Data from the Scottish Groundfish Survey in ICES Division VIb.



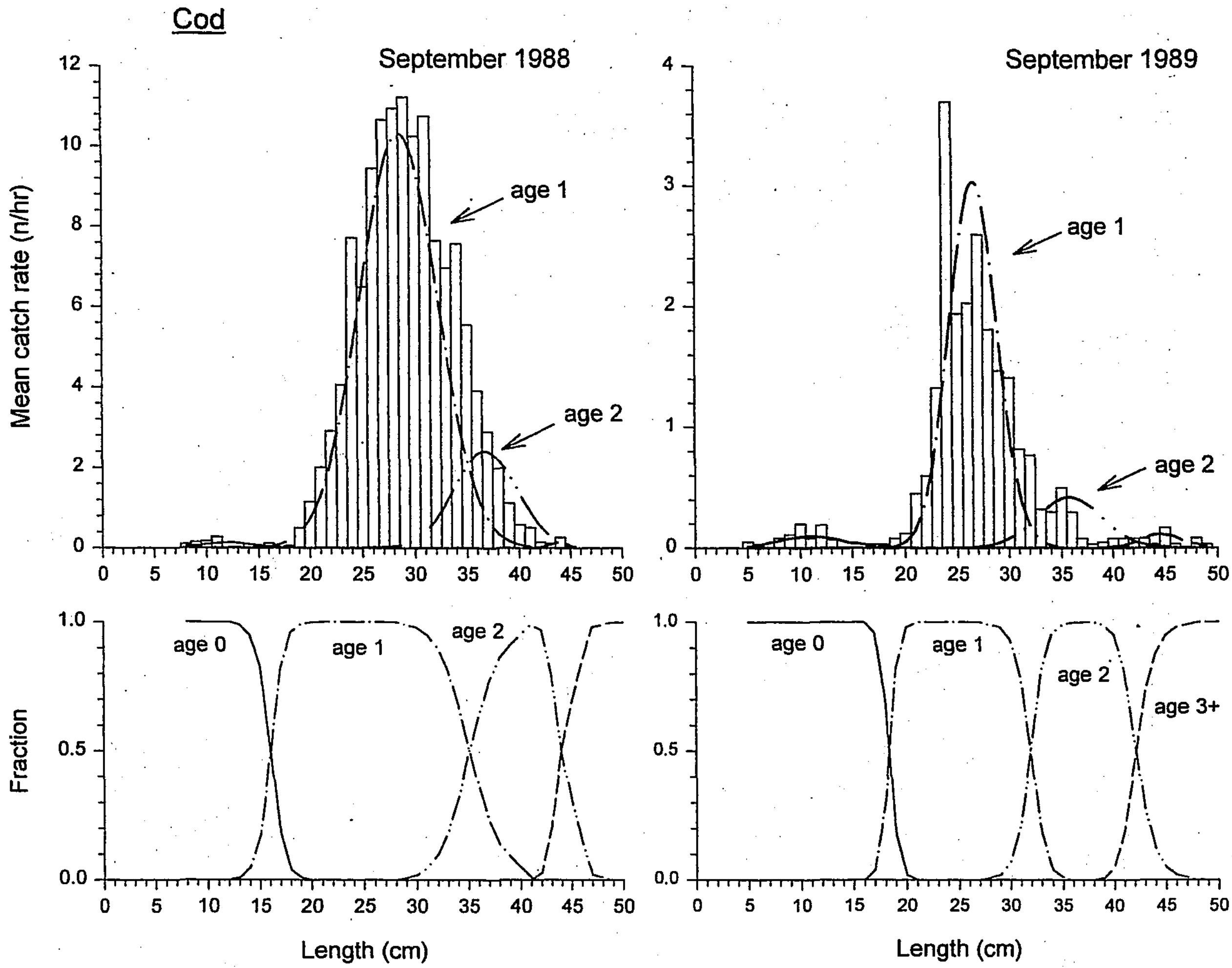


Figure 4: Length frequency distribution and age decomposition of cod catches for September 1988 and 1989. Catches from different areas were pooled. 1988: squares 37F5 and 39F5 (roundfish area 6); 1989: square 40F2 (roundfish area 2), 40F5 (roundfish area 7) and 44F0 (roundfish area 1).

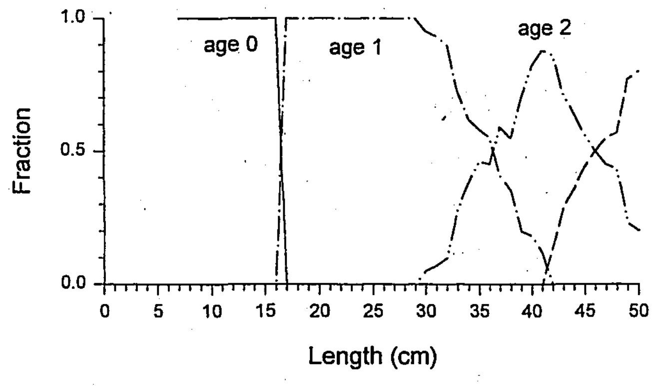


Figure 5: Age length key for cod from the 3 rd quarter 1989. Roundfish areas 1 to 4 combined. Data from the the Scottish Groundfish Survey in ICES Division VIb.

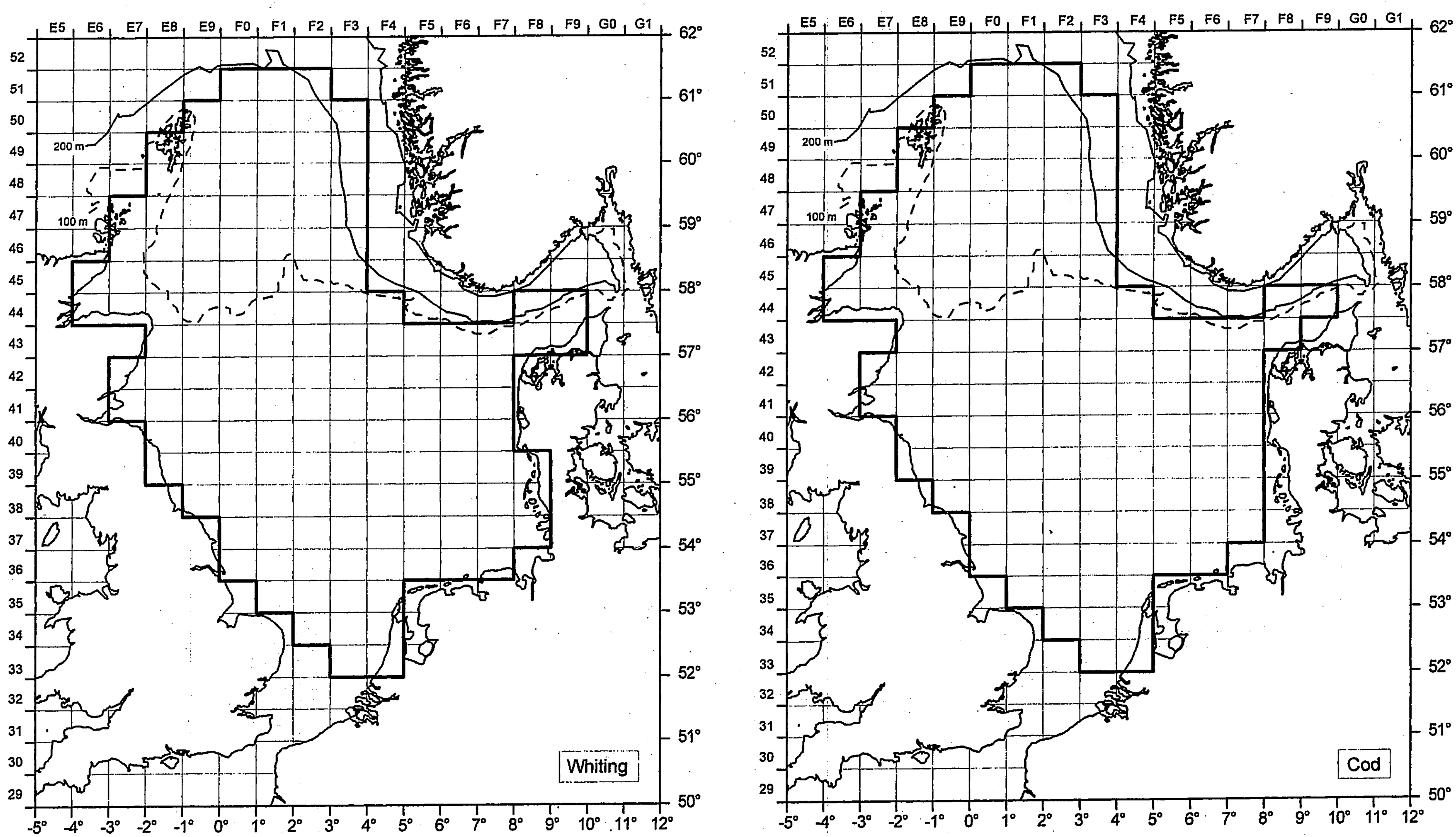
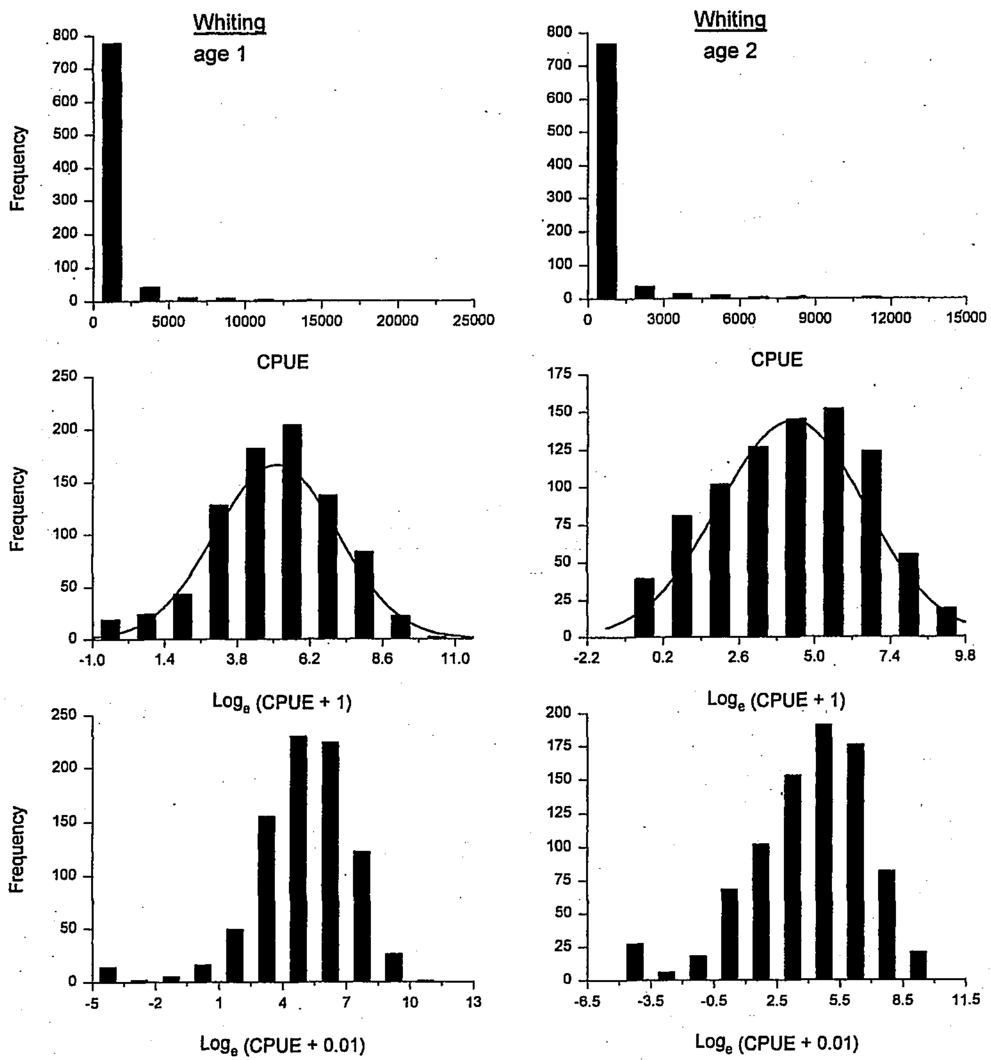


Figure 6: IBTS standard areas for whiting and cod.



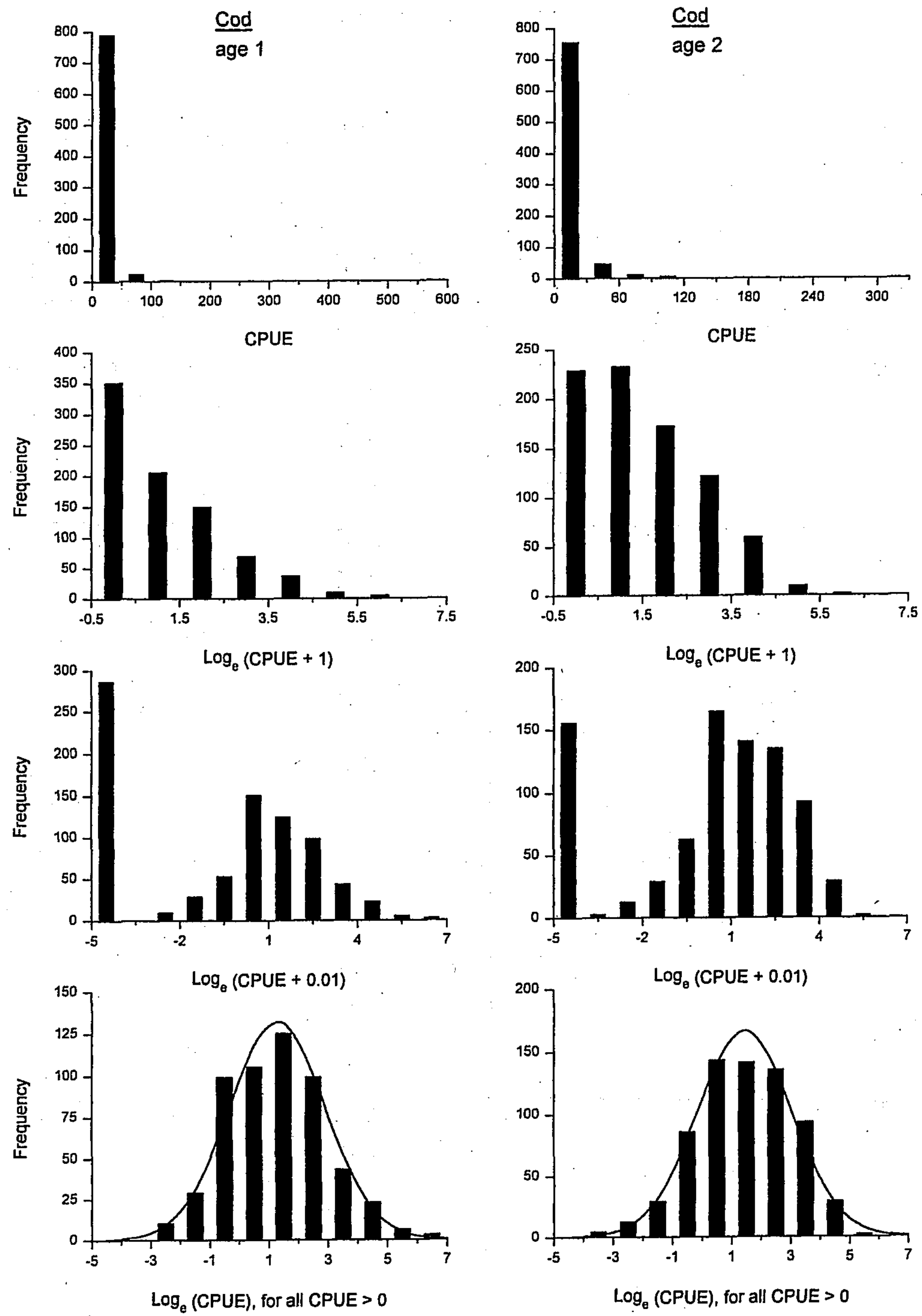


Figure 7: Frequency distributions of age 1 and 2 whiting and cod catches (average CPUE by square) in the 1st quarter IBTS 1991-1996. Solid lines refer to estimated normal distributions.

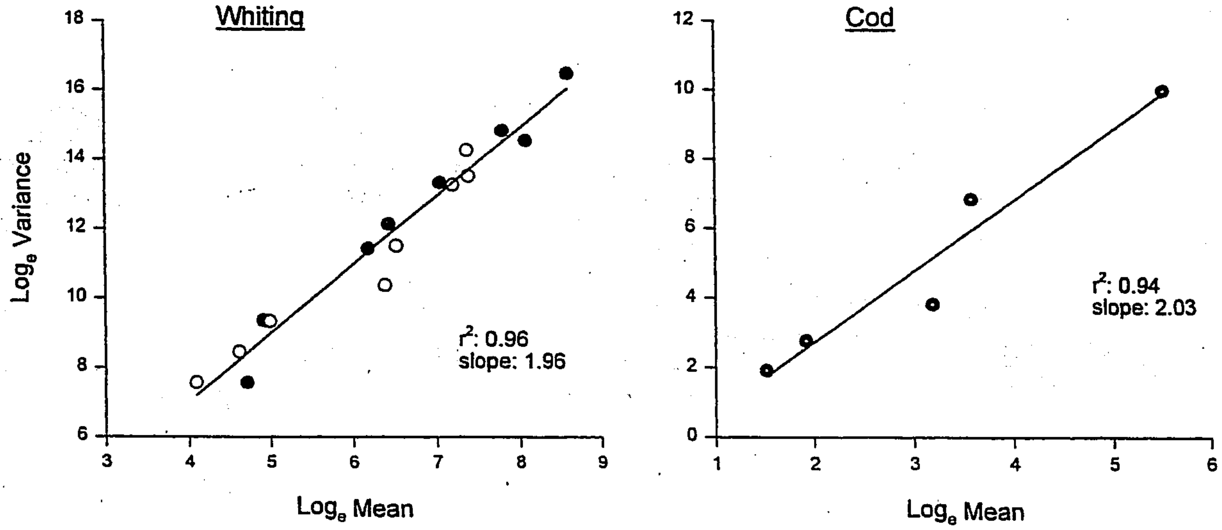


Figure 8: Scatterplots of log-variance vs. log-mean of catches for whiting (CPUE; solid circles: age 1, open circles: age 2) and cod (CPUE + 1; age 1 and 2 combined) at fixed locations. Day and night catches pooled.

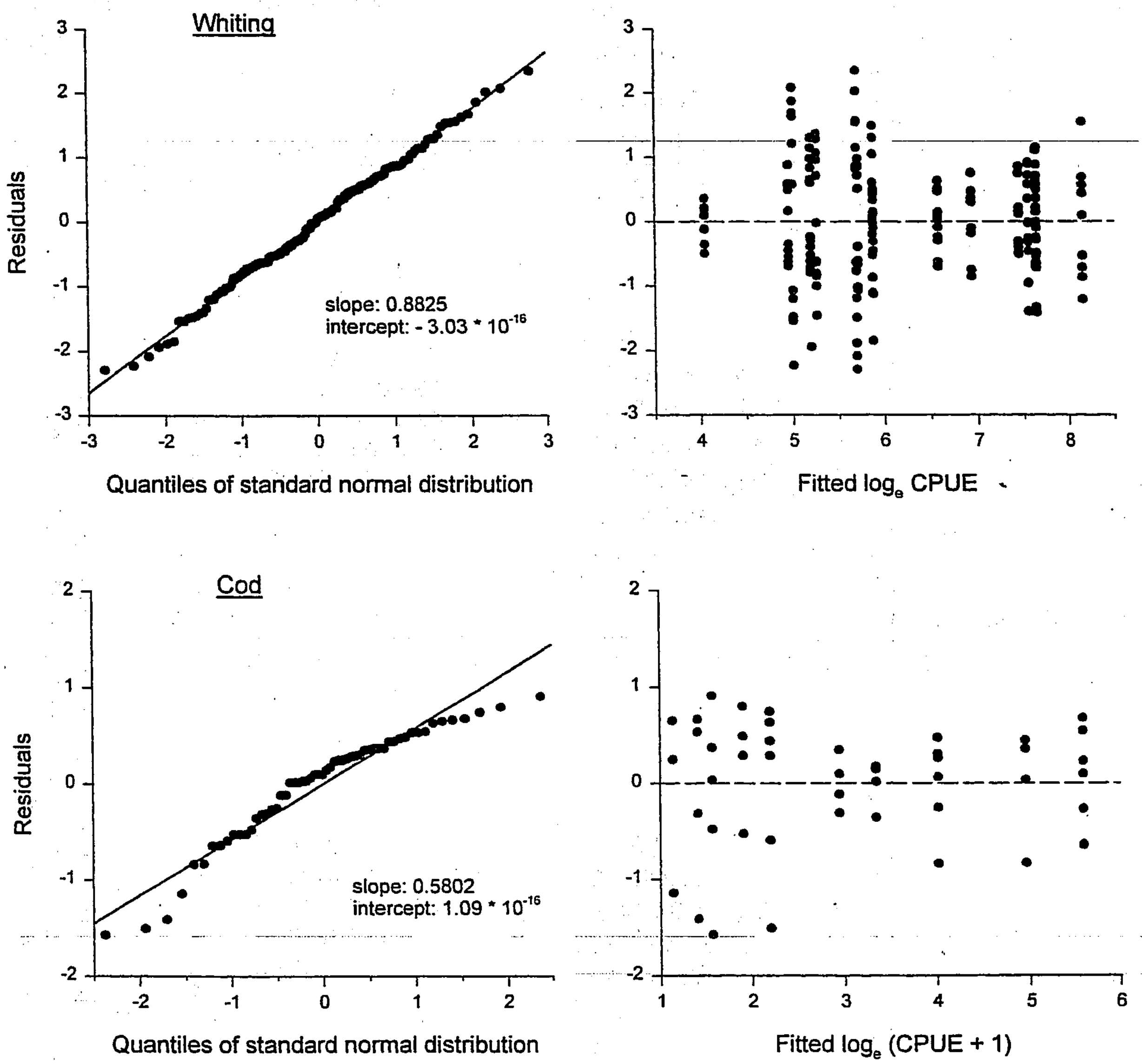


Figure 9: Norm- and scatterplots of residuals vs. fitted values for the GLM on the effect of daylight on whiting and cod catches at fixed locations.

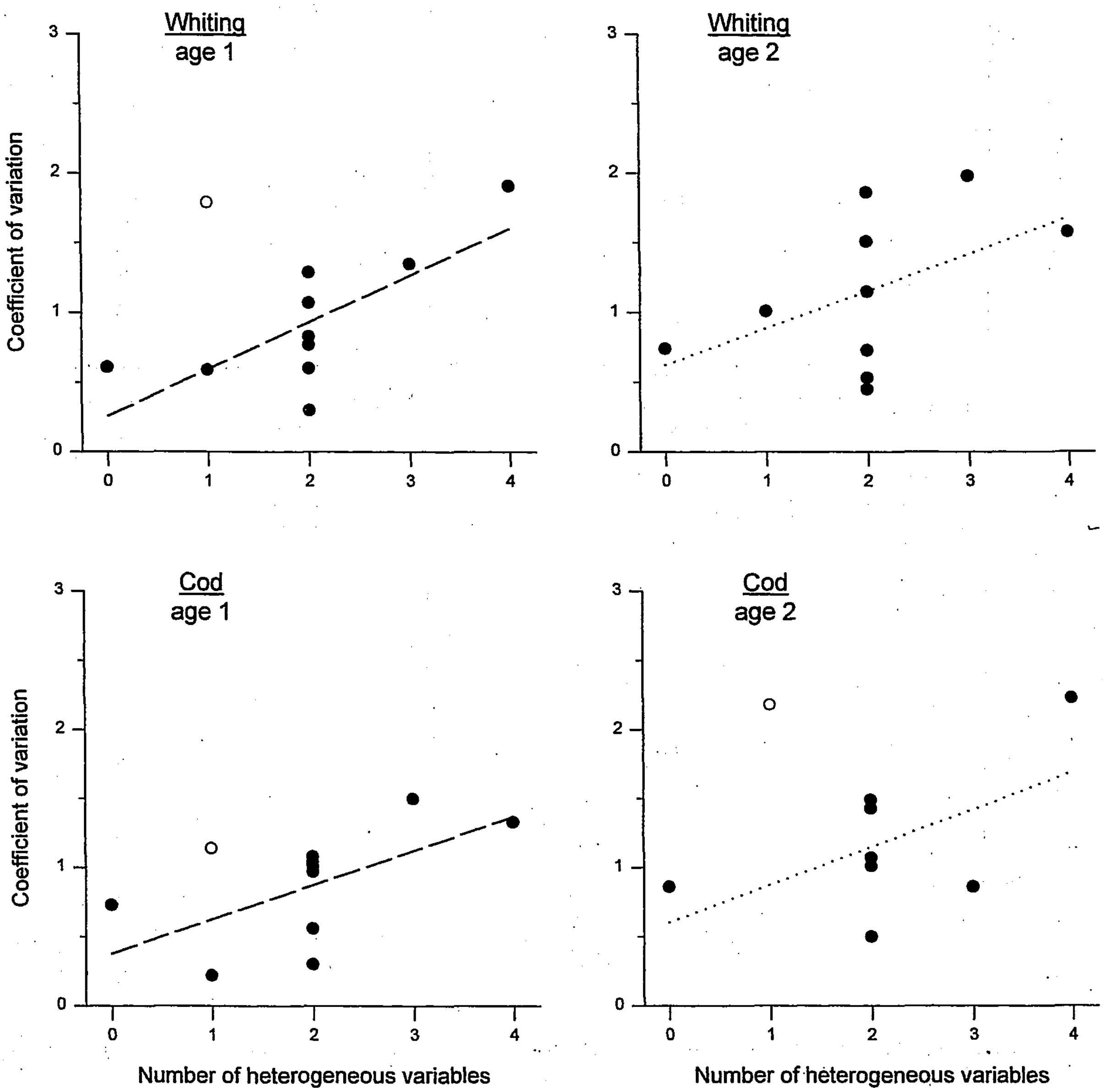


Figure 10: Variability of whiting and cod catches in relation to the heterogeneity within a square. Dashed lines: correlation coefficient significant at 5 % level, dotted lines: n.s.; open circels: data from 1977 for square 41F7 not included in regression.

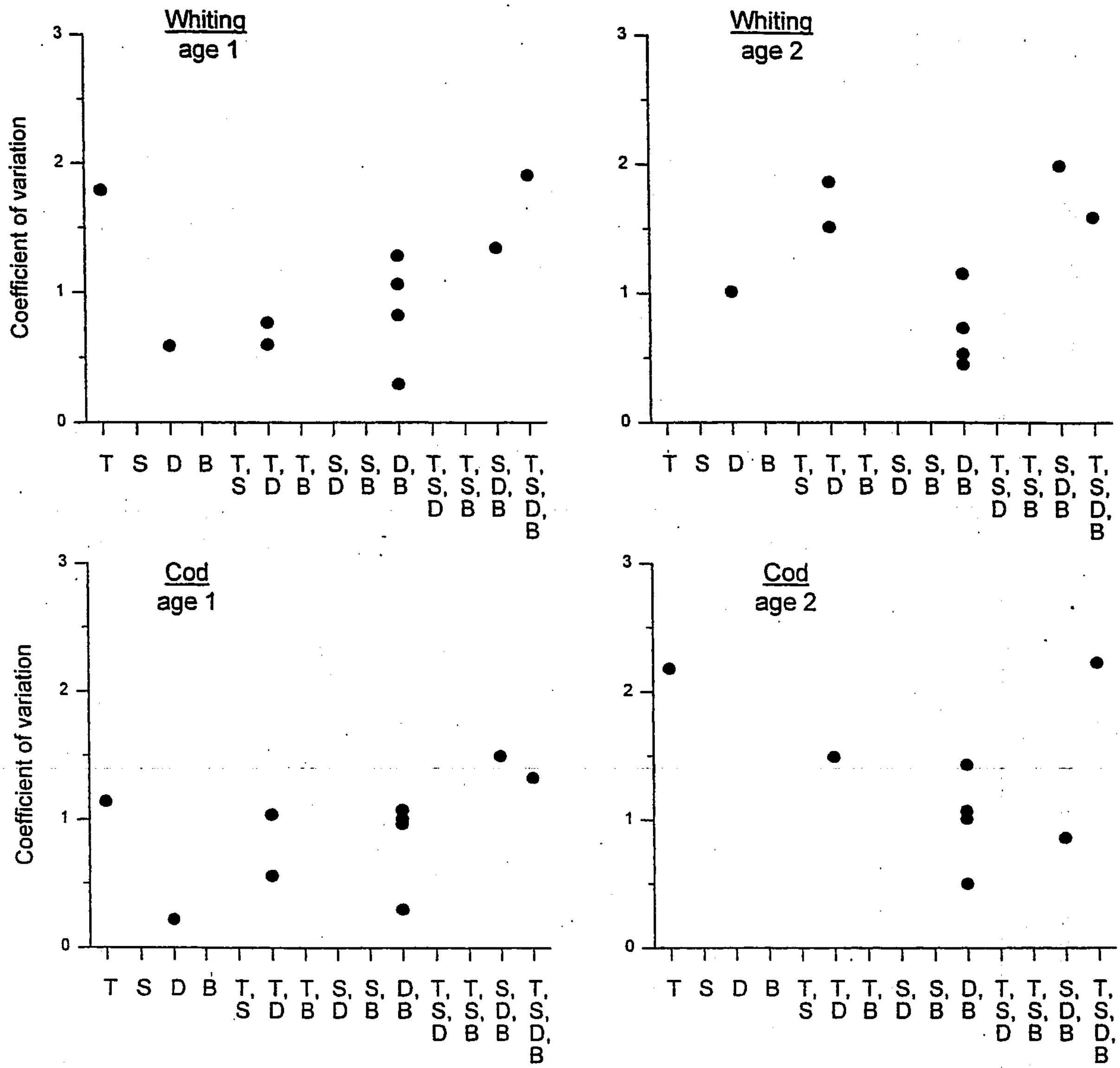


Figure 11: Variability of whiting and cod catches in relation to the type of heterogeneous variables within a square. T: Temperature, S: Salinity, D: Depth, B: Bottom type.

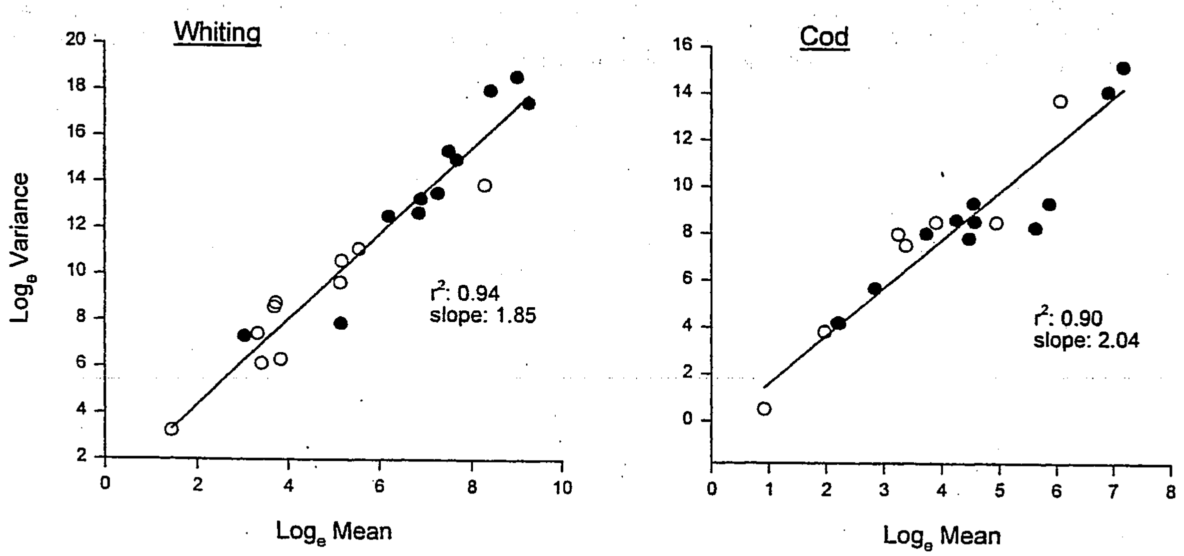


Figure 12: Scatterplots of log-variance vs. log-mean of whiting and cod catches (CPUE +1) within squares (solid circles: age 1, open circles: age 2).

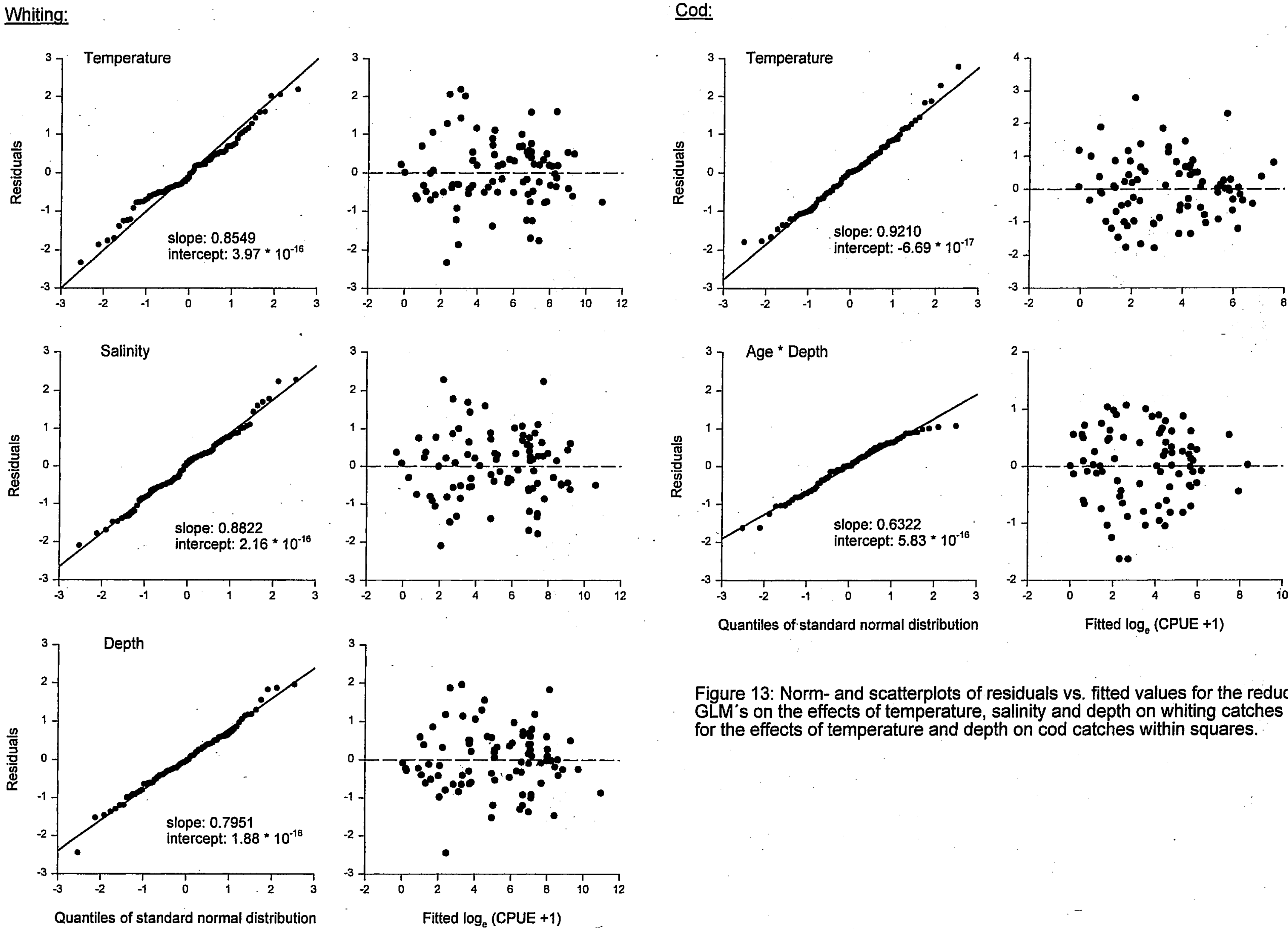


Figure 13: Norm- and scatterplots of residuals vs. fitted values for the reduced GLM's on the effects of temperature, salinity and depth on whiting catches and for the effects of temperature and depth on cod catches within squares.

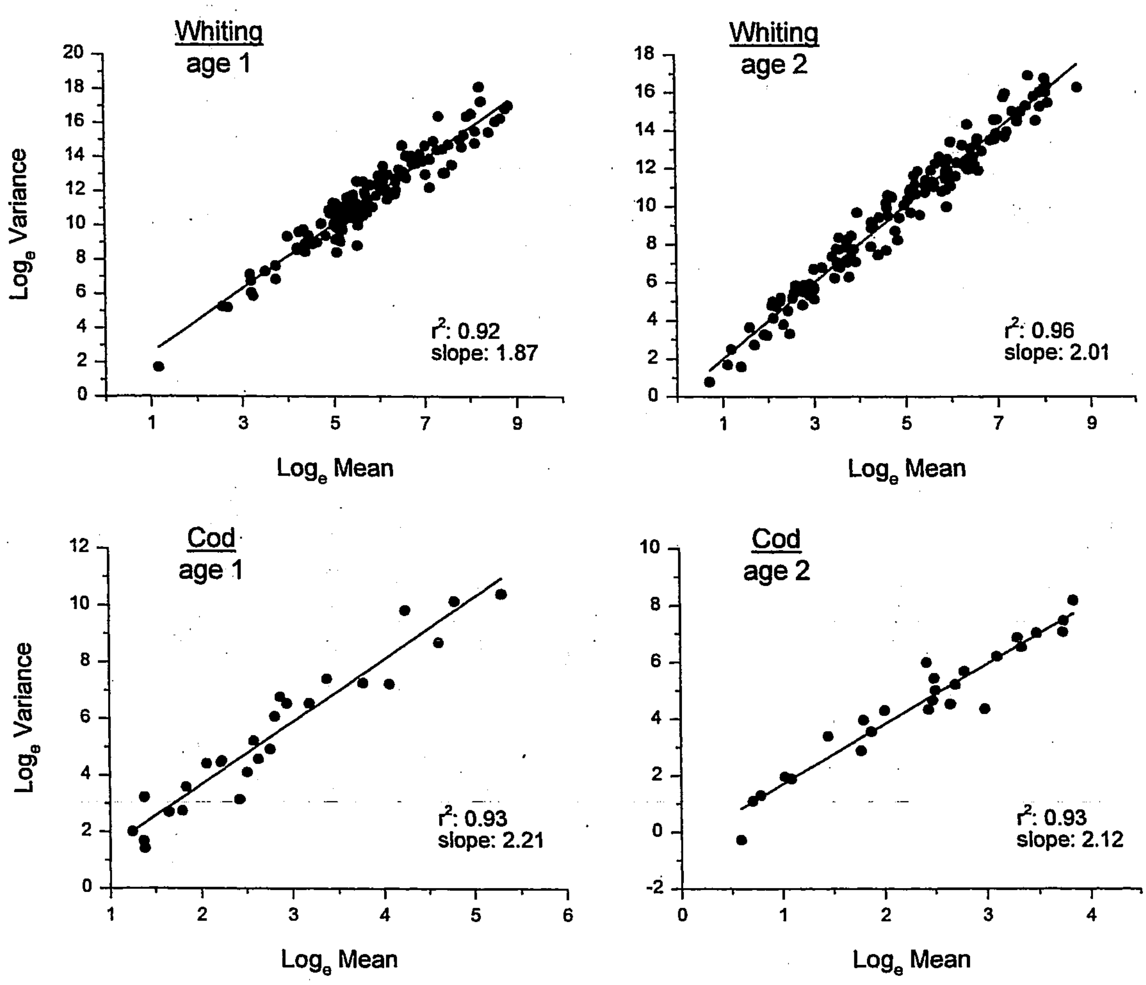


Figure 14: Scatterplots of log-variance vs. log-mean of average catches by square for whiting (CPUE + 1) and cod (CPUE > 0) from the 1st quarter IBTS 1991-1996.

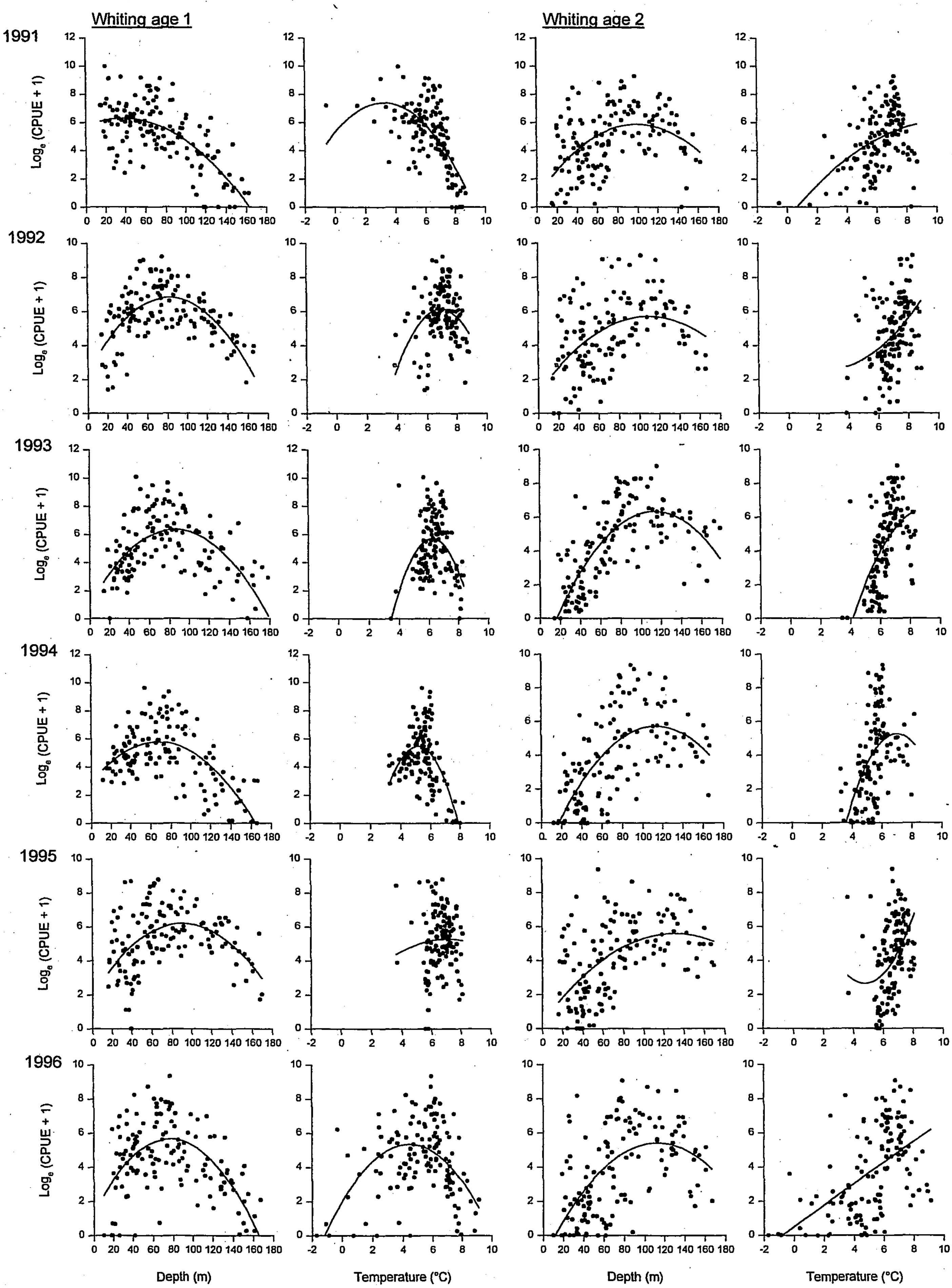


Figure 15: Scatterplots of log-transformed whiting catches (age 1 and 2, CPUE +1) vs. depth and temperature (mean values by square, 1st quarter IBTS 1991-1996, solid lines refer to quadratic regressions).

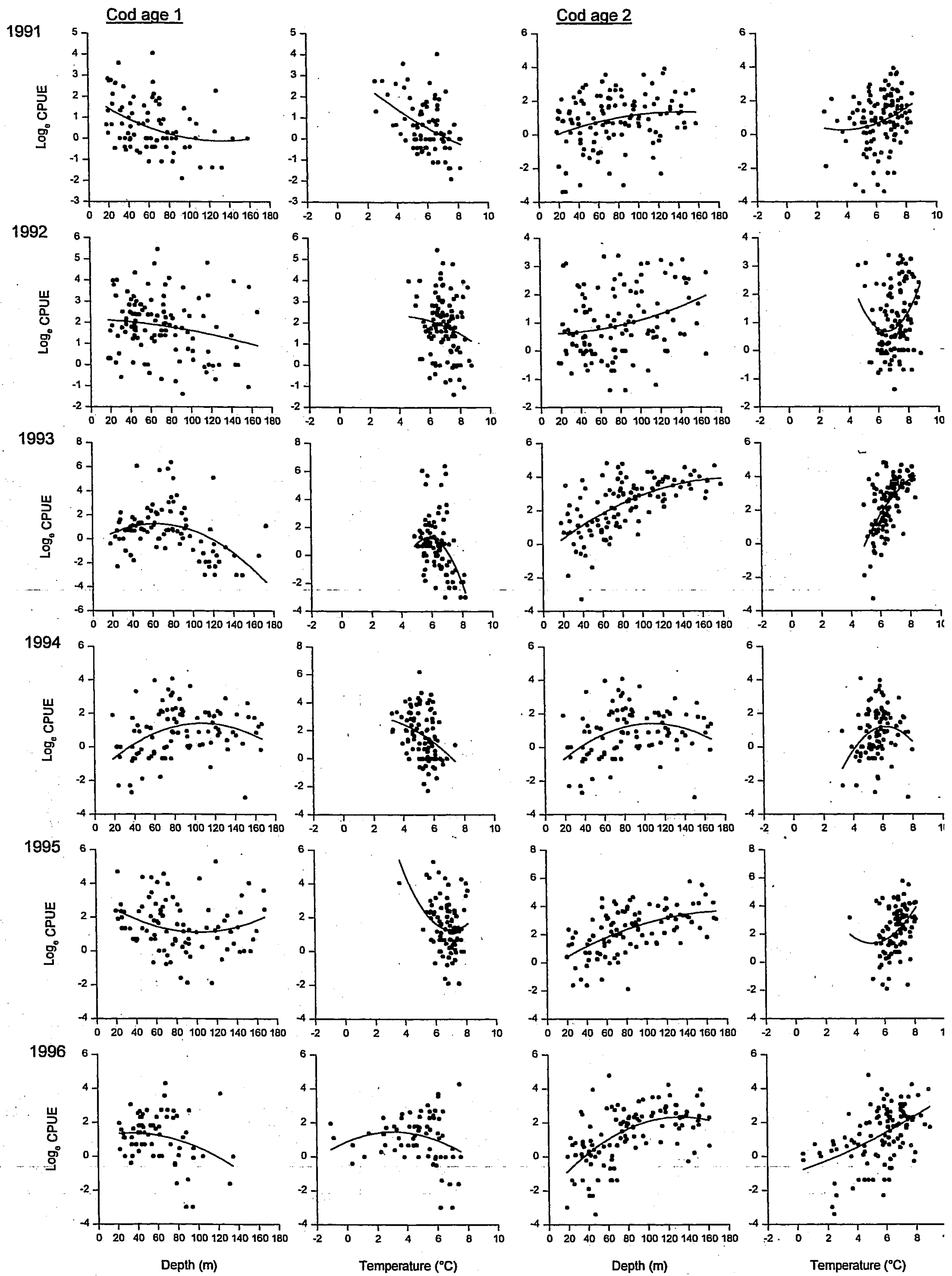


Figure 16: Scatterplots of log-transformed cod catches (age 1 and 2, CPUE > 0) vs. depth and temperature (mean values by square, 1st quarter IBTS 1991-1996, solid lines refer to quadratic regressions).

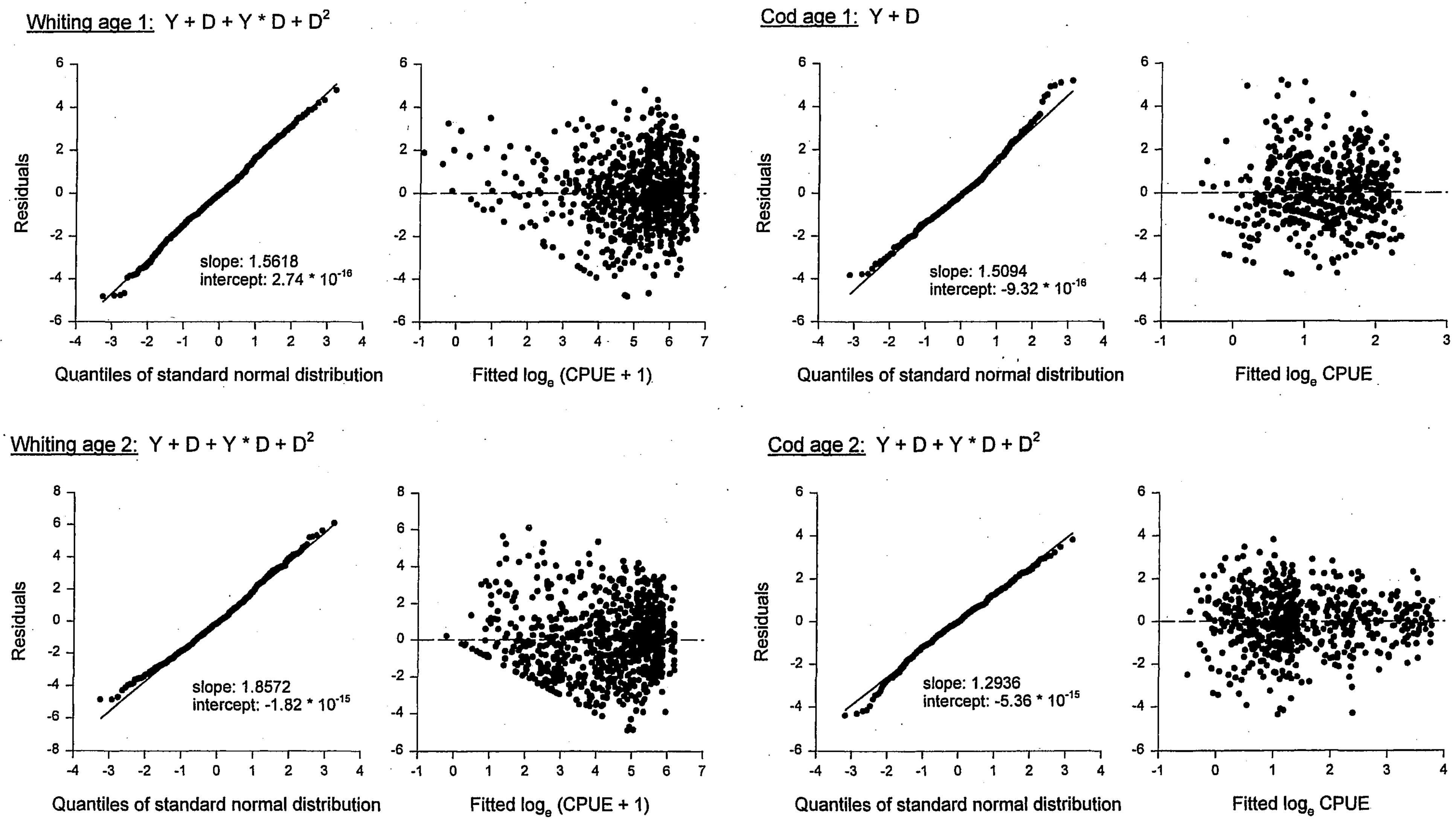


Figure 17: Norm- and scatterplots of residuals vs. fitted values for the final log-normal based GLM's on the effects of year (Y) and depth (D) on the catches of age 1 and 2 whiting (CPUE + 1) and cod (CPUE > 0) within the species-specific IBTS standard areas 1991-1996.

Appendix 2

ICES SGQIBS Working Document
Copenhagen, August 1998

Comparison of first and third quarter IBTS abundance indices for age 1 and 2 whiting and cod

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Introduction

Previous analyses of the quarterly IBTS abundance indices for cod have shown that the 0-group is not well sampled before the third and the fourth quarter and that the maximum catchability of the 1-group is yet not established in the first quarter (ICES 1996). Estimates of total mortality of the 1-group from the first quarter indices yielded negative values in three out of four year classes considered (1990-1993). In some of these years, however, high catches of 1-group cod were recorded in squares adjacent to the standard area used for the calculation of the indices. Besides, highly skewed frequency distributions of the catches have been observed (ICES 1996). In this paper, the effects of both the extension of the area on which the indices are based and the frequency distribution of the catches are studied for age 1 and 2 whiting and cod. IBTS data from the first and the third quarter are analyzed using univariate statistics and estimates of total mortality, and the IBTS abundance indices are compared with recent VPA estimates of year class strength.

Material and Methods

Catches of whiting and cod in numbers per hour trawling (CPUE) by age group were available from the ICES IBTS database. Following the usual IBTS procedure, mean values for the individual statistical squares of the surveyed area were calculated. From these values, arithmetic means for the species-specific standard areas and extended areas, also including the coastal rectangles in the German Bight adjacent to the Wadden Sea for cod and the eastern part of the Skagerrak for both whiting and cod (Fig. 1), were obtained.

For comparison with the conventional method, abundance indices (avg) and variances (var) were computed from the arithmetic mean (μ) and the standard deviation (σ) of log-transformed catches by square (CPUE + 1) for whiting, according to Hoffmann-Jørgensen (1994):

$$avg = \exp(\mu + 0.5 * \sigma^2) - 1$$

$$var = (\exp(\sigma^2) - 1) * avg^2;$$

and the coefficient of variation (CV) is given by:

$$cv = \sqrt{(\exp(\sigma^2) - 1)}\,.$$

Total mortality (Z) was estimated from the first and third quarter abundance indices (N) using the usual equation for exponential decay:

$$Z = \ln(N_{age,\,year} / N_{age+1,\,year+1}),$$

and the most recent assessment (ICES 1998) was used for comparing VPA results with the first and third quarter IBTS abundance indices.

Results and Discussion

Table 1 shows the conventional abundance indices of whiting and cod for the first and the third quarter. There is only little difference between indices for the standard area and the extended area concerning whiting age 1 and 2 and cod age 2 in both quarters. In contrast, the indices for age 1 cod increase substantially in some years when the 'Wadden Sea' (1^{st} quarter 1991, 3^{rd} quarter 1993) and the eastern Skagerrak (1^{st} quarter 1992 and 1995) are included. There, the influence of high catches in the four rectangles adjacent to the Wadden Sea was most pronounced, resulting in an 2-3 fold increase of the abundance indices and the coefficients of variation for age 1 cod in the first quarter 1991 and the third quarter 1993. Mortality estimates for whiting based on the first quarter indices are quite low and do not change very much regardless of whether the standard or the extended area is considered. For cod, negative values occur even when the 'Wadden Sea' and the eastern Skagerrak are included (Tab. 2). Using the third quarter indices the area effect is small for both species, and the obtained mortality rates are much closer to VPA values (Z-values from VPA for year classes 1990-1995: appr. 1.1 year $^{-1}$ for whiting and 0.9 year $^{-1}$ for cod on average). This indicates that the maximum catchability of the 1-group is not established in the first quarter for both species. Furthermore, a higher correlation between the year class strength of whiting and cod at age 1 from VPA and the IBTS is obtained for the third quarter than for the first quarter IBTS (Tab. 3).

Skewness and kurtosis corresponding to the first and third quarter IBTS abundance indices for the species-specific standard areas are given in Table 4. For both species, these values do not show any difference between the first and the third quarter, regardless of whether age 1 or 2 are considered. Low values would reflect a homogeneous distribution of the fish and a uniform catchability throughout the survey area. However, this is neither indicated for the first nor for the third quarter. Moreover, the frequency distributions of the catches deviate considerably from normal distributions in all cases (Figs. 2-5). Thereby, high numbers of zero catches are recorded especially for cod age 1 and 2. A log-transformation of the catches (with 1 added to the average CPUE by square) yields frequency distributions which can be approximated by a normal distribution for whiting age 1 and 2, but not for cod. For cod, the zero catches become clearly isolated from the positive ones when a low constant (0.01) is added (Figs 3 and 5, lower panels). This is much less pronounced for whiting (Figs. 2 and 4, lower panels). Hence, for cod a delta gamma (or delta log-normal) approach might appropriate (Stefánsson 1996, Wieland et al. in prep.) while for whiting mean abundance can directly be computed from the log-transformed catches.

First and third quarter abundance indices for age 1 and 2 whiting based on log-transformed catches, coefficients of variation, and estimates of total mortality are listed in table 5. For both age groups and quarters, the new indices and the corresponding coefficients of variation are considerably higher than the conventional ones (Tab. 1). The high coefficients of variation obtained applying a more realistic frequency distribution of the catches suggest that the conventional method gives a too optimistic impression on the accuracy of the IBTS abundance indices. Estimates of total mortality based on the 'new' abundance indices are unrealistic for the first quarter except in one case (year class 1990), and the correlation with VPA year class strength (Tab. 6) becomes very poor. This emphasises again that the 1-group is not caught efficiently in the first quarter of the year. Whiting mortality estimates for the third quarter are high compared to VPA, except for the 1990 year class. The correlation of the 'new' third quarter indices with VPA year class strength (Tab. 6) is lower than for the conventional ones (Tab. 3), especially for the 1-group.

However, the comparisons of IBTS abundance indices with VPA estimates for the period 1991 to 1996 should be viewed with caution since the time series are short and the VPA values are likely to stem from its nonconverged part. Furthermore, it might be more appropriate to use quarterly data from the MSVPA for comparison, in particular for the evaluation of the usefulness of the third quarter indices. Little agreement between survey estimates and ICES assessment for whiting has been observed in the past irrespectively of a possible bias introduced by misreported commercial data (Cook 1997). VPA results may therefore only be of limited quality for the evaluation of the usefulness of the quarterly IBTS abundance indices, particularly for whiting.

Conclusions

The assessment units for whiting and cod have recently been changed combining the North Sea and the Skagerrak (ICES 1997, 1998). The coastal areas of the German Bight and at times also the Skagerrak are important nursery areas for whiting and cod (Munk et al. 1995), and it therefore appears worthwhile to consider a redefinition of the species-specific standard areas, at least for cod.

Low catchability severely effects the first quarter indices for age 1 cod and, to some lesser extent, those for age 1 whiting. In contrast, the third quarter indices for the 1-group seem to be adequate indicators of year class strength. The third quarter surveys should therefore continue in the future with the same intensity as allocated to the first quarter surveys in the past, both with respect to spatial coverage as well as the number of hauls per square.

Acknowledgements

This study was funded by an EU TMR grant.

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Table 1: Abundance indices (n/hr, arithmetic mean) and coefficients of variation for species specific standard areas compared to extended areas. Area specific mean abundance and CV's were calculated from average CPUE by square (ICES IBTS data base). A: North Sea and western Skagerrak (standard area for cod); B: North Sea incl. 'Wadden Sea' and western Skagerrak (standard area for whiting; C: North Sea incl. Wadden Sea and entire Skagerrak. N: number of squares covered.

1st quarter:

		Whiting age 1		Whiting age 2			Cod age 1		Cod age 2		
Year	Area	Mean n/hr	CV	Mean n/hr	CV	N	Mean n/hr	CV	Mean n/hr	CV	N
1991	A						2.33	2.73	4.73	1.64	139
	B	1010.01	2.47	668.43	2.15	143	7.87	7.02	4.78	1.59	143
	C	1013.07	2.41	665.68	2.18	149	7.57	7.21	4.90	1.60	149
1992	A						12.29	2.19	4.54	1.42	137
	B	923.43	1.70	648.06	2.57	141	13.81	1.84	5.75	2.59	141
	C	954.73	1.64	640.80	2.55	147	16.77	2.47	5.71	2.57	147
1993	A						13.06	4.31	19.50	1.30	139
	B	1087.26	2.62	523.67	2.13	143	12.92	4.83	19.00	1.33	143
	C	1073.00	2.61	524.96	2.09	149	14.30	3.87	18.65	1.33	149
1994	A						14.81	3.16	4.41	1.99	135
	B	721.45	2.60	638.63	2.63	139	15.18	3.05	4.28	2.03	139
	C	694.40	2.65	630.88	2.65	145	15.50	2.94	4.35	1.96	145
1995	A						9.59	2.60	20.26	1.98	136
	B	644.67	1.83	437.65	2.79	140	9.55	2.24	20.58	2.04	140
	C	692.92	1.77	425.67	2.81	146	13.07	2.84	21.79	1.90	146
1996	A						3.46	2.45	8.04	1.82	137
	B	502.36	2.49	485.97	2.40	140	3.44	1.92	7.88	1.88	140
	C	523.73	2.37	477.90	2.40	146	4.60	2.71	9.55	1.91	146
1997	A						39.98	4.57	6.85	2.94	139
	B	287.73	2.11	342.21	2.91	142	40.03	4.93	6.71	2.58	142
	C	288.68	2.07	349.84	2.80	148	39.90	4.44	7.37	2.70	148

3rd quarter:

		Whiting age 1		Whiting age 2			Cod age 1		Cod age 2		
Year	Area	Mean n/hr	CV	Mean n/hr	CV	N	Mean n/hr	CV	Mean n/hr	CV	N
1991	A						8.03	2.50	2.46	2.24	136
	B	694.87	2.70	157.97	1.91	140	7.80	2.54	2.39	2.28	140
	C	681.75	2.70	156.26	1.89	146	8.08	2.43	2.55	2.17	146
1992	A						43.78	1.77	3.61	2.39	136
	B	595.01	1.55	297.85	1.45	140	42.70	1.79	3.51	2.44	140
	C	584.07	1.56	290.61	1.46	146	43.98	1.72	3.72	2.31	146
1993	A						9.99	2.26	7.95	1.28	136
	B	644.83	2.10	178.34	2.01	140	19.88	5.99	7.74	1.30	140
	C	627.39	2.12	171.40	2.06	146	20.55	5.69	7.88	1.26	146
1994	A						43.19	2.44	6.22	1.77	135
	B	671.88	1.96	222.49	2.50	139	43.58	2.41	6.09	1.79	139
	C	724.37	1.88	216.19	2.53	145	50.43	2.28	6.40	1.72	145
1995	A						24.36	3.29	17.16	1.85	128
	B	*614.43*	*3.03*	*281.25*	*2.06*	*128*	*Wadden Sea'*		*not sampled*		
	C	599.32	3.04	274.26	2.07	134	31.44	2.93	16.78	1.86	134
1996	A						29.10	7.47	4.36	1.92	124
	B	370.42	2.33	256.47	4.39	128	28.30	7.56	4.23	1.96	128
	C	361.57	2.34	246.53	4.46	134	31.10	6.75	4.70	1.87	134
1997	A					no	data				
	B					no	data				
	C					no	data				

Wadden Sea': coastal rectangles in the German Bight adjacent to the Wadden Sea.

Table 2: Abundance indices (arithmetic mean of average CPUE by square, n/hr) and estimates of total mortality (Z, per year) for juvenile whiting and cod

Whiting, 1st quarter

	Standard area							Extended area (North Sea incl. Wadden Sea and entire Skagerrak)						
Age \ Year	1991	1992	1993	1994	1995	1996	1997	1991	1992	1993	1994	1995	1996	1997
1	1010.01	923.43	1087.26	721.45	644.67	502.36		1013.07	954.73	1073.00	694.40	692.92	523.73	
2		648.06	523.67	638.43	437.65	485.97	342.21		640.80	524.96	630.88	425.67	477.90	349.84
Z	0.44	0.57	0.53	0.50	0.28	0.38		0.46	0.60	0.53	0.49	0.37	0.40	

Whiting, 3rd quarter

	Standard area							Extended area (North Sea incl. Wadden Sea and entire Skagerrak)						
Age \ Year	1991	1992	1993	1994	1995	1996	1997	1991	1992	1993	1994	1995	1996	1997
1	694.87	595.01	644.83	671.88	614.43	370.42		681.75	584.07	627.39	724.37	599.32	361.57	
2		297.85	178.34	222.49	281.45	256.47			290.61	171.40	216.19	274.26	246.53	
Z	0.85	1.20	1.06	0.87	0.87			0.85	1.23	1.07	0.97	0.89		

Cod, 1st quarter

	Standard area							Extended area (North Sea incl. Wadden Sea and entire Skagerrak)						
Age \ Year	1991	1992	1993	1994	1995	1996	1997	1991	1992	1993	1994	1995	1996	1997
1	2.33	12.29	13.06	14.81	9.59	3.46		7.57	16.77	14.30	15.50	13.07	4.60	
2		4.65	19.37	4.38	20.12	7.98	6.85		5.71	18.65	4.35	21.79	9.55	7.37
Z	-0.69	-0.45	1.09	-0.31	0.18	-0.68		0.28	-0.11	1.19	-0.34	0.31	-0.47	

Cod, 3rd quarter

	Standard area							Extended area (North Sea incl. Wadden Sea and entire Skagerrak)						
Age \ Year	1991	1992	1993	1994	1995	1996	1997	1991	1992	1993	1994	1995	1996	1997
1	8.03	43.78	9.99	43.19	24.36	29.10		8.08	43.98	20.55	50.43	31.44	31.10	
2		3.61	7.95	6.22	17.16	4.36			3.72	7.88	6.40	16.78	4.70	
Z	0.80	1.71	0.47	0.92	1.72			0.78	1.72	1.17	1.10	1.90		

Table 3: Correlation (r^2) between VPA and IBTS abundance indices (arithmetic means of average CPUE by square), 1991-1996.

	Whiting age 1				Whiting age 2			
Index	standard area		extended area		standard area		extended area	
1st quarter	0.42	($p < 0.05$)	0.38	(n.s.)	0.04	(n.s.)	0.06	(n.s.)
3rd quarter	0.82	($p < 0.01$)	0.81	($p < 0.01$)	0.38	(n.s.)	0.39	(n.s.)

	Cod age 1				Cod age 2			
Index	standard area		extended area		standard area		extended area	
1st quarter	0.48	(n.s.)	0.52	(n.s.)	0.85	($p < 0.01$)	0.92	($p < 0.001$)
3rd quarter	0.64	($p < 0.05$)	0.70	($p < 0.05$)	0.80	($p < 0.01$)	0.81	($p < 0.01$)

Table 4: Skewness and Kurtosis for 1st and 3rd quarter IBTS abundance indices (n/hr, arithmetic mean of average CPUE by square) referring to species-specific standard areas.

		Whiting age 1		Whiting age 2		Cod age 1		Cod age 2	
Year	Quarter	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis	Skewness	Kurtosis
1991	1	5.20	34.30	3.90	18.17	6.09	45.26	3.28	13.02
	3	5.71	41.86	3.61	14.90	5.10	30.91	3.65	14.88
1992	1	3.32	13.11	4.32	19.40	5.38	36.87	2.11	4.05
	3	3.15	12.55	3.08	12.85	3.79	18.58	5.91	42.33
1993	1	5.20	32.52	3.86	19.16	5.86	35.92	1.97	4.25
	3	4.42	24.88	3.41	12.96	3.95	17.96	1.79	3.59
1994	1	5.14	31.62	4.08	18.79	8.50	85.58	3.92	18.16
	3	3.08	10.37	4.99	29.53	5.93	45.56	3.54	13.87
1995	1	3.19	10.68	6.77	56.99	4.85	29.32	4.63	27.62
	3	7.33	65.36	3.33	12.39	6.75	53.14	3.15	10.80
1996	1	5.87	44.46	4.25	21.57	5.31	36.44	4.41	26.76
	3	4.22	20.80	9.22	93.55	10.81	118.92	4.49	28.00
1997	1	5.69	43.65	5.31	32.91	10.38	115.93	6.12	43.84
	3				no data				

Table 5: 1st and 3rd quarter abundance indices, coefficients of variation and estimates of total mortality (Z, per year) for age 1 and 2 whiting based on log-transformed catches (CPUE + 1) from the standard area.

Whiting, 1st quarter

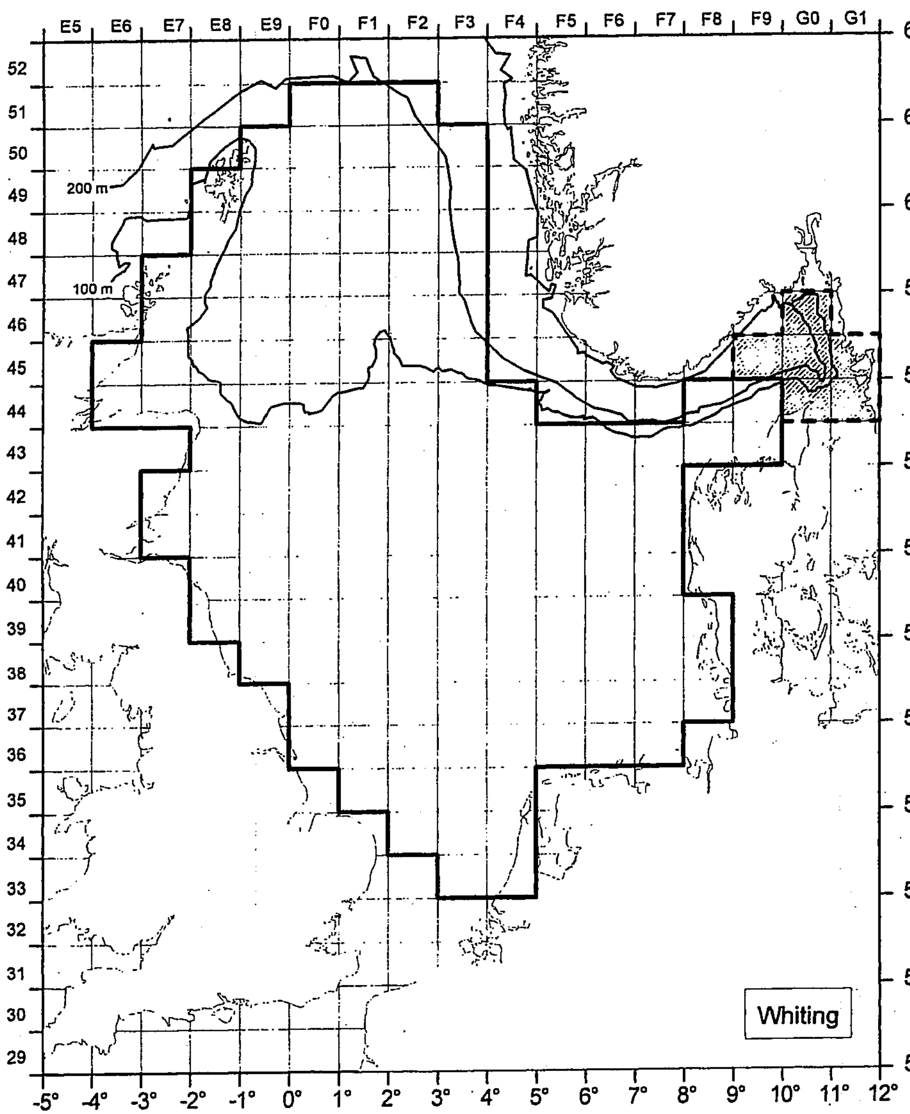
	Abundance index							Coefficient of variation						
Age \ Year	1991	1992	1993	1994	1995	1996	1997	1991	1992	1993	1994	1995	1996	1997
1	1909.35	1130.09	1387.74	992.55	898.16	809.39	368.57	10.81	3.30	8.58	8.47	4.76	9.18	4.28
2	1165.52	851.52	1155.90	1139.28	760.01	1116.22	628.19	9.67	7.57	15.90	24.71	12.12	24.66	23.27
Z	0.81	-0.02	0.20	0.27	-0.22	0.25								

Whiting, 3rd quarter

	Abundance index							Coefficient of variation						
Age \ Year	1991	1992	1993	1994	1995	1996	1997	1991	1992	1993	1994	1995	1996	1997
1	1444.45	1221.80	1481.21	2069.67	979.24	864.74	no	23.27	7.22	14.09	21.78	14.47	22.74	no
2	236.52	540.34	223.34	323.49	428.87	283.07	data	5.56	5.31	5.25	6.62	8.87	11.11	data
Z	0.98	1.70	1.52	1.57	1.24									

Table 6: Correlation (r^2) between VPA and IBTS abundance indices based on log-transformed catches, 1991-1996.

	Whiting, standard area			
Index	age 1		age 2	
1st quarter	0.13	(n.s.)	0.24	(n.s.)
3rd quarter	0.48	(n.s.)	0.23	(n.s.)



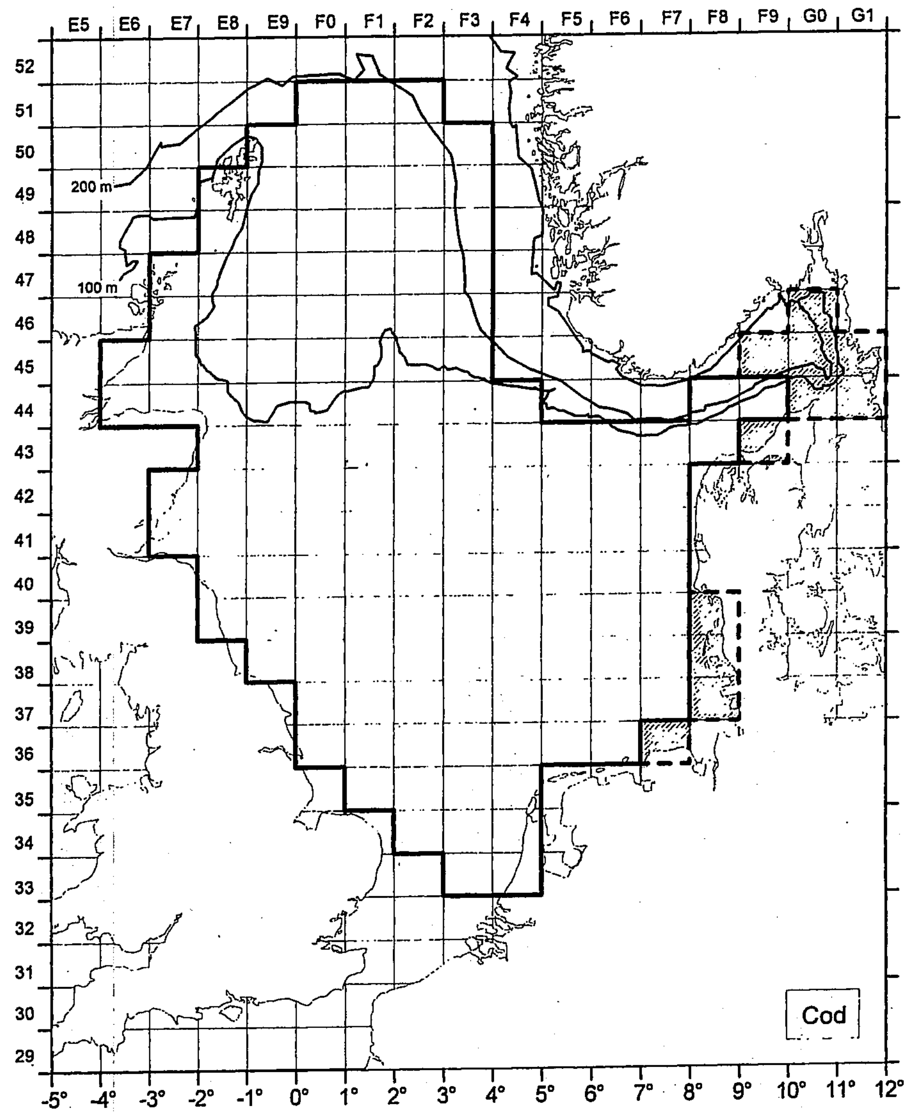


Figure 1: IBTS standard areas (bounded by solid lines) for whiting and cod and extended areas (shaded, bounded by dashed lines) used for the calculation of abundance indices.

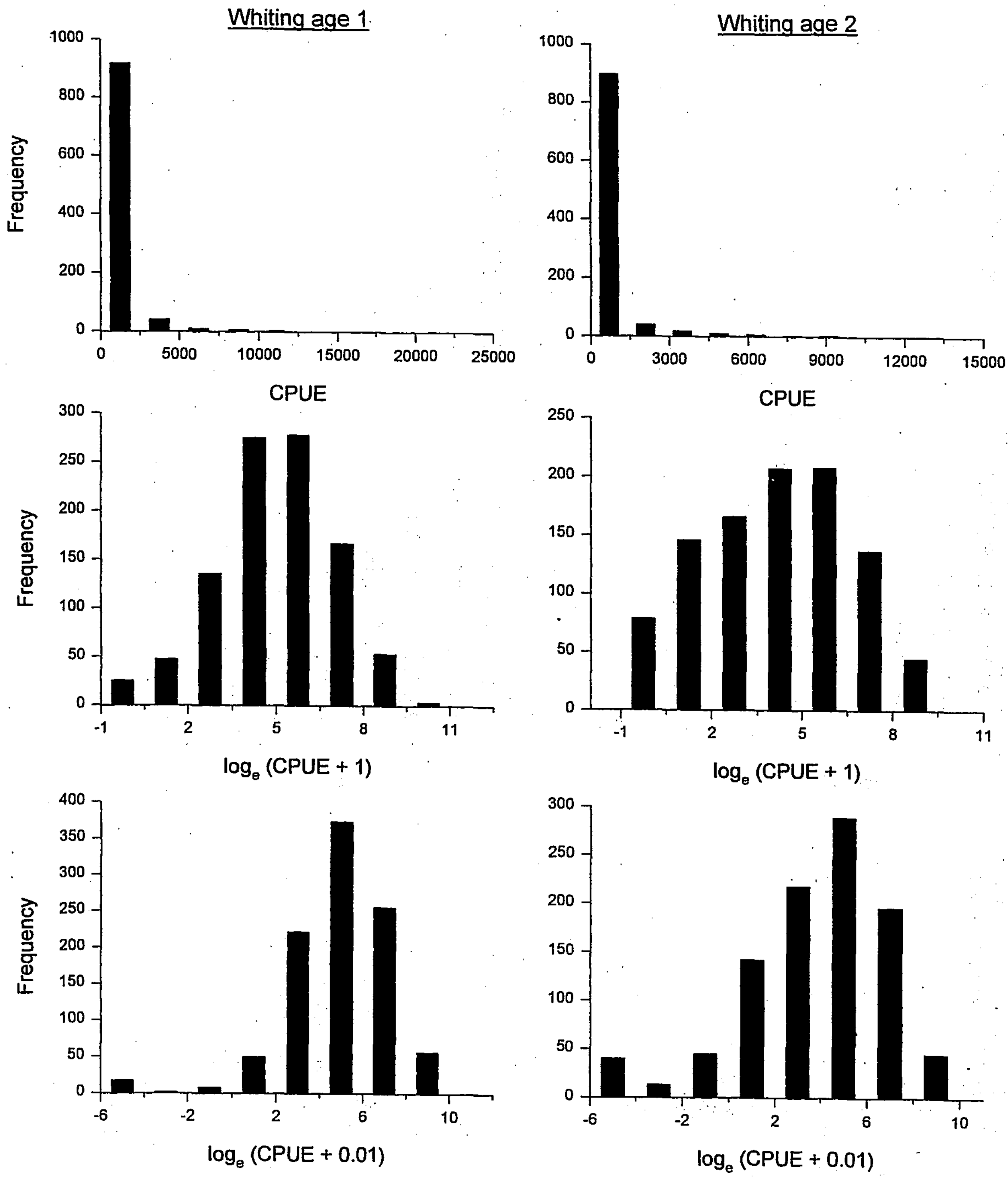


Figure 2: Frequency distributions of whiting catches (average CPUE by square) in the 1st quarter IBTS 1991-1997 (standard area).

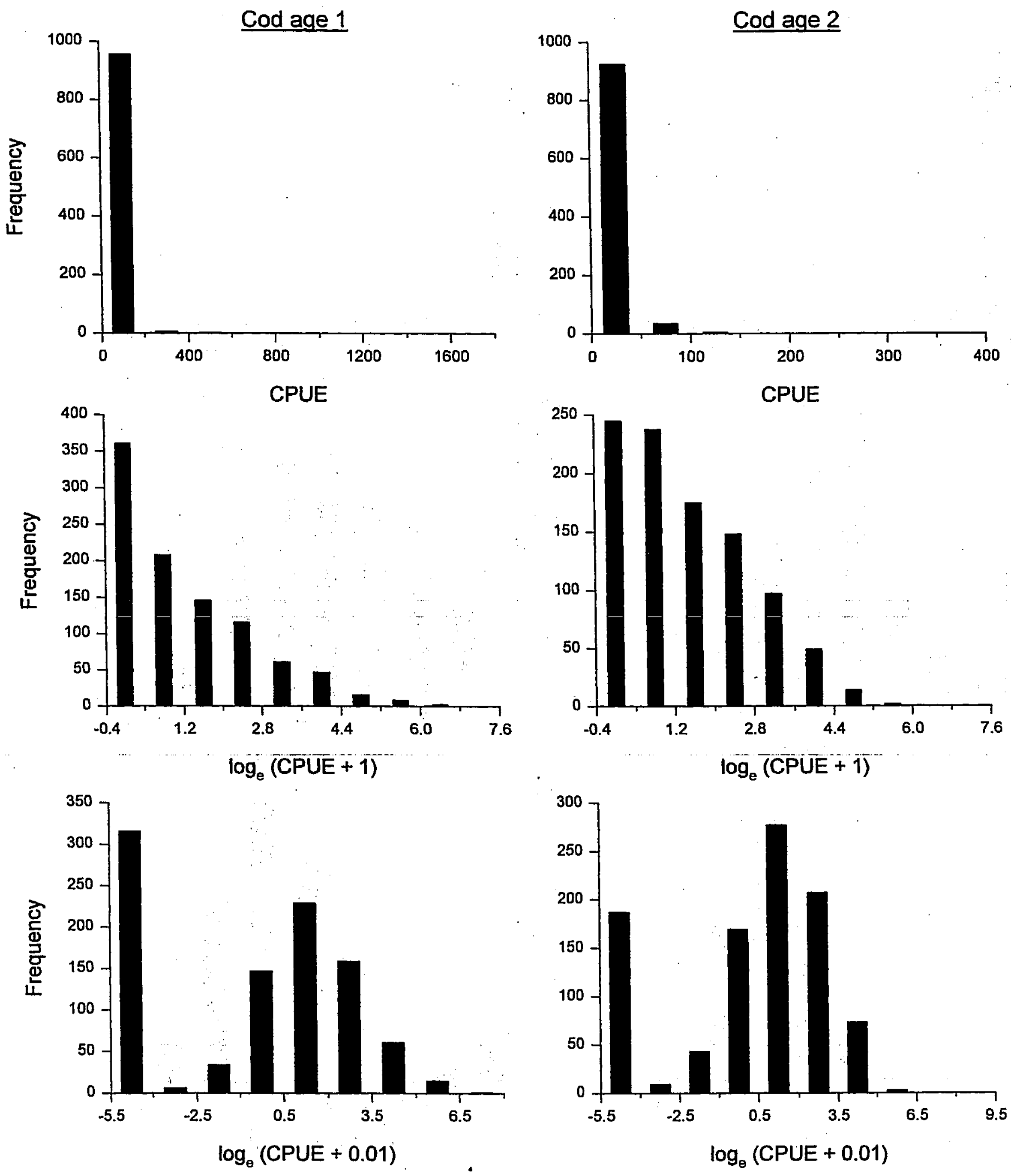


Figure 3: Frequency distributions of cod catches (average CPUE by square) in the 1st quarter IBTS 1991-1997 (standard area).

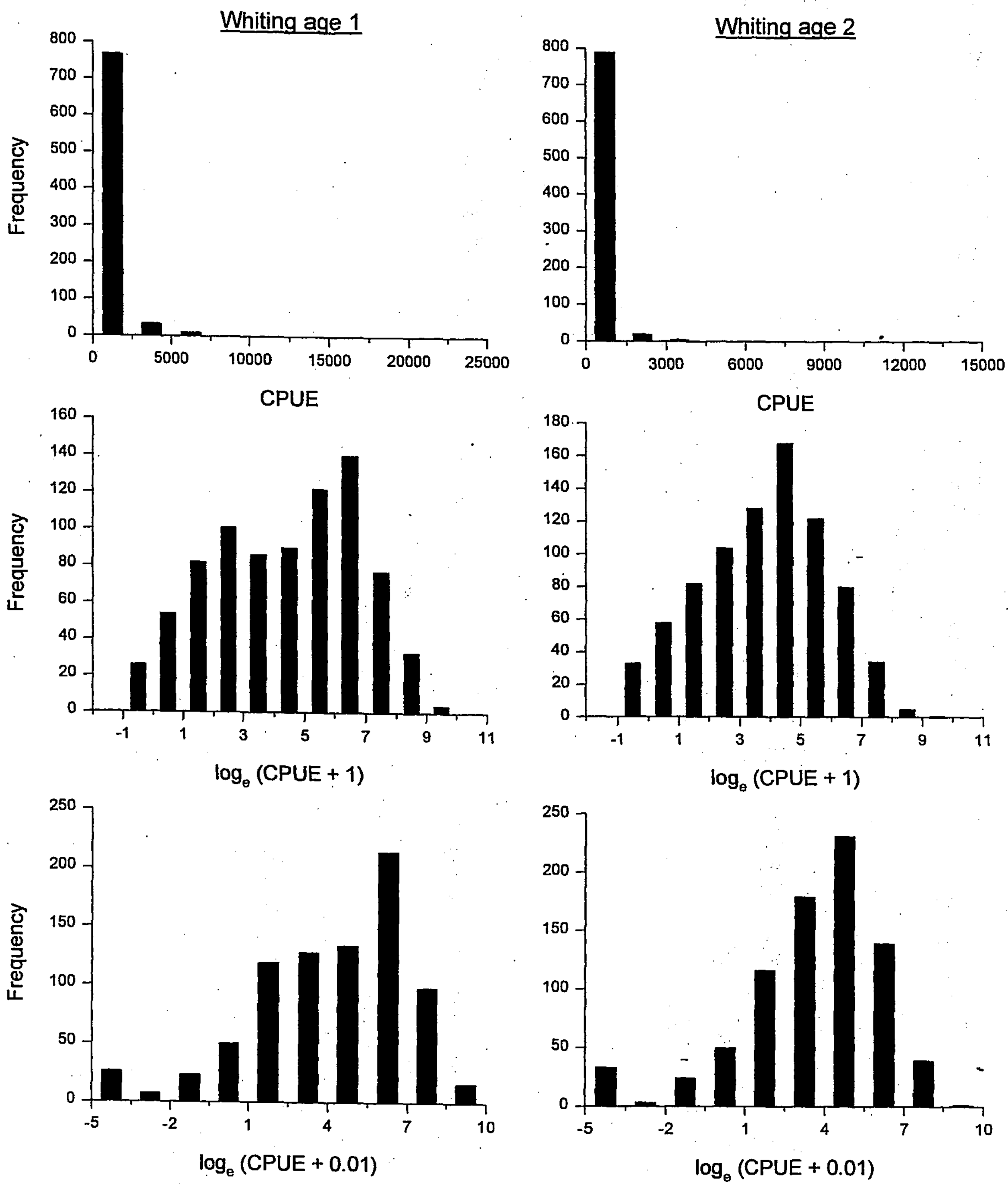


Figure 4: Frequency distributions of whiting catches (average CPUE by square) in the 3[rd] quarter IBTS 1991-1996 (standard area).

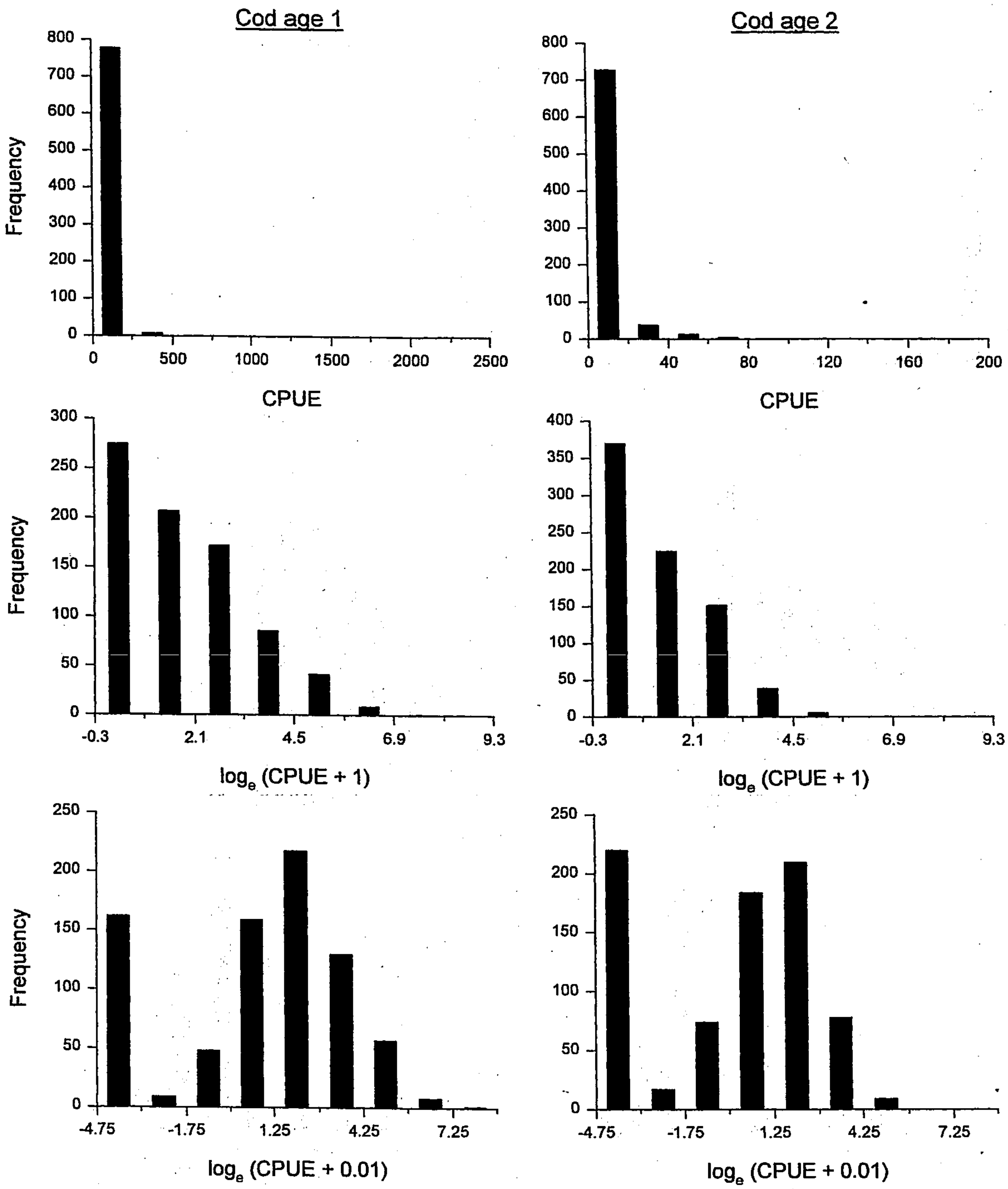


Figure 5: Frequency distributions of cod catches (average CPUE by square) in the 3rd quarter IBTS 1991-1996 (standard area).

Spatial structures in the distribution of age 2 whiting in the North Sea – a geostatistical analysis of the 1st quarter IBTS data 1991-1996

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Introduction

Geostatistics makes it posssible to consider explicitly the spatial structures in fishery survey data and may therefore lead to a more realistic estimation of abundance indices than classical methods. Recent years have seen increasing interest in the application of spatial statistics to fisheries data in particular for analysing hydroacoustic surveys (e.g. Petitgas 1993). However, in practice these techniques have not been generally used. This is due, in part, to the skewed density distributions often encountered in surveys of fish abundance that leads to poor estimation of the underlying spatial structure and low confidence in subsequent modelling (Maravelias et al. 1996).

In the geostatistical approach, the first thing is to look at the spatial structure of the data. The spatial structure is often described by the variogram, which measures the half mean variability γ between two points x and x+h as a function of their distance h. This so-called experimental (or empirical) variogram is first computed on the data and then a variogram model is fitted. The model is afterwards used for linear interpolation using kriging in order to map (contour plots) and to estimate stock abundance in a specified area.

The estimation of the variogram is widely regarded as the most critical step in a geostatistical analysis (Cressie 1993). Hence, at first different methods of calculating experimental variograms were tested. Subsequently, distribution maps and global abundance estimates for a predefined area, the domain, were derived using ordinary kriging (Cressie 1993).

Material and Methods

Standardized catches (in number per hour trawling, n/hr) of age 2 whiting by sampling location from the 1st quarter IBTS were analysed. The data set was obtained from the ICES IBTS database. The domain was specified as the IBTS standard area for whiting with an extension towards the eastern Skaggerrak (Fig. 1). Within that area the number of observations ranged between 382 (in 1991) and 286 (in 1996). Sampling positions were converted into decimal units, and the reference latitude for a transformation of longitudes as required to obtain Euclidean distances for the calculation of a variogram was 56.75 (average latitude of the domain):

transformed longitude = decimal longitude * cos (56.75).

Experimental variograms were computed using three different approaches: the classical method (Matheron 1963), the robust method (Cressie & Hawkins 1980) and the use of the noncentered covariance

(Guiblin et al. 1995). The same options were applied in all cases, i.e. concerning number of lags (= 20) and the lag increment (= 10 nautical miles, nm). Compared to the classical approach, the robust method reduces the effect of extreme values without removing specific data points from the data set. The use of the noncentered covariance enables a better characterisation of the spatial structure when the correlation range is small and the data set contains many zero and a few high values.

Experimental variograms were further computed with an increased lag increment (15 nm) with the classical method by direct estimation and by backtransformed log data using the formula from Guiblin et al. (1995):

Data transform $y = \ln(x/m + 1)$ where m is the mean of the observations

Log variogram $\gamma_{ij} = (y_i - y_{i+j})^2 / (2n_j)$

Back transformed variogram $\gamma = (4m^2 + \sigma_x^2)(1 - \exp(-(\sigma_c^2(\gamma_{ij}/\sigma_y^2)))$

with: $\sigma_c^2 = \ln(1 + \sigma_x^2 / (4m^2))$.

The use of backtransformed log data has been proven to reduce the fluctuations in the variogram, which allows an improved estimation of the variogram model in the case of highly skewed density distributions (Fernandes 1996, Simmonds 1996).

The classical and the robust variograms were computed using the S+ SPATIALSTATS software module (Mathsoft 1996). For the noncentered covariance estimator, which is not available in S+ SPATIALSTATS, the EVA2 program (Petitgas & Lafont 1997) was used. The variograms were fitted in S+ by applying spherical models using weighted nonlinear least squares as recommended by Cressie (1985). EVA2 allows visual fitting but does not contain such a least squares procedure, and thus the values from the noncentered covariance variograms were exported to S+ for fitting.

Distributional maps were produced by ordinary kriging based on the appropriate variogram model with a resolution of 7.5 nm using SURFER (Golden Software 1995). Estimates of mean abundance were then obtained as the volume given by the kriged surface and the zero level divided by the area of the domain. These values were compared with the simple arithmetic mean of the original data and the IBTS standard index.

Results and Discussion

Postplots of whiting age 2 density in the 1st quarter IBTS 1991 to 1996 are given in Figure 2. The number of hauls in the area under consideration decreased throughout the years from 382 in 1991 to 286 in 1996 and the number of zero catches ranged between 7 in 1992 and 39 in 1994. High numbers of whiting age 2 were found regularly in the western North Sea, both north-east off Scotland and east off England. High catches were also found in the German Bight in two years (1991 and 1992), but not in the Skagerrak.

Figures 3a to 3d compare omnidirectional variograms for age 2 whiting in the study period computed with different methods using a lag increment of 10 nm. With the lag of 10 nm the number of pairs in the smallest distance interval was always above 30 which is considered as a practical threshold level (Journel & Huijbregts 1978). The obtained results, however, were highly variable. The classical variograms indicate spatial autocorrelation for 1991 and 1995 but little (1992, 1996) or no (1993, 1994) spatial pattern for the other years. The robust variograms either had a long spherical range or increased steadily. The latter may indicate the presence of a large-scale trend or a nonstationary underlying stochastic process. The robust method, however, downweights the high values to an extent that was not appropriate in the present case because high catches can be regarded as valid data and not as pure measurement errors. Except for 1992, the noncentered covariance variograms were basically flat indicating little or no autocorrelation. However, the use of the noncentered covariance is based on stronger hypotheses, in particular stationarity of the variable, than the previous two methods. The stationarity condition was obviously not met here and it thus must be concluded that the noncentered covariance variograms did not describe the data adequately.

Omnidirectional variograms for age 2 whiting in the 1st quarter IBTS 1991 to 1996, computed with the classical method using an increased lag increment of 15 nm (instead of 10 nm) are shown in Figure 4. They revealed some consistency between the years, and spherical models could be fitted in all cases. Corresponding log backtransformed variograms are given in Figure 5. The use of backtransformed log data did not change the general structure, but substantially reduced the fluctuation within the various variograms and the total sill (sill + nugget in Tab. 1) became close to the sample variance in all cases. Furthermore, the values for the range (distance at which the data are not longer autocorrelated) and the nugget (micro-scale variation and/or measurement error) were smaller than those derived from the untransformed data (Tab. 1).

Kriged maps on the distribution of age 2 whiting that were produced with the parameters of the log backtransformed variograms (Tab. 1) are given in Figures 6a to 6f for the years 1991 to 1996, respectively. The maps gave a more appropriate and clearer overview of the distribution of the fish density than the postplots (Fig. 2). Areas of high fish density were always found south from the Shetland Isles and east off the English coast, but the location of maximum density varied between the two areas in the different years. The German Bight and the Skagerrak were much less important, and in the central North Sea the density of age 2 whiting was low in all years.

Estimates of mean abundance of age 2 whiting derived from the geostatistical analysis were higher than the arithmetic means in all years except for 1992 (Tab. 2), where a few exceptionally high catches occurred in a restricted area (Fig. 2). The geostatistical means were similar to the IBTS standard indices in general except for one year (1992) in which the difference between the both was more pronounced (Tab. 2). The correspondence with assessment results was considerably closer for the geostatistical means than for the arithmetic means. However, they did not correlate better with the assessment than the IBTS standard index (Tab. 2).

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Table 1: Sample variance and variogram parameters (spherical model) for age 2 whiting. 1st quarter IBTS 1991-1996. Experimental variograms estimated using the classical method. Lag: 15 nm.

	Sample	Direct estimation			Backtransformed log data		
Year	variance	Range (nm)	Sill	Nugget	Range (nm)	Sill	Nugget
1991	3.27E+06	163	8.50E+05	2.69E+06	143	1.06E+06	2.35E+06
1992	4.59E+06	168	1.33E+06	3.26E+06	175	1.51E+06	3.22E+06
1993	1.99E+06	144	5.86E+06	1.14E+06	215	1.23E+06	8.16E+05
1994	4.73E+06	231	2.08E+06	3.33E+06	189	1.78E+06	3.12E+06
1995	1.44E+06	219	7.06E+06	9.44E+05	174	7.08E+05	8.01E+05
1996	1.87E+06	187	7.63E+05	1.16E+06	180	8.38E+05	1.08E+06

Table 2: Mean density (n/hr) of whiting age 2, 1st quarter IBTS 1991 - 1991.
r^2: correlation with assessment results (ICES 1998).

Year	Arithmetic mean	Geostatistical mean	IBTS standard index
1991	601.76	716.90	686.43
1992	819.24	758.63	648.06
1993	489.16	564.88	523.67
1994	631.41	697.08	638.63
1995	405.07	456.11	437.65
1996	472.67	518.73	485.97
r^2	0.0067	0.0357	0.0437

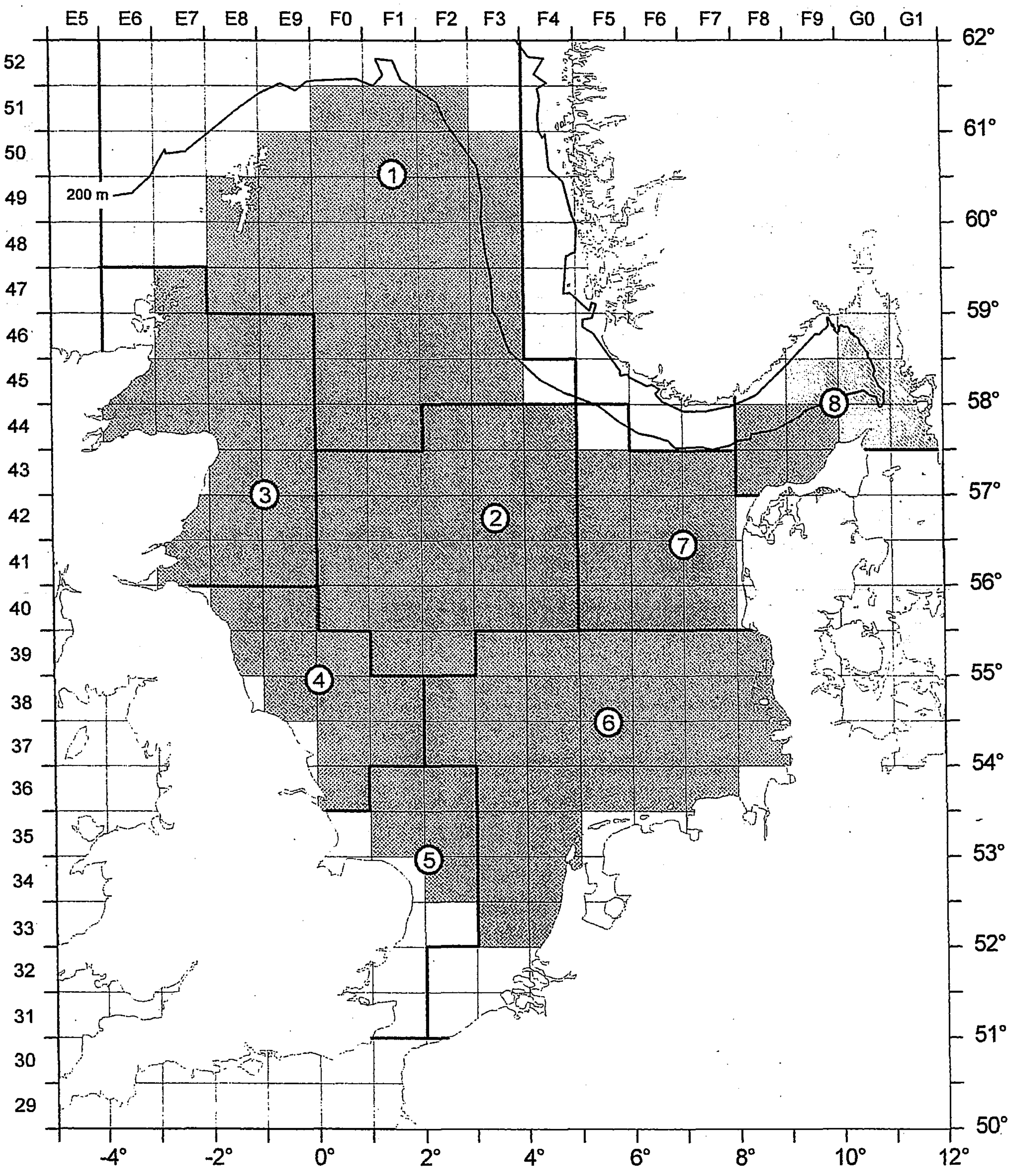

Figure 1: ICES statistical rectangles and roundfish sampling areas in the North Sea.

IBTS standard area for whiting

extended area

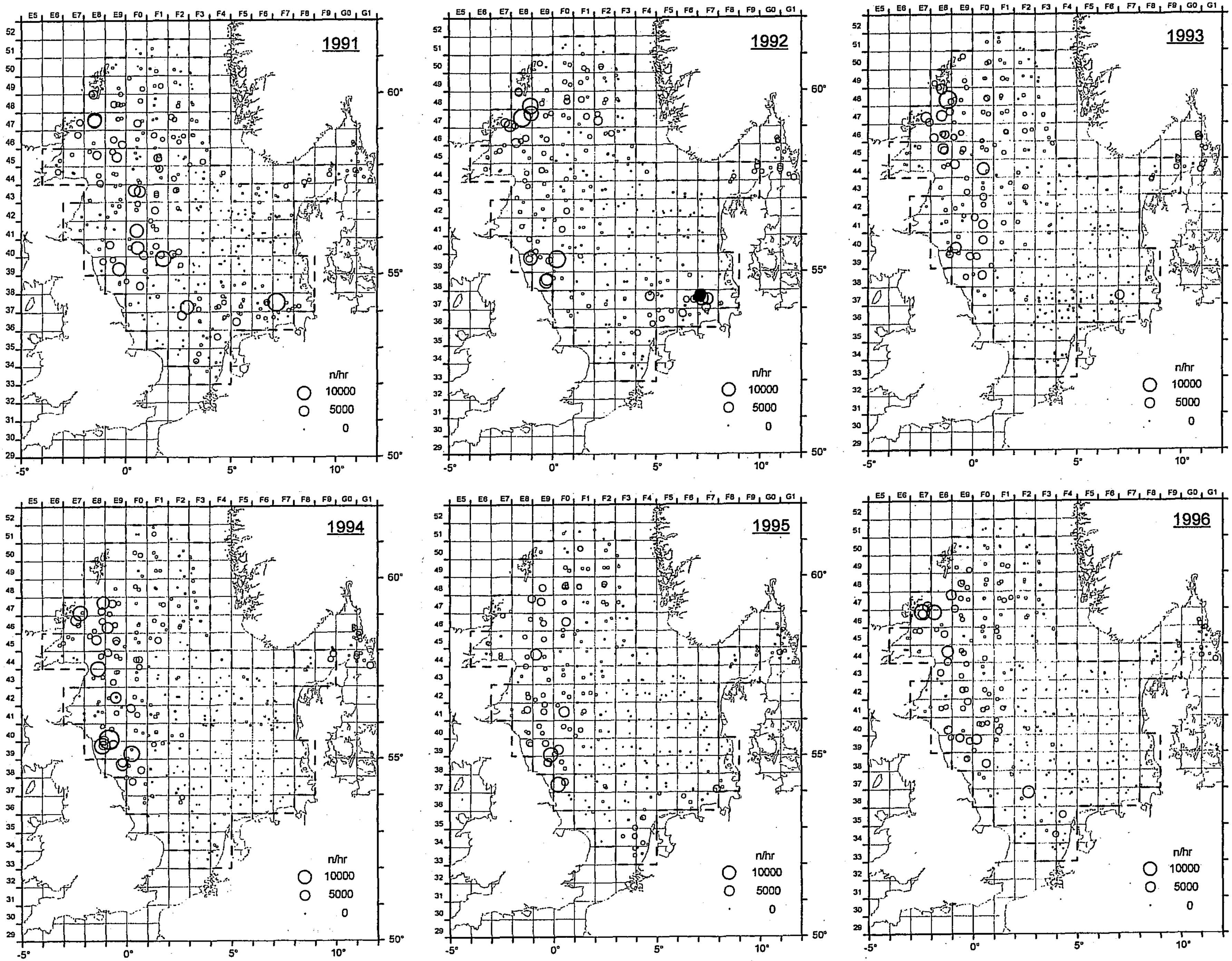

Figure 2: Postplots of catches (n/hr) of age 2 whiting in the 1st quarter IBTS 1991-1996. Dased lines: IBTS standard area for whiting.

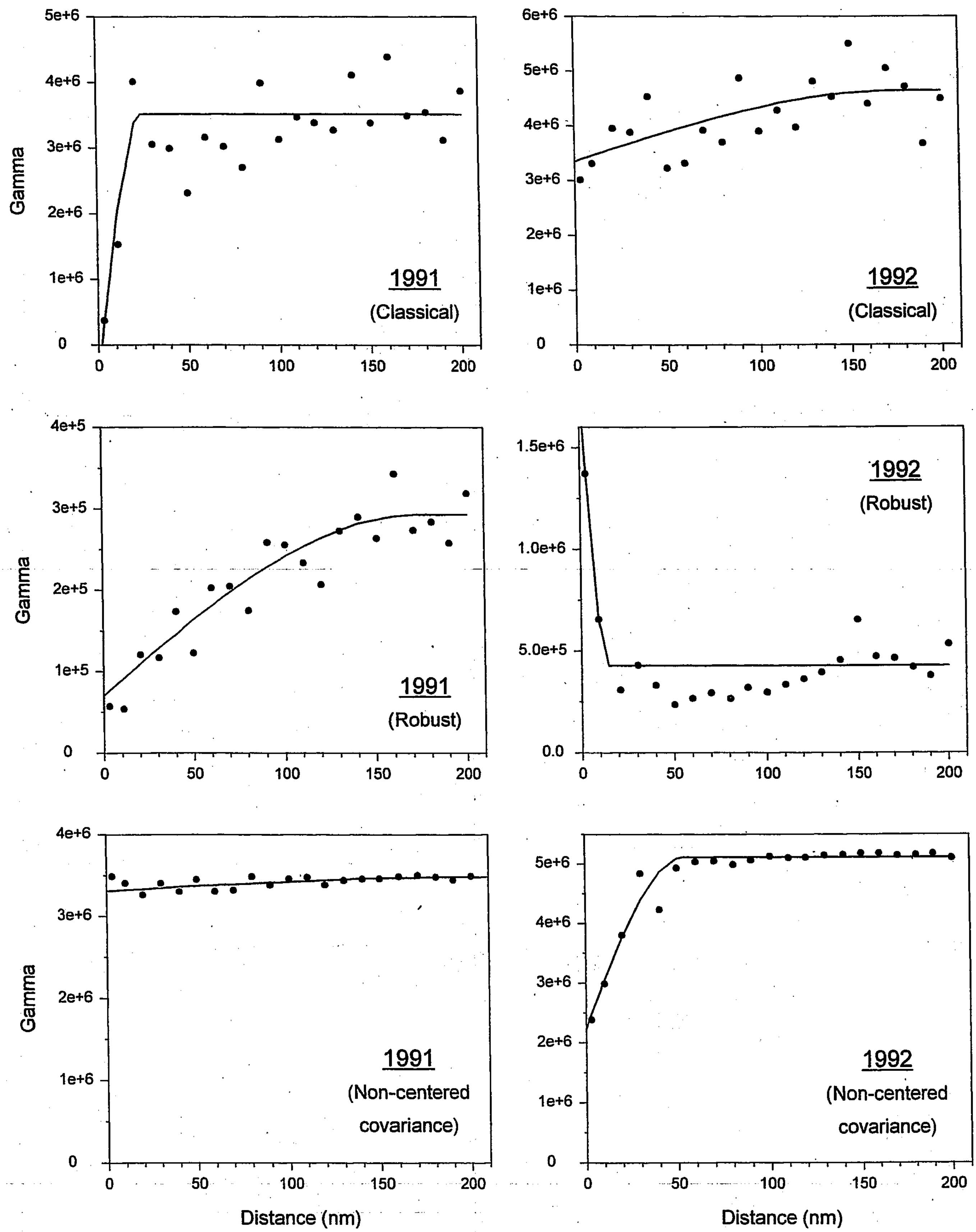

Figure 3a: Omnidirectional variograms for whiting age 2. 1st quarter IBTS 1991 and 1992. Lag: 10 nm. Solid lines fitted by weighted nonlinear least squares (spherical model).

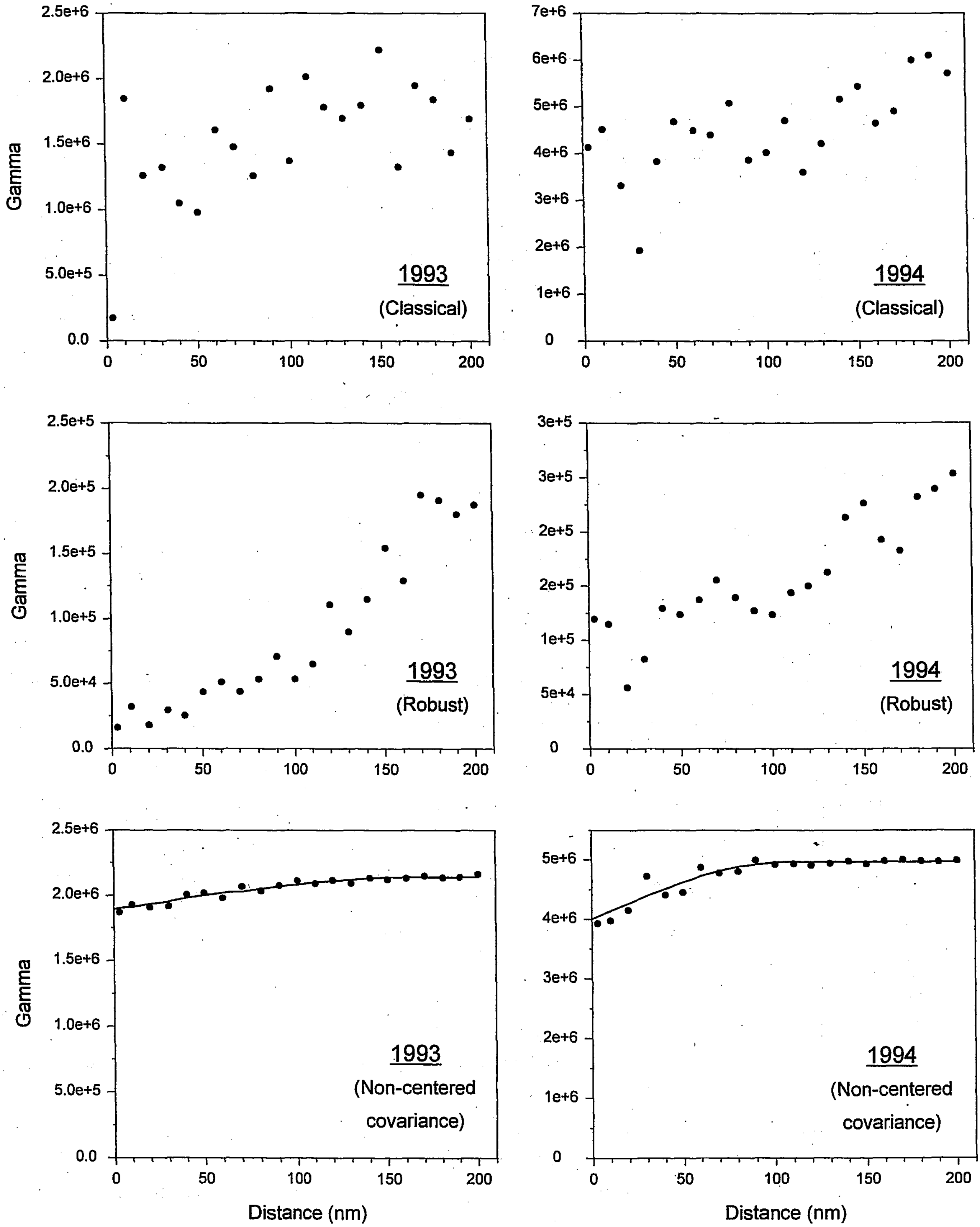

Figure 3b: Omnidirectional variograms for whiting age 2. 1st quarter IBTS 1993 and 1994. Lag: 10 nm. Solid lines fitted by weighted nonlinear least squares (spherical model).

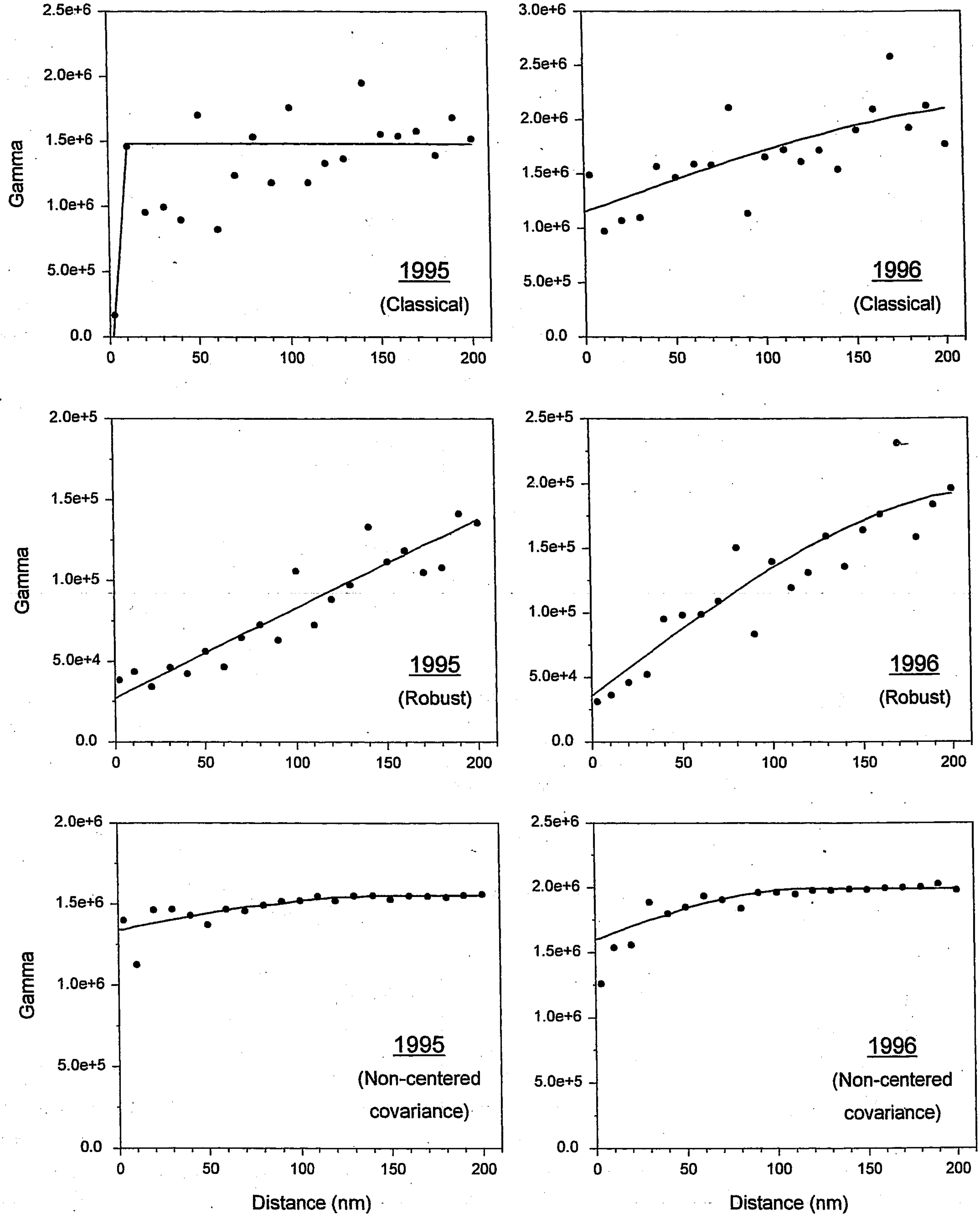

Figure 3c: Omnidirectional variograms for whiting age 2. 1st quarter IBTS 1995 and 1996. Lag: 10 nm. Solid lines fitted by weighted nonlinear least squares (spherical model).

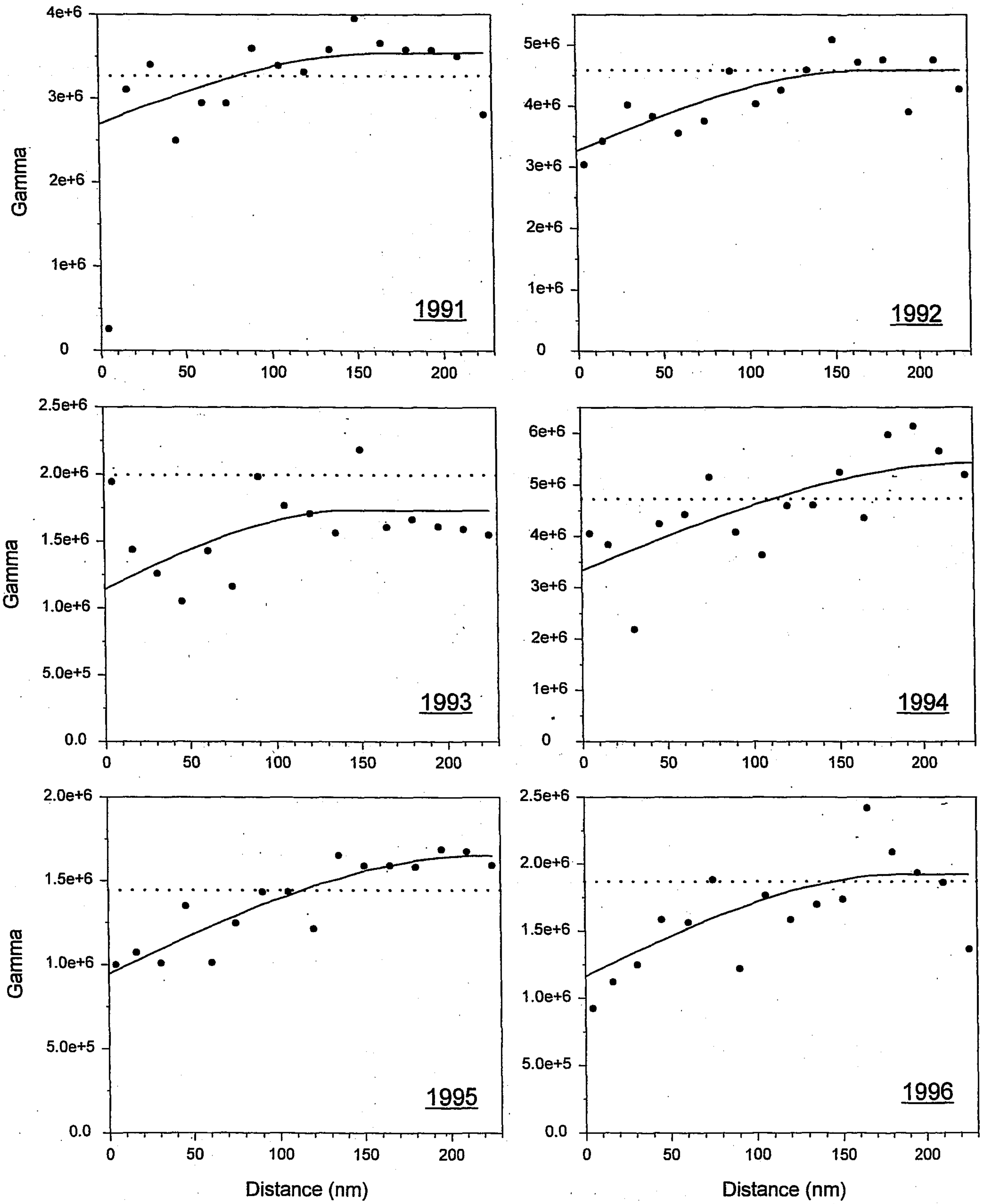

Figure 4: Omnidirectional variograms for whiting age 2. 1st quarter IBTS 1991 to 1996. Lag: 15 nm. Experimental variograms estimated using the classical method. Solid lines fitted by weighted nonlinear least squares (spherical model). Dotted lines: sample variance.

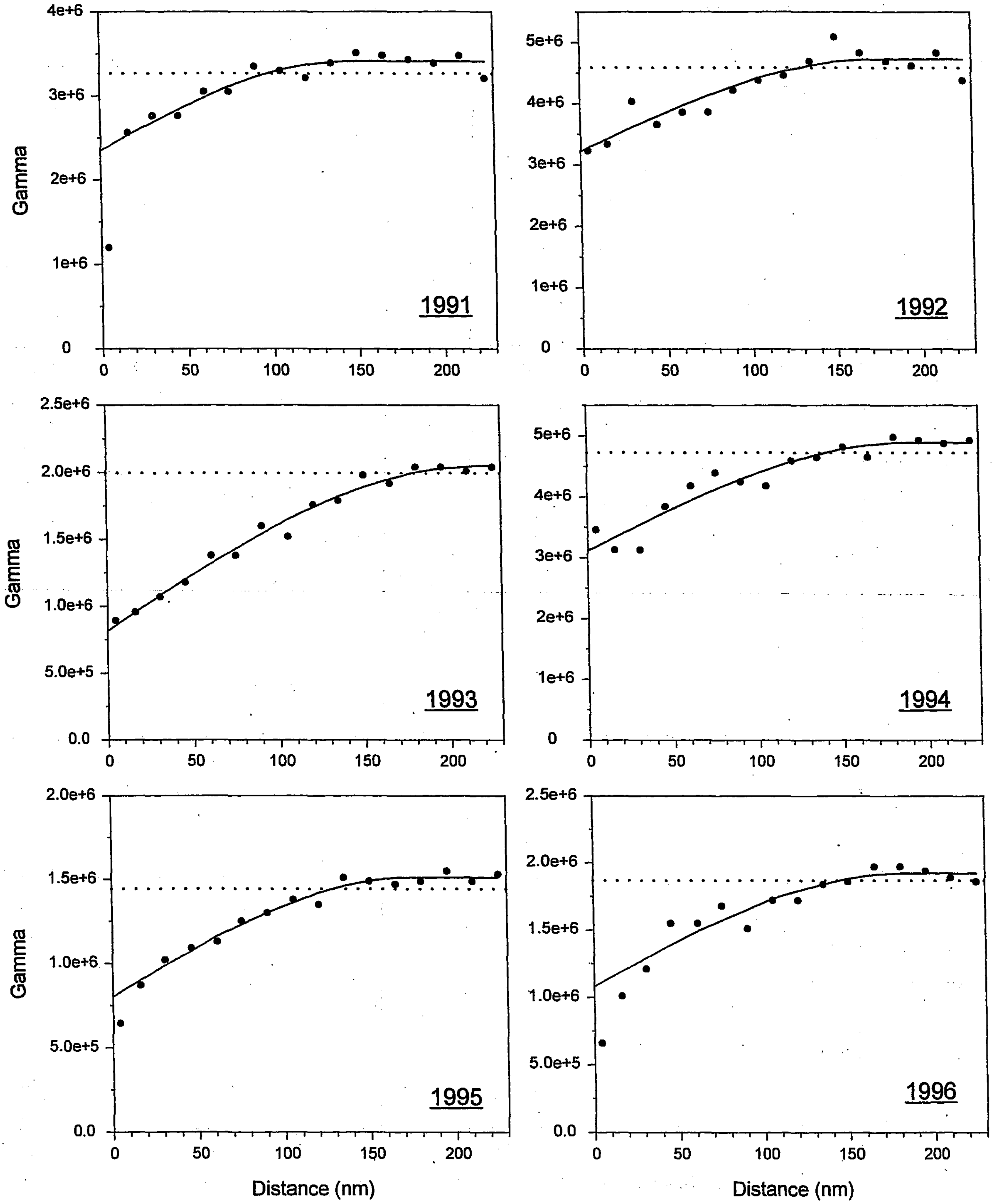

Figure 5: Omnidirectional variograms for whiting age 2. 1st quarter IBTS 1991 to 1996. Lag: 15 nm. Experimental variograms estimated using the classical method with back-transformed log data. Solid lines fitted by weighted nonlinear least squares (spherical model). Dotted lines: sample variance.

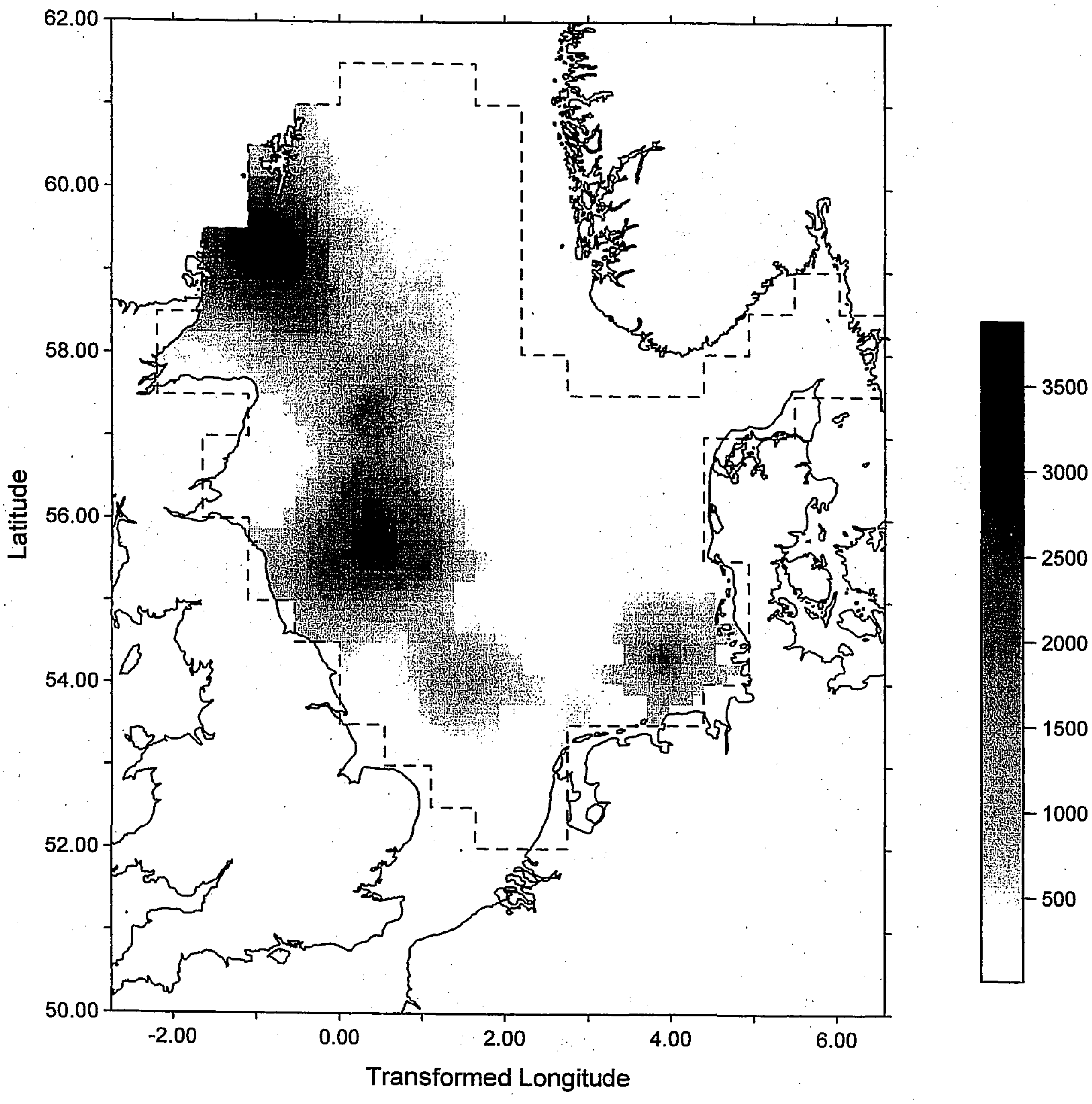

Figure 6a: Kriged map of whiting age 2 density (n/hr) 1st quarter IBTS 1991. Resolution: 7.5 nm.

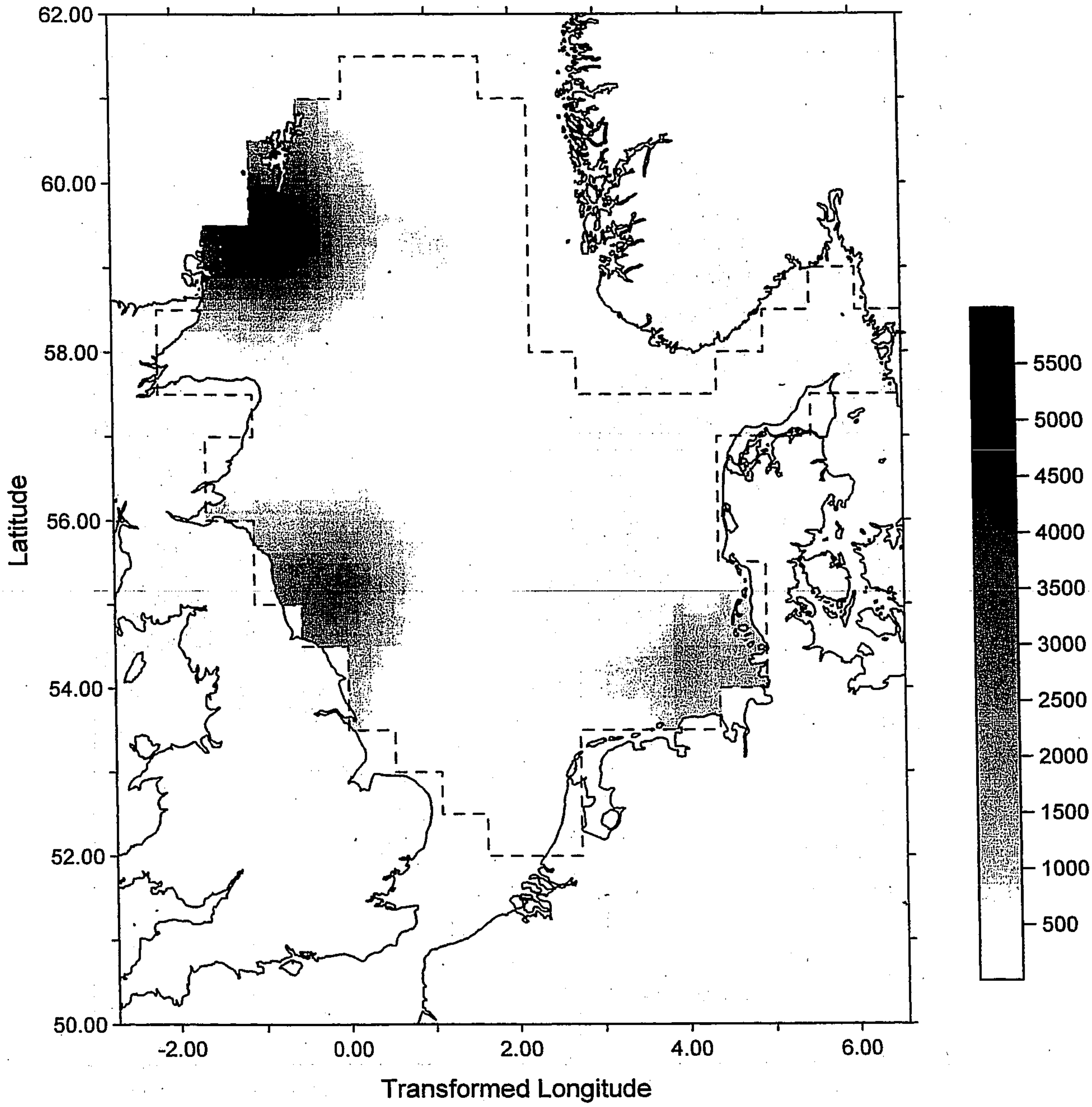

Figure 6b: Kriged map of whiting age 2 density (n/hr) 1st quarter IBTS 1992. Resolution: 7.5 nm

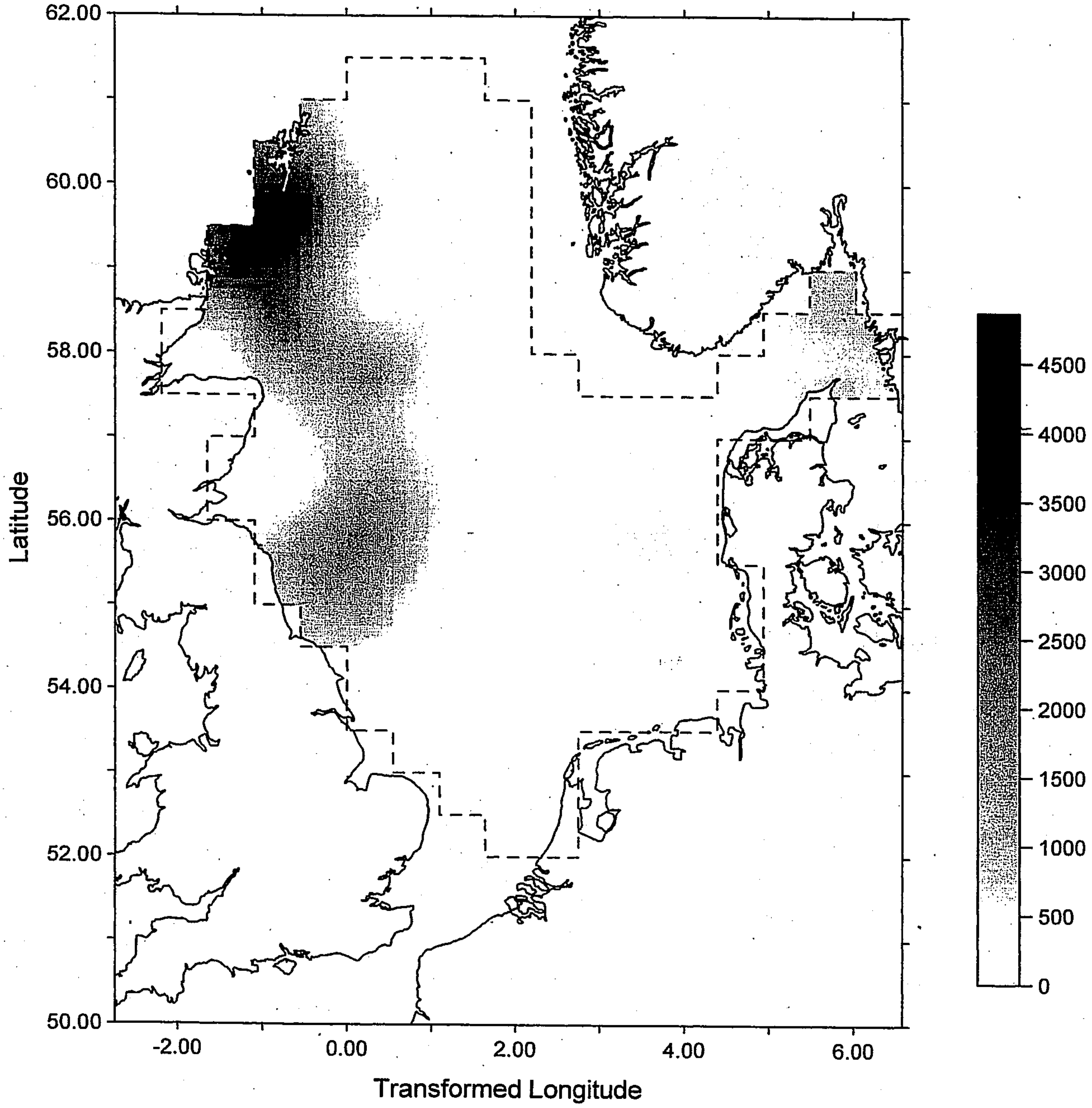

Figure 6c: Kriged map of whiting age 2 density (n/hr) 1st quarter IBTS 1993. Resolution: 7.5 nm.

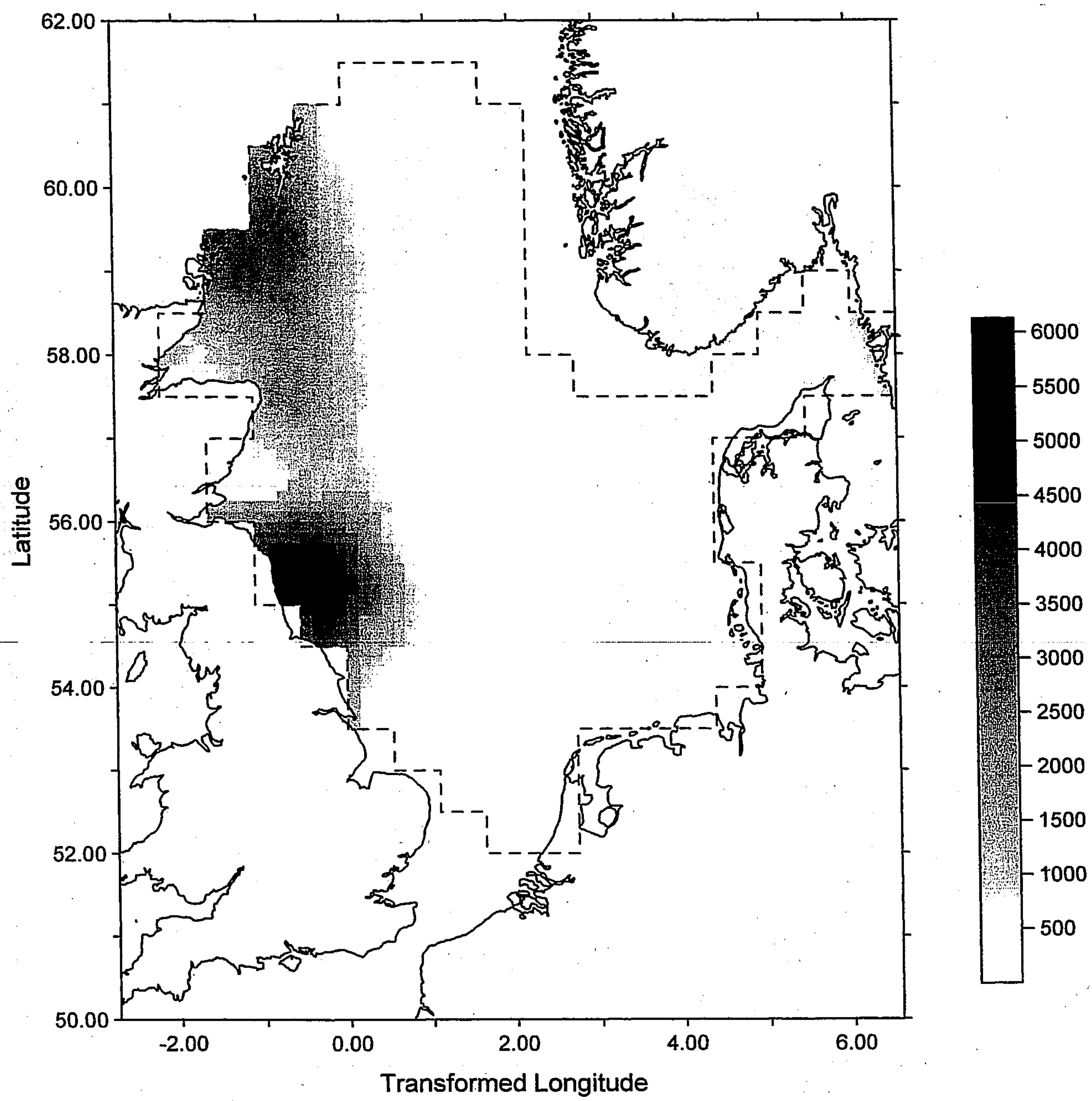

Figure 6d: Kriged map of whiting age 2 density (n/hr) 1st quarter IBTS 1994. Resolution: 7.5 nm.

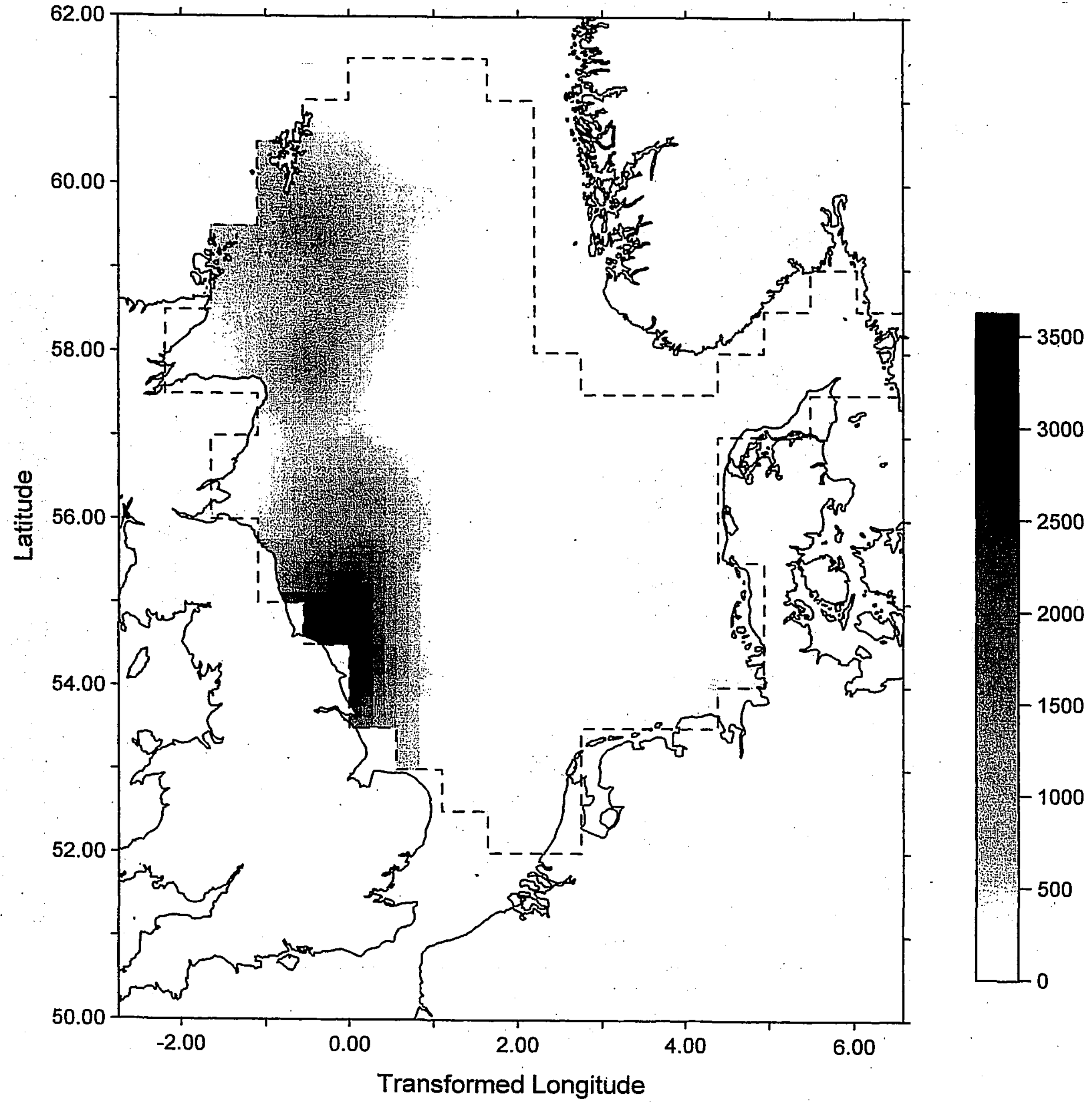

Figure 6e: Kriged map of whiting age 2 density (n/hr) 1st quarter IBTS 1995. Resolution: 7.5 nm.

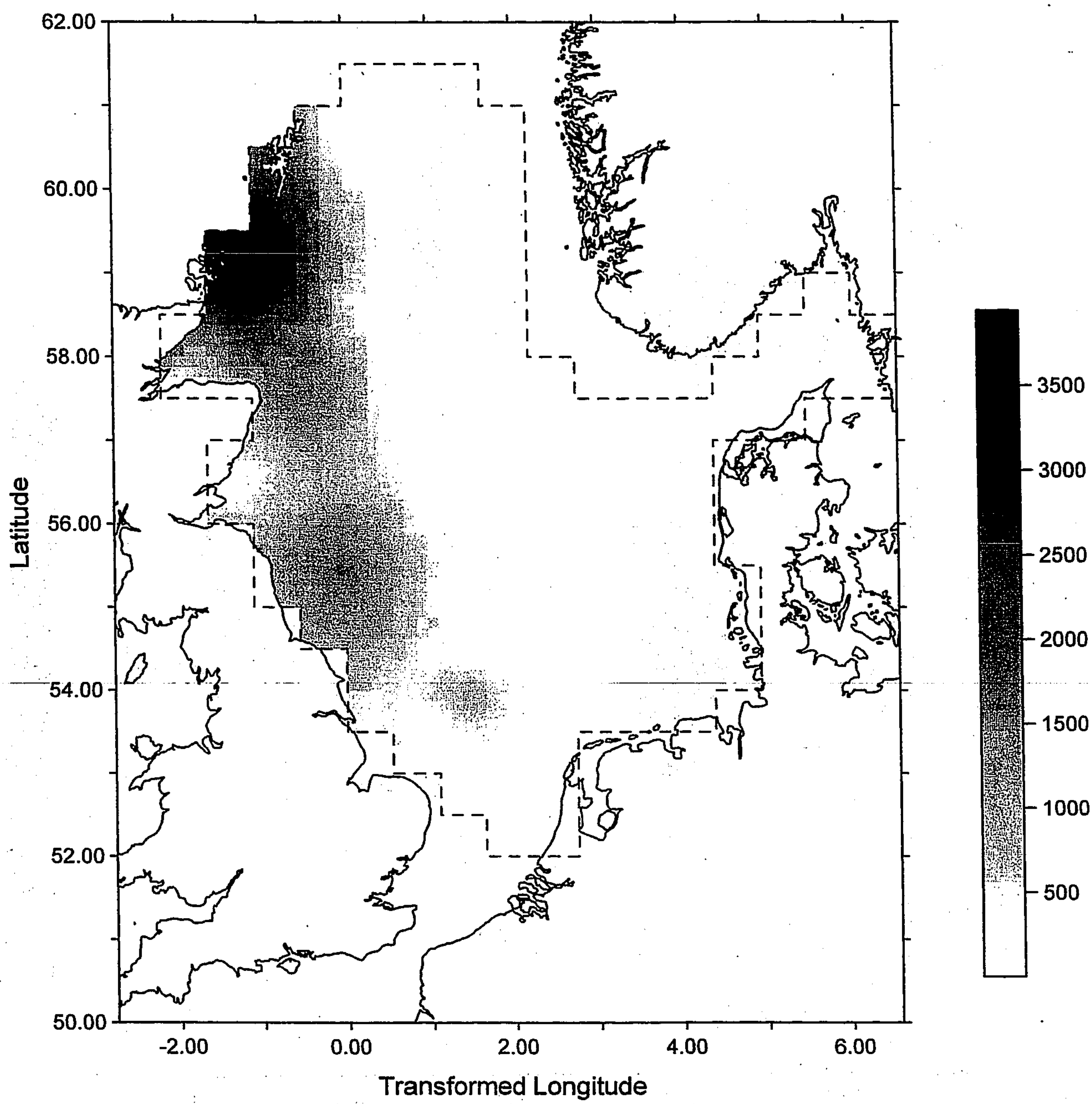

Figure 6f: Kriged map of whiting age 2 density (n/hr) 1st quarter IBTS 1996. Resolution: 7.5 nm.