INTERNATIONAL COUNCIL FOR
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Pelagic Fish Committee

COMBINATION OF HERRING LARVAL ABUNDANCE ESTIMATES OF THE DIFFERENT NORTH SEA AREAS INTO A SINGLE SPAWNING STOCK INDEX

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ABSTRACT

The International Herring Larval Surveys produce separate abundance indices for each of the North Sea subpopulations, while Virtual Population Analysis (VPA) only produces reliable stock biomass estimates for the North Sea as a unit. In order to allow the calibration of larval abundance against VPA spawning stock size estimates, the ICES Herring Assessment Working Group have carried out separate VPA's for each of the subpopulations. But, because the catches used in these VPA's are of mixed origin, this solution might lead to misleading spawning stock size projections.

An alternative solution, firstly proposed by Corten (1978, 1980), is to combine the herring larval abundance indices of the various spawning areas into overall figures for the North Sea, and to compare these values to the VPA estimates of total North Sea stock size.

This paper gives the results of the comparison between North Sea VPA spawning stock estimates and combined larval indices for the years 1972 to 1983. Length categories of <10 and 10-15mm (<11 and 11-16mm in the southern North Sea area) have been used to calculate two different larval abundance indices.

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INTRODUCTION

The aim of the Herring Larval Surveys programme is to provide adequate larval abundance figures in order to obtain fishery independent estimates of the spawning stock size. In spite of the fact that herring larval abundance data are available since 1967 and in some North Sea areas since 1955, appropriate annual indices are only obtainable from 1972 onwards (ANON., 1977a).

Herring Larval Surveys not only provide information about the total abundance of larvae per haul, but also the length frequency distribution of the captured larvae. The abundance per square metre is summarised in three length categories: <10, 10-15 and >15mm. Different categories are used in the southern North Sea area (<11, 11-16 and >16mm) to account for the large size of these larvae at the moment of hatching.

The main procedure used to obtain larval abundance indices has been to integrate the abundance of the smallest size category in depth, space and time. Sampling standard areas and periods are defined in Anon., 1985b. An individual annual index is obtained for each of the North Sea spawning areas: northern (Orkney-Shetland), central (Bank) and southern (Downs) North Sea.

The ICES Herring Assessment Working Group until 1985 only used the smallest size category of herring larvae for stock assessment purposes because larval abundance in the earliest stages is less influenced by mortality and migration. However, the choice of this category has the disadvantage of increasing sampling errors because of the patchy distribution of larvae during the earliest stages. If the medium sized larval category is considered, sampling errors will be reduced but on the other hand, the risk of including a given cohort more than once in the larval abundance index will increase (CHRISTENSEN, 1985).

Because mortality during the earliest stages is unknown, larval indices can only be used as a relative index of spawning stock size. For obtaining an absolute estimate of stock abundance from larval indices, the latter must be calibrated against independent estimates of spawning stock size, for example the Virtual Population Analysis (VPA) spawning stock estimates. But Herring Larval Surveys produce separate indices for each of the North Sea subpopulations, while VPA only produces reliable stock biomass estimates for the North Sea stock as a unit. To overcome this problem, separate VPAs have been carried out for each of the individual subpopulations using the catch data for Division IVa as referring to the Shetland-Buchan spawning stock, the catch data for Division IVb as referring to the Bank spawning stock, and the catch data from Divisions IVc and VIId and e, as referring to the Downs stock (ANON., 1977b). The ICES Herring Assessment Working Group adopted this solution although it was realized that the catches used in these VPAs are of mixed origin. A major part of the catch is taken outside the spawning season, when the various subpopulations have mixed. But it was thought that the error due to this was small.

Because of the poor fit of the VPA spawning stock estimates - <10mm larval abundance regressions in most areas (ANON, 1986a), new methods for calculating adequate indices of spawning size from larval surveys have been propposed (ANON., 1986a; BURD, 1985; CHRISTENSEN, 1985; LASSEN & PEDERSEN, 1985). Utilizing the length frequency distribution of herring larvae, they try to correct for the loss of larvae due to mortality and emigration. Not much attention has been paid to the degree of reliability of the separate VPA spawning stock estimates, to explain the lack of correlations.

In order to avoid the use of separate VPAs, Corten (1978, 1980) combined larval production estimates of the various spawning areas into one overall figure for the North Sea and compared the total larval production to the VPA spawning stock size estimates of the total North Sea stock.

The present report gives the results of the comparison between North Sea VPA spawning stock estimates and combined larval indices for the years 1972 to 1983, considering the North Sea herring population as a single unit. Few modifications have been done to the procedure proposed by Corten (1978, 1980). Length categories of <10mm and 10-15mm (<11 and 11-16mm in the southern North Sea area) have been used to calculate two different larval indices.

MATERIALS AND METHODS

Herring Larval Survey data were supplied on magnetic tape by the Marine Laboratory, Aberdeen, Scotland. Methodology of Herring Larval Surveys is described in Anon., 1985a.

- <u>Calculation of larval abundance indices for individual spawning grounds</u>.

The calculation was done basically following the procedure proposed in Anon. 1984, 1985b. However some modifications have been introduced:

- The Orkney-Shetland standard area given in Anon. 1985b was modified. The new area includes those stations that have been sampled in at least half the years in the database (Figure 1).

- Single missing values were extrapolated in all years with incomplete coverage following the 'Nearest Neighbour Method'. A minimum of three real data values were required for each estimation. Such interpolated values were never used for further extrapolation of other individual rectangles. Only in years with a sampling coverage less than 30%, this procedure was not followed and the interpolations were done following the 'Ratio Method' described in Anon., 1985b.

- Periods with incomplete coverage after the single missing values estimation, were filled using the 'Ratio Method' defined in Anon., 1985b. The abundance of the closest years were used to calculate the ratio between larval abundance of the unsampled and the total areas.

The procedure was applied both to <10 and 10-15mm larval abundance indices (<11 and 11-16mm in the southern North Sea area).

- Combination of larval production estimates for northern, central and southern North Sea into one spawning stock index.

The larval production can be described as:

$$P = W \cdot Fec \cdot (1-N)$$

where P = larval abundance,
W = spawning stock biomass,
Fec = fecundity in number of eggs per unit weight,
and N = larval mortality.

For the North Sea herring:

$$W_t = \sum_{i=1} \frac{P_i}{Fec_i \cdot (1-N_i)}$$

where 't' indicates the total North Sea and 'i' the different spawning areas.

In order to combine the different larval abundance indices into a single index for the whole North Sea, different fecundities have to be considered for each of the subpopulations. In the present report annual fecundity variations due to changes in the age composition of the spawning population, are also considered.

The mean fecundity depends on the age composition of the spawning stock, and also on the mean length per age group. Fecundity-length relationships used were taken from Van de Kamp (1981):

Northern North Sea.... $Fec_1 = -84796 + 7.711 \cdot L^3$
Central North Sea..... $Fec_2 = -80812 + 6.962 \cdot L^3$
Southern North Sea.... $Fec_3 = -45909 + 4.084 \cdot L^3$

Mean length at age data were available from the Dutch market sampling (Table 1); for the northern and central North Sea, data from July and August were used, and for the southern North Sea data from October and November. The age composition of the different spawning subpopulations was extracted from the 1986 Herring Assessment Working Group Report (ANON., 1986b). Stocks were taken at the 1st of January, and the corresponding correction factors to mortality were applied to account for the individuals that died before the spawning season. The estimated age composition for the different years and spawning areas is shown in Tables 2 a-c, together with the calculation of the mean number of eggs per kilogram of spawning stock.

Following the model outlined above, and considering N_i constant and the same in the different spawning areas, the North Sea herring spawning stock biomass can be described as:

$$W_t = \frac{1}{1-N} \cdot \sum_{i=1} \frac{P_i}{Fec_i} = \frac{1}{1-N} \cdot I_t$$

where I_t represents the spawning stock biomass index for North Sea calculated from larval surveys.

This model assumes that larval growth and mortality are constant from year to year and the same in the different North Sea areas. It also assumes that all hatching periods are completely covered and larval migration is negligible.

- Comparison of the indices to VPA spawning stock estimates.

Ordinary predictive regressions have been utilized in the different comparisons. The VPA spawning stock biomass estimates were taken from Anon., 1986b. Only years prior to 1984 were considered in the comparisons because it was thought that only for those years VPA estimates had converged sufficiently.

RESULTS

Table 3 shows the larval abundance estimates of the different North Sea spawning areas both for the smallest size category and for the medium sized larvae. In order to compare our approach with the procedure utilized by the ICES Herring Larval Working Group until 1985, regressions of <10mm larval abundance indices on VPA individual spawning stock size estimates have been done. These regressions are presented in Figures 2 a-c. The correlations found are highly significant ($p<0.01$). The hypothesis that the regression lines go through the origin is rejected in the case of the regressions for the northern and southern North Sea subpopulations ($p<0.05$).

Before the integration of the individual indices into one overall figure is possible, fecundity estimates are needed. The calculation of such estimates is shown in Tables 2 a-c. Highly significant differences are found between the number of eggs per kilogram of spawning stock of the different North Sea areas ($p<0.01$). Although there are not significant differences between years, separate fecundity values have been used in each year in order to correct for annual variations in age composition of the spawning subpopulations.

Following the model outlined above, annual spawning stock biomass indices have been calculated for the total North Sea (Table 4). Their regressions on North Sea VPA spawning stock biomass estimates are shown in Figures 3 a-b. The correlation is significant ($0.01<p<0.05$) when the spawning stock index is obtained from 10-15mm larval abundance (11-16mm for the Downs subpopulation) and highly significant ($p<0.01$) when the spawning stock index is based on the smallest size category. The latter regression line goes through the origin ($p>0.05$), wich agrees with the obvious fact that if the stock is zero, larval production will be nil and vice versa.

Spawning stock biomass projections ('expected' values) for the years 1972 to 1985 have been calculated for the different North Sea areas using the old procedure and the one propposed in the present paper (Figure 4). The central North Sea spawning stock biomass estimates are very similar using both methods. But important differences are found in the values for the northern and southern North Sea subpopulations. The sign of these differences might reflect the influence of using mixed catches as input values for the separate VPAs.

DISCUSSION

Anon (1977a) and Saville (1978, 1981) have suggested that the individual larval production estimates for different spawning areas are not necessarilly additive to give a total estimate for the North Sea herring stock, because of variation between stocks in larval growth and mortality rates and in fecundity. But it seems possible to avoid these problems if it is assumed that the effect of the variation in growth and mortality between areas on the larval abundance variance is negligible, and if fecundity estimates are available.

Christensen et al.(1985), Hempel & Schnack (1971), Karasiova (1981), Wood & Burd (1976) studied daily growth rates of North Sea herring in different spawning areas. These rates ranged from 0.14 - 0.35 mm/day. Lassen & Pedersen (1985) calculated growth rates for the Orkney-Shetland subpopulation from 1974 to 1983. The annual values ranged from 0.06 - 0.31 mm/day. Therefore, if it is assumed that larval growth rate is the same for the different subpopulations, it seems that the range of variation between populations will not be bigger than the variation within one subpopulation.

Christensen (1985) reviewed information on daily growth and mortality rates of herring. The values that he presented illustrate how variable mortality estimates for herring larvae are. Although no doubt exists that the extra yolk of larger eggs may provide a higher survival potential to the resulting larvae (BLAXTER & HEMPEL, 1963), larval mortality is not only influenced by starvation, but also by predation and the modifying effects of physical factors (SISSENWINE, 1984). Little is known about wich proportion of larval mortality is caused by the different factors. But mortality estimates obtained by Christensen using a new larval production model (Anon., 1986a) suggest that the bias introduced by assuming the same larval mortality does not have to be larger in case of the combined North Sea subpopulations than in case of a single subpopulation. The mortality values calculated in Anon., 1986 show the same range of larval mortality in different years in the same spawning area as in different areas.

In the method used in the present report it has been assumed that larval mortality and growth rates are constant from year to year and the same for the different North Sea subpopulations. This assumption is probably far from the reality. But considering the range of variation of the data available on larval growth and mortality, it is concluded that these sources of variability will not affect significantly the overall larval abundance variance. This seems to be true when the smallest size category of larvae is considered, because a highly significant correlation is found between the spawning stock biomass estimated from VPA and the index, and this regression practically goes through the origin (Figure 3 a). But the regression between North Sea herring spawning stock biomass and the index obtained from 10-15mm larval abundance is less significant (Figure 3 b). This is probably due to the following reasons:

- The larvae of this category will have sustained higher values of mortality and their abundance will be more influenced by variations in mortality than that of the smallest size group.

- The probability of including into the index a given cohort more than once is bigger when 10-15mm category is considered than in the case of <10mm larvae.

Because the three North Sea herring subpopulations mix at a common feeding area in the central and northern North Sea and a major part of the catch is taken outside the spawning season -when the various subpopulations have mixed, the individual regressions shown in Figures 2 a-c probably lead to misleading spawning stock projections. The comparison of 1972 to 1985 spawning stock size projections using both methods reflects an overestimation of the biomass of the northern North Sea stock and an underestimation for the southern North Sea subpopulations when separate VPA spawning stock size estimate-larval index regressions are applied (Figure 4). The differences between estimates can be explained by the migration pattern of the North Sea herring. The northern North Sea catches would include individuals from the central and southern North Sea subpopulations. And the migration of the central North Sea subpopulation to the north could be virtually counterbalanced by the immigration of Downs herring.

In the present paper it has been considered that the relation between spawning stock biomass and larval abundance is linear. This is probably true at least over the range of low stock sizes in years prior to 1983. But more pairs of values out of the range mentioned are needed in the figure in order to prove the applicability of a linear relationship. Density - dependent factors might affect the linearity after some spawning stock level has been reached, and then spawning stock size projections from larval surveys would not be reliable anymore.

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Table 1. Mean length at age.

a – Northern North Sea

Year	Age 2	3	4	5	6	7	8	9
1972	22.3*	24.8	27.3	28.8*	29.2*	30.3*	30.8*	29.5*
1973	-	25.6	26.9	28.1	29.4*	29.6	30.0	-
1974	-	25.7	27.6	28.3	29.0	29.9	30.0	31.0*
1975	-	26.2	28.0	28.7	29.0	30.0	30.1*	30.9*
1977	-	26.3	27.7	28.7	29.1	30.0	29.8	30.0*
1978	-	26.5	28.1	28.8	29.1	29.1*	30.0*	29.9*
1981	-	26.3	27.3	28.5	29.6	29.9	30.2	30.8*
1982	-	25.5	27.3	28.1	29.3	29.9	30.2	31.0
1983	-	24.7*	27.3	28.5	29.1	29.8	30.0	30.5
MEAN	22.3$	25.9	27.5	28.5	29.2	29.9	30.0	30.2$

b – Central North Sea

Year	2	3	4	5	6	7	8	9
1972	22.3	25.6	27.5	28.4	29.0	30.2*	31.8*	31.3*
1973	22.6	25.9	26.6	28.3	29.2	29.2*	-	-
1974	19.4*	25.9	27.6	28.7	29.3	29.9*	-	30.3*
1975	21.9	25.3	27.5	28.7	29.2	29.8	33.3*	31.3*
1976	22.6	24.9	27.3	28.7	29.8	29.8*	31.0*	30.5*
1979	-	27.1*	28.4*	28.9	30.8*	30.6*	31.3*	31.8*
1981	22.2	25.9	28.4*	30.0*	29.3*	31.3	31.8*	-
1982	20.7	24.3	26.5	29.4*	-	30.8*	31.3*	-
1983	19.5	24.1	26.1	26.8*	-	30.8*	-	-
1984	20.5	25.8	27.8	28.7	28.3*	31.1*	-	31.2
MEAN	21.5	25.3	27.1	28.6	29.3	30.5	31.4$ (1)	

c – Southern North Sea

Year	2	3	4	5	6	7	8	9
1972	23.4	24.6	26.5	27.6	28.3	28.2*	29.3*	-
1973	23.2	24.8	26.3	27.5	28.7*	29.2	28.8*	-
1974	23.3*	24.8	26.6	27.7	28.4*	29.8*	29.6*	-
1975	23.5*	24.9*	26.8	27.5*	28.8*	-	-	-
1976	24.2	24.9	26.7	28.9*	-	-	-	-
1979	26.3*	27.6	-	-	-	-	-	-
1980	24.7	26.0	28.7	29.1	30.2	30.8*	31.1*	31.8*
1981	23.9*	25.3	27.6	29.2	30.1*	30.7	30.8*	-
1982	23.0	25.1	26.9	28.5	30.0	31.0	31.2*	30.3
1983	23.9	25.1	27.0	27.8	29.1	30.5*	30.3*	-
MEAN	23.7	25.4	27.0	28.2	29.4	30.3	30.4$ (1)	

- The symbol '*' indicates that the mean length estimate is based on less than 10 observations.
- The symbol '$' indicates that the estimates denoted with the '*' symbol have been used in the calculations.

(1) Mean length of 8 and 9 year old herrings.

Table 2a. Calculation of the number of eggs per kilogram of spawning stock for the northern North Sea area.

Year	SPAWNING STOCK BIOMASS (E5 ton)	SPAWNING STOCK (MILLIONS) Age 3	4	5	6	7	8	9+	NUMBER OF EGGS (x E3) PER KLGR OF S. STOCK
1972	2.07	947	176	106	39	7	2	1	182
1973	1.47	393	291	72	40	15	4	1	186
1974	0.88	168	136	104	23	12	6	3	189
1975	0.65	166	68	58	42	7	2	3	190
1976	1.06	465	80	33	31	27	2	2	196
1977	0.88	155	173	52	22	23	22	1	191
1978	1.08	107	137	116	45	18	20	50	196
1979	1.12	146	96	122	105	40	16	0	196
1980	1.31	102	127	86	109	94	36	19	201
1981	1.38	172	86	100	63	85	72	34	198
1982	1.92	460	153	72	80	48	67	76	191
1983	3.07	927	360	120	54	58	34	109	187
1984	5.33	2099	638	215	67	35	33	62	183
1985	5.46	1527	1172	323	96	30	16	36	196
No egg/fish		49175	75569	93707	107185	121326	123401	127593	

Table 2b. Calculation of the number of eggs per kilogram of spawning stock for the central North Sea area.

Year	SPAWNING STOCK BIOMASS (E5 ton)	SPAWNING STOCK (MILLIONS) Age 3	4	5	6	7	8	9+	NUMBER OF EGGS (x E3) PER KLGR OF S. STOCK
1972	0.43	152	64	15	7	1	1	1	126
1973	0.80	382	45	27	7	2	1	2	114
1974	0.78	256	140	20	11	4	1	1	126
1975	0.30	53	51	36	5	4	1	0	146
1976	0.13	37	12	8	8	2	2	1	149
1977	0.09	11	11	8	3	4	1	2	164
1978	0.14	40	5	9	7	2	4	2	148
1979	0.19	41	36	3	7	6	1	3	144
1980	0.30	70	33	32	3	6	6	2	148
1981	0.51	139	56	29	29	2	6	5	144
1982	1.01	318	110	47	25	26	2	10	135
1983	2.02	666	247	89	41	22	23	2	130
1984	4.37	1511	521	195	71	34	18	33	128
1985	5.34	813	1169	418	156	57	27	42	148
No egg/fish		31933	57749	82055	94308	116718	134726	134726	

Table 2c. Calculation of the number of eggs per kilogram of spawning stock for the southern North Sea area.

Year	SPAWNING STOCK BIOMASS (E5 ton)	SPAWNING STOCK (MILLIONS) Age 3	4	5	6	7	8	9+	NUMBER OF EGGS (x E3) PER KLGR OF S. STOCK
1972	0.30	131	58	8	2	0	10	0	98
1973	0.07	28	11	1	0	0	0	0	65
1974	0.07	45	6	2	0	0	0	0	88
1975	0.06	45	4	0	0	0	0	0	85
1976	0.02	10	2	0	0	0	0	0	93
1977	0.06	42	6	1	0	0	0	0	89
1978	0.14	57	35	4	1	0	0	0	97
1979	0.28	123	42	26	3	0	0	0	96
1980	0.20	93	32	10	6	1	0	0	96
1981	0.55	348	46	11	3	2	1	0	89
1982	0.42	167	107	16	4	0	1	0	97
1983	0.39	182	52	36	4	1	0	0	96
1984	0.43	229	55	16	11	2	0	0	94
1985	1.22	801	44	7	3	2	0	0	78
No egg/fish		21016	34476	45678	57874	67700	68829	68829	

Table 3. Larval abundance indices (x E9) for the different North Sea spawning areas.

<10mm

Year	Orkney-Shetland	Buchan	NORTHERN NS	CENTRAL NS	SOUTHERN NS
1972	6240	46	6286	447	74
1973	2468	9	2477	2933	16
1974	1321	313	1634	3742	9
1975	444	467	911	434	7
1976	958	1	959	301	4
1977	1943	273	2216	825	1
1978	4184	333	4517	1646	64
1979	6439	201	6440	738	291
1980	4243	20	4263	688	498
1981	4165	22	4187	1446	2216
1982	3786	831	4617	1436	2479
1983	4418	4488	8906	3340	858
1984	3703	4369	8072	4192	790
1985	9930	4266	14196	15232	2171

10-15mm

Year	Orkney-Shetland	Buchan	NORTHERN NS	CENTRAL NS	SOUTHERN NS
1972	2363	21	2384	536	88
1973	1685	9	1694	945	73
1974	1435	157	1592	1391	9
1975	1078	50	1128	1054	11
1976	380	23	403	237	24
1977	2646	63	2709	847	10
1978	1014	177	1191	705	35
1979	5543	1252	6795	962	177
1980	8069	492	8561	879	766
1981	3036	582	3618	2035	3559
1982	4577	992	5569	586	1213
1983	5129	2860	7989	1870	1410
1984	3349	2945	6294	4924	1477
1985	4024	5337	9361	7423	1875

Table 4. Spawning stock indices (P / Fec) obtained from <10mm and 10-15mm larval abundance (<11mm and 11-16mm in the southern North Sea) .

<10mm

YEAR	NORTHERN N.S.	CENTRAL N.S.	SOUTHERN N.S.	TOTAL
1972	3.45	0.35	0.08	3.88
1973	1.33	2.57	0.02	3.92
1974	0.86	2.97	0.01	3.84
1975	0.48	0.30	0.01	0.79
1976	0.49	0.20	0.00	0.69
1977	1.16	0.50	0.00	1.66
1978	2.30	1.24	0.07	3.69
1979	3.29	0.51	0.30	4.10
1980	2.12	0.46	0.52	3.10
1981	2.11	1.00	2.49	5.60
1982	2.42	1.06	2.56	6.04
1983	4.76	2.57	0.89	8.22
1984	4.41	3.28	0.84	8.53
1985	7.24	10.29	2.78	20.31

10-15mm

YEAR	NORTHERN N.S.	CENTRAL N.S.	SOUTHERN N.S.	TOTAL
1972	1.31	0.43	0.09	1.83
1973	0.91	0.83	0.11	1.85
1974	0.84	1.10	0.01	1.95
1975	0.59	0.72	0.01	1.32
1976	0.21	0.16	0.03	0.40
1977	1.42	0.52	0.01	1.95
1978	0.61	0.48	0.04	1.13
1979	3.47	0.67	0.18	4.32
1980	4.26	0.59	0.80	5.65
1981	1.83	1.41	4.00	7.24
1982	2.92	0.43	1.25	4.60
1983	4.27	1.44	1.47	7.18
1984	3.44	3.85	1.57	8.86
1985	4.78	5.02	2.40	12.20

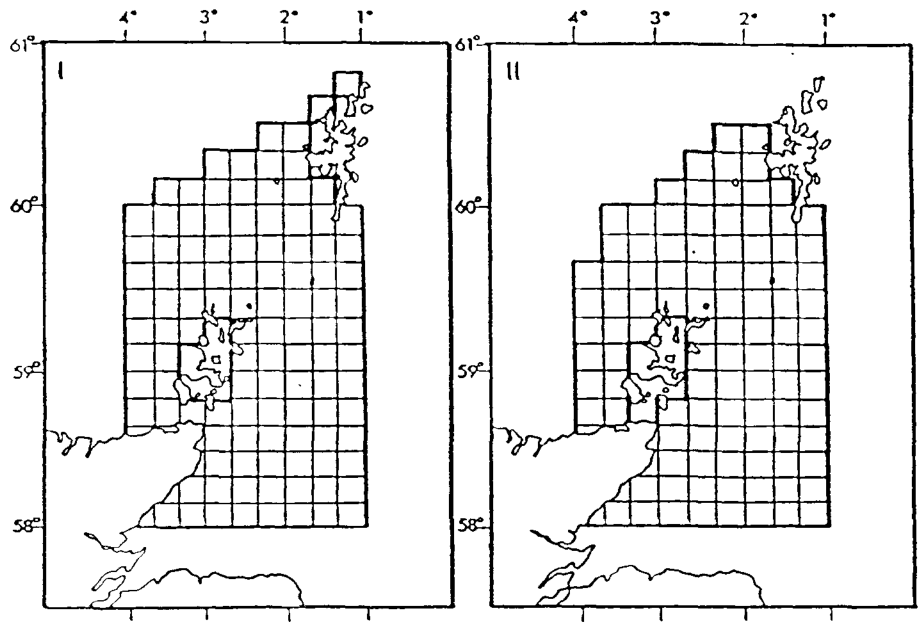
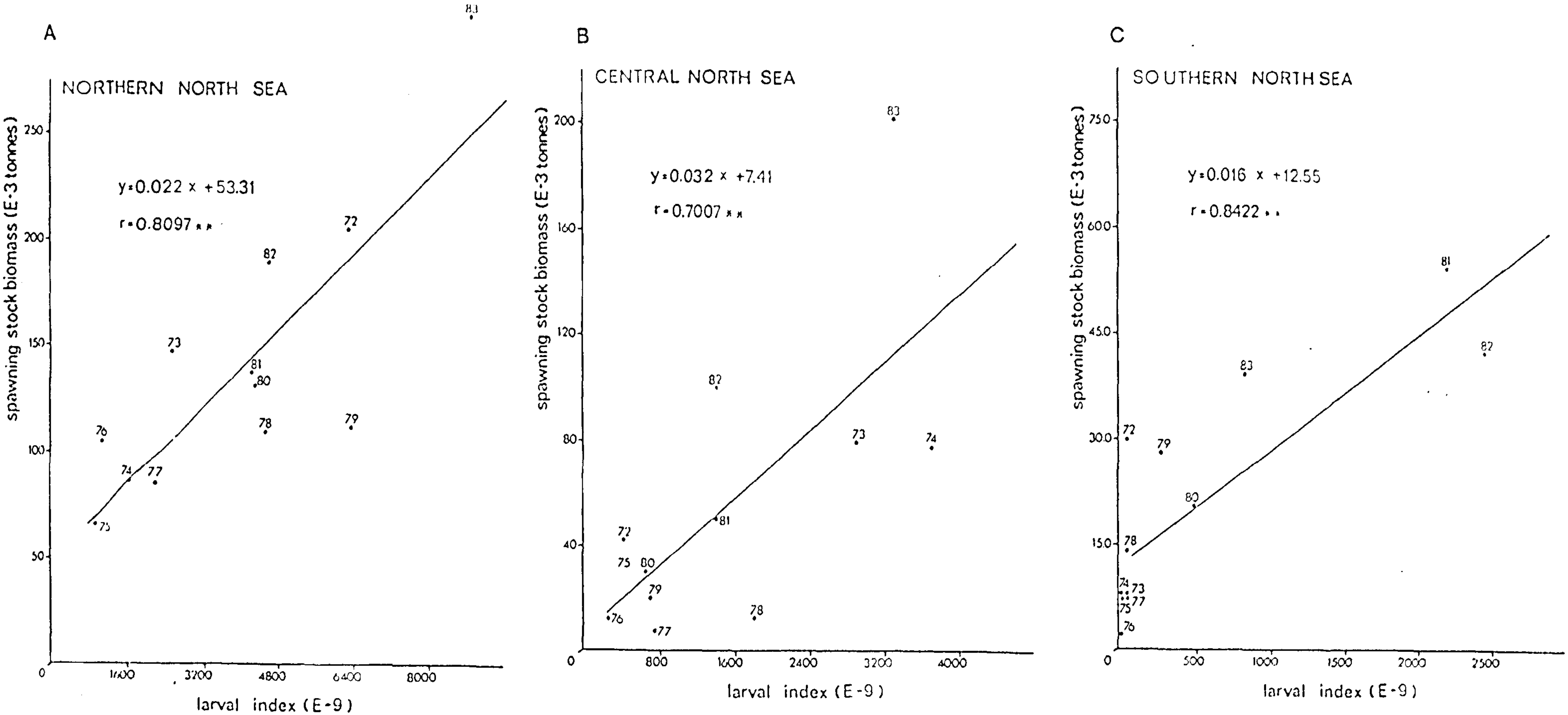
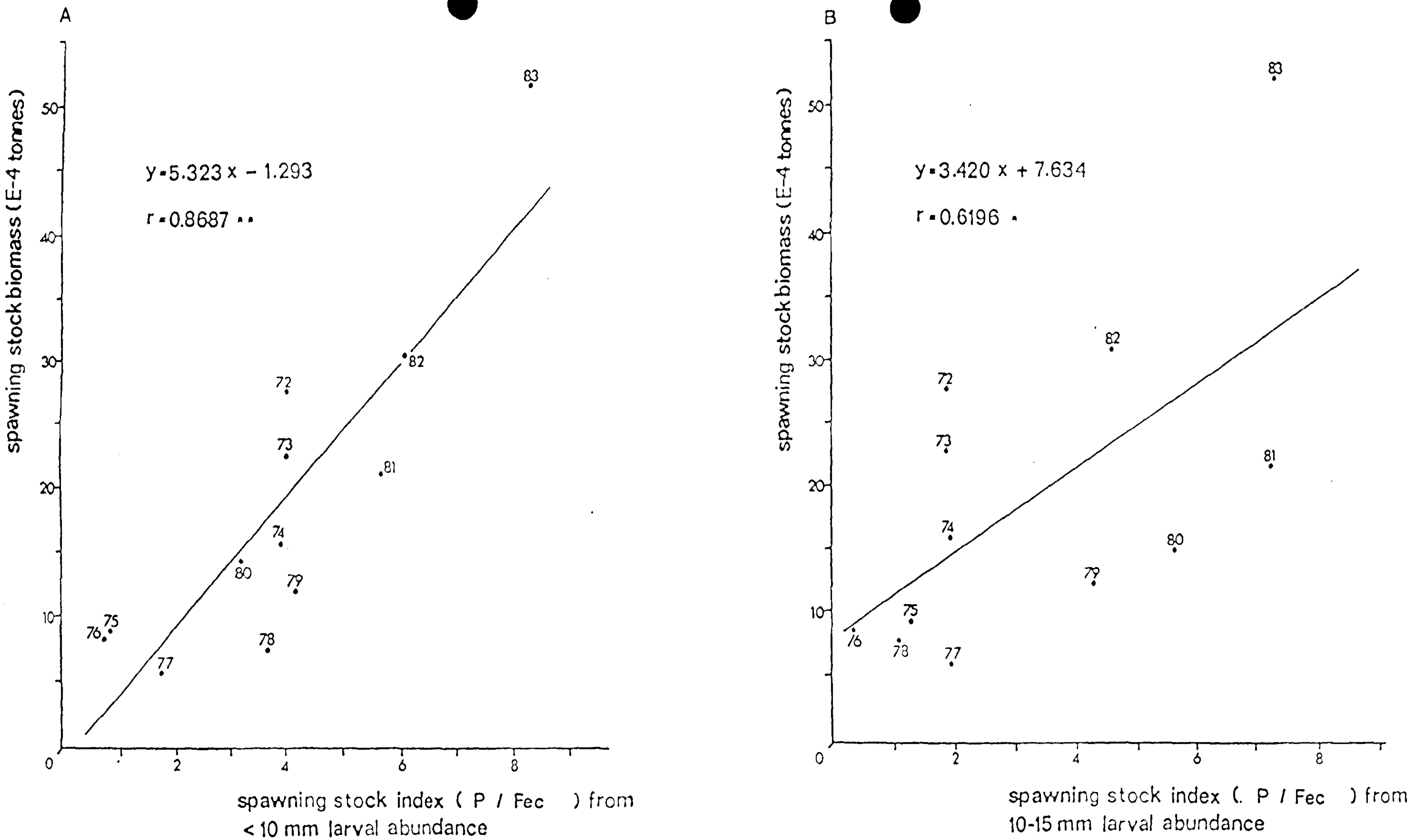


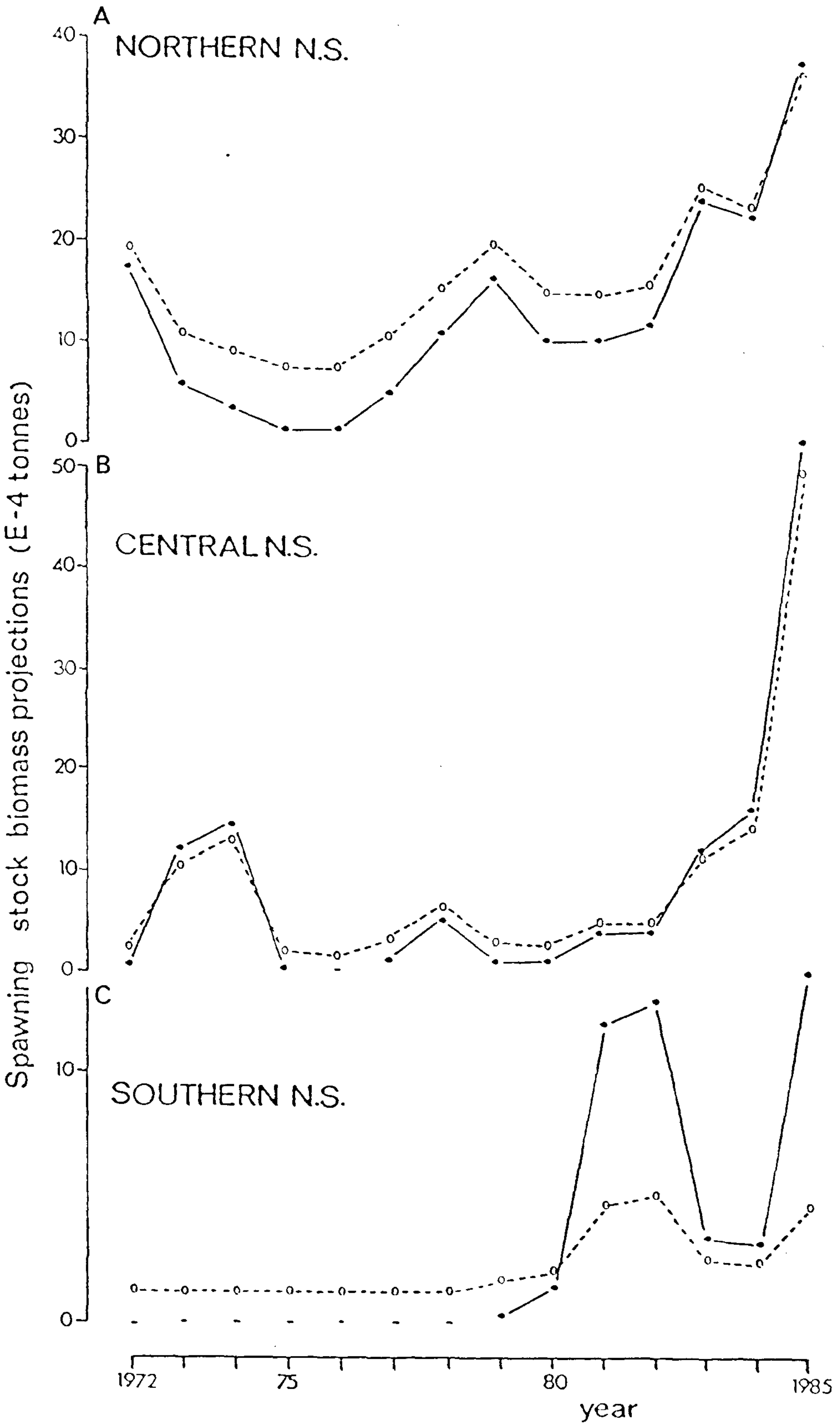
Figure 1. Stratum areas for periods I and II in the Orkney-Shetland area.



Figures 2 a-c. Larval indices for northern (a), central (b) and southern North Sea (c) plotted against separate VPA's spawning stock biomass estimates. The symbols '**' indicates that correlations are highly significant.



Figures 3 a-b. Spawning stock indices obtained from <10mm and 10-15mm larval abundance (<11mm and 11-16mm in the southern North Sea) plotted against North Sea VPA spawning stock biomass estimates. The symbol '*' indicates significant correlation, and '**' highly significant correlation.



Figures 4 a-c. Spawning stock biomass projections ('expected' values) from the regressions obtained using the old procedure (0-------0) and the proposed by Corten (1978, 1980) and this report (0————0).