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The mixing of the three spawning groups in the northern North Sea in summer

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There are three groups of autumn spawning herring in the North Sea, the Downs, Dogger and Buchan stocks. There are three mixed fisheries in the northern North Sea, the Buchan pre-spawning fishery, the Shetland fishery and the Fladen fishery. Here we are concerned with the proportions of the three spawning groups found in the three mixed fisheries. Wood (1936) showed that the Shetland and Buchan fisheries were to some degree related and that Dogger fish and probably Downs fish were to be found on the Fladen. Andersson (1950) showed that Fladen fish, probably Buchan spawners, were to be found in winter in the Skagerrak. Downs fish were shown to move through the Shields fishery in early summer, presumably northwards, and in late summer, presumably southwards (Burd, in Burd and Cushing, 1962). With the use of meristic characters, Krefft (1954) showed that Downs fish were to be found in summer in the Fladen/Gut region.

Cushing (1961) in a progress report to the Herring Symposium of I.C.E.S. attempted to estimate the proportions of Downs fish in the mixed fisheries in the northern North Sea. The method used was to correlate catches/effort in the East Anglian fishery with those in the mixed fisheries. In order to obtain the greatest quantity of information, catches/effort of a number of age groups were used. Adjustments were made for the effects of mortality between ages and differences in abundance between years. Regressions were calculated and the estimates of mixing used were the means of $(1 - a/\bar{y})100$ and $(1 - a^1/\bar{x})100$, where $\bar{y}$ is the mean of the measures of Downs stock, where $\bar{x}$ is the mean of the measures of the stock in the mixed fishery, where a is a positive intercept in the regression $y = a + bx$ and where a^1 is a positive intercept in the regression $x = a^1 + b^1y$. A bias was detected in the method (Cushing, Revisions and additions, Working Group, Hamburg), when one age distribution changes its shape relative to the other, as for example through a recruitment change in time confined to one stock, or through a change in mortality in time confined to one stock. The consequence is that an average estimate from 1930-58 cannot be made, but that the period had to be split in two parts, one before the recruitment change in 1950-1 and one after it. The results for the pre-war period are given in Table I (taken from Cushing's progress report to the Herring Symposium, 1961).

Table I The proportions of Downs fish in the summer fisheries in the northern and central North Sea

	Ages	$(1-a/\bar{y})100$	$(1-a^1/\bar{x})100$	Mean
Buchan pre-spawning (1930-55)	4-7	73.9%*	57.8%*	65.8%
Buchan spawning (1930-50)	3-9	Not s	Not s	
Shetland (1930-50)	3-9	Not s	Not s	
Fladen (1930-50)	3-9	24.4%*	29.5%*	26.9%
Dogger (1930-50)	3-6	36.3%*	35.9%*	36.1%

Note: An asterisk indicates that the regression was significantly different from zero.

There are two conclusions to be drawn from this table, that the Downs fish are found in significant proportions in the fisheries where they might have been expected from an examination of the literature (Buchan pre-spawning fishery, Fladen and Dogger) and that they are not found in significant proportions in the two fisheries where they might not have been expected (Buchan spawning fishery and Shetland). So, qualitatively, the method revealed the structure that had previously emerged from the examination of age distributions and meristic characters referred to above. Quantitatively, the method is subject to a major source of error, in that the measure of mixing and year class correlation cannot be distinguished. Such year class correlation could be positive or negative. A main part of this paper will be concerned with the proper estimation of the year class correlation.

In the early fifties two extensive biological changes took place. The first was the change in the recruitment pattern in 1950-1, which was extensively spread over the North Sea (Cushing and Burd, 1957; Parrish and Craig, 1957; Burd and Cushing 1962). The second, which was probably a further facet of the recruitment change, was the sharp increase in the magnitude of recruitment to the Buchan spawning fishery in 1953, increasing the total stock in that fishery by 1955 (Parrish and Craig, 1962). The effect of the recruitment change on the Downs stock was to make recruitment complete at three years of age; on the Buchan and Dogger spawning stocks, its effect was to make recruitment nearly complete at four years of age, but not quite. Figure 1 shows the percentages of recruitment as at three, four and five years of age in the Buchan spawning fishery, the Dogger spawning fishery and in the East Anglian fishery. A natural mortality rate of 0.2 was taken and values for Z for the particular years were estimated from catches/effort taken from Parrish and Craig (1961) and Gilis (1957, 1958 a and b, 1959, 1961). It will be seen that since 1953 East Anglian recruitment has been practically complete at three years of age, whereas in the Buchan spawning fishery and in the Dogger spawning fishery a peak of three year old recruitment was reached in 1953, after which it declined till 1957. This apparent retrogression of the recruitment

changes on Buchan and Dogger is of the greatest interest, as some small evidence of such retrogression was given in Burd and Cushing (1962); however, we are more concerned here with the unexpected persistence of partial recruitment to the two northern stocks during the fifties.

Analysis of the biological changes in the early fifties has been much aided by the use of the October Belgian age distributions on the Dogger, which are probably composed predominantly of Dogger spawners [Gilis, 1957, 1958 a and b, 1959, 1961; région centrale de la Mer du Nord]. Table II gives the proportions of fish in stages VI, VII and VII/II on the Dogger in October.

Table II The proportion of fish in stages VI, VII and VII/II on the Dogger in October contributing to the Belgian age distributions from Région Centrale (Gilis, 1957, 1958 a and b, 1959, 1961)

1949	89.8%	
1950	46.3%	
1951	28.6%	
1952	30.7%	No maturity stage sample in the Scottish/German data
1953	51.3%	
1954	41.5%	
1955	64.0%	
1956	No sample	
1957	76.9%	
1958	12.0%	
1959	59.1%	

The low values in 1951, 1952 and 1958 mean either that some East Anglian fish were present or that there are small annual variations in the ratio of spawned to unspawned fish in the fishery. East Anglian fish are not present in the Silver Pit fishery in early October (largely because the main body of East Anglian fish is already further south) and so it is thought that the variations in the ratio of spawned to unspawned fish is the more likely cause. The average value of the ten samples in stages VI, VII and VII/II is 50%; as a fair proportion of fish in stage V must also have been Dogger spawners, it is reasonable to assume that these samples were predominantly Dogger spawners.

When an attempt was made to estimate mixing on the Fladen from 1953-8 by correcting the catches/effort of age groups for differences in mortality and abundance, a pronounced negative correlation is found (Figure 2). Such a negative correlation did not exist in the pre-1950 material (Table I), so it is possible that it was generated either by the recruitment change or by the increase in magnitude of the Buchan stock. Figure 3(a) shows a relationship in catch per effort between the four year olds at East Anglia and those on the Fladen from 1930-48 (before the recruitment change) and Figure 3b shows that between the three year olds at East Anglia and those on the Fladen from 1953-9 after the recruitment change. In both cases there is a negative

regression of the stock of fully recruited fish at East Anglia on the stock of the same age at Fladen. This suggests that the negative regression shown in Figure 2 like that in Figure 3 is a form of year class correlation. No correlation emerges between three year old stock at East Anglia and that on the Fladen before the recruitment change or between four year old stock at East Anglia and that on the Fladen after the recruitment change.

Figure 4(b) shows a significant regression of the sum of Dogger and Buchan spawners of three years of age on the Fladen stock of the same age, during the fifties. This might suggest that the Fladen stock was composed only of Buchan and Dogger spawners. There is a positive intercept in this regression, which implies that a proportion of the Buchan and Dogger spawners does not reach the Fladen. Figure 4(a) shows a negative (but not significant) regression of East Anglian three year old fish on the sum of Dogger and Buchan spawners - which tends to explain the negative regression found in Figures 2 and 3. This analysis shows that the negative year class correlation in Figures 2 and 3 can appear between East Anglia and Fladen when fish of the Buchan and Dogger stocks are present. This conclusion rests on the correlation between Fladen and the sum of Buchan and Dogger spawners and upon the negative correlation between East Anglia and Fladen. The present conclusion is that there is a real negative year class correlation between East Anglia and the other two stocks at three years of age.

It is worth noting that the negative year class correlation found between the East Anglian fish and Fladen fish is of the same nature as Popp Madsen's (personal communication) description of events on the Bl$\emptyset$den ground - the East Anglian recruitment during the fifties was inversely related to the modal length of II group fish in the Bl$\emptyset$den autumn fishery. If this connection is a real one, the obverse conclusion can be suggested - that the Bl$\emptyset$den ground fishery probably consists of East Anglian, Buchan and Dogger spawned fish.

The most important question is whether the negative relationship between East Anglia and the sum of Dogger and Buchan spawners is found in total recruitment. Figure 5 shows the relationships in recruitment between East Anglia and Dogger spawners (1949-59), Dogger spawners and Buchan spawners (1949-59) and East Anglia and Buchan spawners for two periods (1930-38 and 1949-60). The recruitment is estimated as stock of three year old fish, stock of four year old fish, the sum of threes and fours and the total recruit stock as at three years of age. There is no correlation at all between any of the possible variables. This means that there is no year class correlation between the three spawning stocks taken separately.

Figure 6 shows the relationship between the total recruitment at East Anglia and the sum of total recruits to the Dogger and Buchan spawning fisheries. There is no relation, although there might be a negative regression in the years 1953-57, which might account for the negative regression found in the corrected data (Figure 2). The most important point,

however, is that the negative regression found at three years of age (Figure 3(b)) has disappeared. If the negative year class correlation between East Anglia and the Fladen were of the same type as that found by Popp Madsen, then its disappearance in total recruitment must mean that there are sources of recruitment to one or both the Buchan and Dogger stocks, which are outside the Blφden area. The other important conclusion is that by the time of total recruitment, there is no evidence of year class correlation between the stocks taken together as well as taken separately. Therefore the mixing rates for some fisheries using the corrected data where only two spawning stocks are involved (e.g. East Anglia and Dogger) in Table I are probably good estimates. Elsewhere where three stocks are involved, good estimates are likely so long as totally recruited fish are used. It is thought that the case shown in Figure 2 is special; it arises nowhere else but on the Fladen from 1953-58, when the proportion of partial recruitment to the Buchan and Dogger stocks was minimal. It should be recalled that the relation between East Anglian three year olds and the sum of Buchan and Dogger three year olds is not significant. The argument rests on three points:

1. the negative regression of East Anglian four year olds on Fladen four year olds before the recruitment change and that of East Anglian threes on Fladen threes during the fifties;
2. the lack of correlation between the East Anglian fish and Buchan or Dogger spawners, taken separately during the fifties;
3. the lack of correlation between the East Anglian recruitment and the sum of total recruitment to the Buchan and Dogger stocks during the fifties.

Therefore it seems that the negative year class correlation found is a special case in the recruitment mechanisms.

The analysis of the pre-war mixed fisheries given in Table I used the mixed stock and one spawning stock. The estimate of mixing so obtained includes a component of year class correlation. Figure 5 shows that year class correlation between the three spawning stocks taken separately is non-existent. Figure 6 shows that year class correlation between stocks taken separately in total recruitment is non-existent. However, there is a special case of a negative year class correlation between fully recruited East Anglian fish and the sum of partially recruited Buchan and Dogger spawners of the same age as the East Anglians. This negative year class correlation disappears at full recruitment to the Buchan and Dogger stocks, but it is possible that a special case occurred on the Fladen from 1953-58, when the partial recruitment tended to be minimal. So year class correlation probably played little part in the pre-recruitment change estimates given in Table I.

In the post-war fisheries it is possible to estimate the degree of mixture using the mixed stock and all three spawning stocks (using the data sources quoted above). Then it becomes necessary to add the estimates of mixing based

on different scales. This can be done by putting the estimates into standard measure. The correlation coefficient and the mean of regression coefficients are the same thing, being independent of units of measurement. Hence, we can use the correlation coefficients directly as measures of mixing, so long as the stocks are reasonably the same in size (see Working Group Report).

The data on which the correlation coefficients are based and the original catch per effort data are worth showing in some detail. The purpose of so doing is to show why the combined data are separated sometimes into two sets of age groups and to show that the process of combination does not distort the original data. There is a large quantity of information in the figures and it will be set out in this text as a list of figures with notes.

Figure 7 The relationship between Buchan spawners and the Fladen fishery in catch/effort data.

(a) Buchan spawners on Fladen, for each age separately, 1930-47. /There are slight positive regressions of y on x for the ages 5, 6 and 7 only; the complementary regressions are non-existent, implying that the Buchan spawning stock comprised only a small part of the Fladen stock at this time./

(b) Buchan spawners on Fladen, ages 3 and 4 combined ($r = 0.05$), and ages 5-9 combined ($r = 0.22$), and corrected for differences in mortality and abundance, 1930-47.

(c) Buchan spawners on Fladen, for each age separately, 1953-59. /Clear regressions are found for the ages 3, 4 and 5, but poor ones for the older fish./

(d) Buchan spawners on Fladen, ages 3 and 4 combined ($r = 0.69^{++}$) and ages 5-9 combined ($r = 0.48^{++}$) and corrected for differences in mortality and abundance, 1953-59.
/If the combined data are separated into the ages 3, 4, 5 and 6, 7, 8, the respective correlation coefficients are:- $r_{3,4,5} = 0.69^{++}$ and $r_{6,7,8} = 0.23$. So the combination of the data leads to the same conclusion as the qualitative study of ages taken separately./

Figure 8 The relationship between Buchan spawners and Buchan pre-spawners in catch/effort data.

(a) Buchan spawners on Buchan pre-spawners, 1930-47 and 1952-60, each age taken separately.
/Both before the recruitment change and after it, there is correlation between the two groups at recruitment, which is not maintained amongst the older fish./

(b) Buchan spawners on Buchan pre-spawners, 1930-47 (ages 3-4, $r = 0.40$, and 5-7, $r = 0.43^{+}$, separately), combined, and corrected for differences in mortality and abundance.

Figure 8

(c) Buchan spawners on Buchan pre-spawners, 1952-60 (ages 3-4, $r = 0.67^{++}$, and 5-7, $r = 0.40^{+}$, separately) combined, and corrected for differences in mortality and abundance.
/In the combined data, rather low correlation is found amongst the recruits before the recruitment change, presumably because of the lack of correlation amongst the three year old fish. After the recruitment change, the contrast between recruiting and older fish is shown clearly in the combined data./

Figure 9 The relationship between the Buchan spawning fishery and the Shetland fishery in catch/effort data.

(a) Buchan spawners on Shetland, 1930-47, ages 3-9, each age taken separately.

(b) Buchan spawners on Shetland, 1952-60, ages 3-9, each age taken separately.
/In the period 1930-39, there is a positive but low relationship at all ages, possibly absent at ages four and five; during the fifties there is a clear relationship amongst the recruits and five year olds, which persists, if less markedly, amongst the older fish./

(c) Buchan spawners on Shetland, combined for all ages and corrected for mortality and abundance, in the two periods, 1930-47, $r = 0.30^{+}$, and 1952-60, $r = 0.77^{++}$.
/The increase in the proportion of the Buchan stock can be seen not only in the greater degree of correlation in the combined data, but by comparing the two sets of regressions, $x = a^{1}+b^{1}y$; in the later period, this regression has a slope, but there is only a slight slope in the former period./

Figure 10

(a) The relationship between the October Dogger fishery and the Buchan pre-spawning fishery (1949-59), Shetland (1949-59) and Fladen (1953-58), each age taken separately.
/For the Buchan pre-spawning fishery, there are significant regressions for the threes, fives, sevens and eights; all have positive intercepts, indicating other components, although this is less marked amongst the older age groups. With the Fladen fishery, there are positive regressions at all ages, but only one (the five year olds) was significantly different from zero. For the Shetland fishery, there are poor regressions for each age taken separately, save that for nine year olds./

Figure 10

(b) Relationship between the October Dogger fishery and the Buchan pre-spawning fishery (ages 3-4 combined, $r = 0.64^{++}$; ages 5-8 combined, $r = 0.56^{++}$) corrected for differences in mortality and abundance, 1949-59.

(c) Relationship between the October Dogger fishery and the Fladen fishery; all ages combined, $r = 0.59^{++}$, and corrected for differences in mortality and abundance.
[For ages 3-4 combined, $r = 0.80^{++}$ and for ages 5-8 combined, $r = 0.63^{++}$]

(d) Relationship between the October Dogger fishery and the Shetland fishery, ages 5-8 combined, $r = 0.35^{+}$, and corrected for differences in mortality and abundance.
[In each set of relationships with the October Dogger fishery, there is no difference between the regressions taken separately and the combined data.]

Figure 11 Relationship between East Anglia and the northern fisheries.

(a) East Anglia on Buchan spawners 1930-47 and 1949-60, each age taken separately; the points for 1957-60 are shown as open circles.

(b) East Anglia on Buchan spawners, data combined for the period 1930-55 and corrected for differences in mortality and abundance.
[In the period 1930-47, there is a significant and positive correlation for the four year olds, which is not found amongst the older fish. It is presumably a year class correlation of the type referred to above. In the period 1949-60 there are no significant regressions, some being positive and some negative. The regressions for the oldest fish, 7, 8 and 9 are positive because of the disproportionate mortality suffered by the oldest East Anglian fish. There is no evidence from these regressions of a marked change between the two periods, nor of any real difference with ages. In the combined data for the period 1930-55, the correlation is not significant ($r = 0.16$), although slightly positive.]

(c) East Anglia on Shetland, 1930-47 and 1949-60, each age taken separately.

(d) East Anglia on Shetland, data combined for the period 1930-55 and corrected for differences in mortality and abundance.
[There is a negative regression at four years of age from 1930-48, just as found on the Fladen; this regression is significantly different from zero and is probably the negative

Figure 11 continued

(d) year class correlation referred to above. For the fish older than four, no regressions are significant, but three are positive and two are negative. During the period 1949-60, there is no regression amongst the recruits. For ages 4-6, the regressions are negative and those for 7-9 are positive; that for the nine year olds is significantly different from zero. The interesting point here is that the regression is not made by the points from 1957-60 (as with the Buchan spawners), but is made by points from the early part of the period as well. Perhaps the oldest East Anglian fish, like the older Dogger fish, found their way to Shetland to some degree during the later period. The combined data from 1930-55 yield a low positive and a non significant regression for all ages. This conclusion does not conflict with that for the ages taken separately, even if the oldest fish did reach Shetland during the later period/

(e) East Anglia on Fladen, 1930-48 and 1953-8, each age taken separately.

(f) East Anglia on Fladen, 1930-48, data combined and corrected for differences in mortality and abundance.

/Except for the four year olds, with the negative regression as explained above, there is a positive but not significant regression for each age group. In the combined data there is a significant correlation of 0.26 for the period 1930-48. After the recruitment change, there are negative regressions in the data for each age taken separately; for fives, sevens, and eights, the regressions are positive. Figure 2 shows the negative regression in the combined data, which, of course, as estimate of mixing is failure/

(g) Relationship between East Anglia and Buchan pre-spawners, 1930-55, each age taken separately.

(h) Relationship between East Anglia and Buchan pre-spawners, 1930-55 (ages 4-7), combined and corrected for differences in mortality and abundance. The figure also gives separate regressions in combined data (for ages 5-7) for the two periods 1930-8 and 1952-60.

/In the period 1930-55, positive regressions are found for all ages save eight and nine and those for five and six are significantly different from zero. For the combined ages 4-7 in the period, the correlation coefficient is positive and significantly different from zero ($r = 0.66^{++}$). A variant is also given for ages 5-7, for the two periods separately (1930-48, $r = 0.72^{++}$; 1949-60, $r = 0.63^{++}$)./

Figures 7-11 show the detailed relationships between the three spawning stocks and the three mixed fisheries in the northern North Sea. In general they show that the combination of the catch/effort data does not create spurious relationships. If the individual age regressions are positive and negative, as with the Buchan spawning and Shetland/East Anglian regressions, the combined correlations are not significant. If the age regressions show different characters between recruits and older fish, the combined data are split and show the same relationship, as with the Buchan spawners on the Fladen or with the Buchan spawners on the Buchan pre-spawners. Again, a split between periods, as with the Buchan spawners and Shetland, emphasizes, in the combined data, the domination of the Shetland fishery by the Buchan spawners during the later period. When the age regressions separately are consistently positive, but not significant, as with East Anglia on Fladen (1930-47), there is a low, but significant correlation in the combined data.

The data shown in Figures 7 to 11 may be summarized by tabulating the correlation coefficients. The pre-recruitment change data are given in Table III and those after the change are given in Table IV.

Table III Correlation coefficients of catches/effort in a spawning stock on those in a mixed stock, corrected for differences in mortality and abundance during the thirties and forties

Mixed fishery		Spawning fishery		
		Buchan spawning	East Anglia	Dogger
Buchan pre-spawners	3-4	0.40	0.36	?
	5-7	0.43+	0.72++	?
Shetland	3-9	0.30+	0.05	?
Fladen	3-4	0.05		?
	5-9	0.22		?
	3-9		0.27+	?

Table IV Correlation coefficients of catches/effort in a spawning stock on those in a mixed stock, corrected for differences in mortality and abundance, during the fifties

Mixed fishery		Spawning fishery		
		Buchan spawning	East Anglia	Dogger
Buchan pre-spawners	3-4	0.67++		0.64++
	5-7	0.40+	0.63++	0.56++
Shetland	3-9		0.05	0.35+
Fladen	3-4		negative	0.80++
	3-5			
	5-9			0.63++(5-8)
	6-8			

Note: The negative correlations in the fifties between East Anglia and Fladen were discussed above.

\+ correlation coefficient is significant at p = 0.05

++ " " " " " p = 0.01

Comparing Table I with Table III, it will be seen that the correlation coefficient yields the same estimate of mixing as the mean of $(1 - a/\bar{y})100$ and $(1 - a/\bar{x})100$, as is to be expected if the two stocks being correlated are of roughly the same size. Comparing Tables III and IV, it will be seen that the East Anglian component in the Buchan pre-spawning fishery [ages 4-7] is about the same before 1950 as it is after that date. The Buchan spawning component of recruits increased in the Buchan pre-spawning fishery after the recruitment change, but the proportion of older Buchan spawners has remained constant through the recruitment change. On the Fladen before the recruitment change there must have been very few Buchan spawning recruits indeed and not many older fish; after the recruitment change, the proportion of Buchan spawning recruits on the Fladen increased greatly, but the proportion of older fish did not increase so much. At Shetland before the recruitment change, there was a small proportion of Buchan spawners, but after it the Shetland fishery consisted in the main of Buchan spawners of all ages. After the recruitment change, there is a small proportion of Dogger spawners in the Shetland fishery. There are no pre-war samples of Dogger spawners, but in the Shetland material them, there is an unspecified remainder, which might have been composed of Dogger spawners or of spring spawners.

The correlation coefficients in Table IV can be used for a more specific purpose than merely sketching the major changes which have taken place. If we assume in any of the three mixed fisheries there are potentially three components, the correlation coefficients may be combined and expressed as percentages to give estimates of mixing. Here it is assumed that the stocks are roughly of the same size. Because the correlation coefficient is the square root of the product of sums of squares of deviations from either regression, the correlation coefficients are squared before they are added. In the Buchan pre-spawning fishery, the East Anglian recruits play little part and Buchan and Dogger spawners comprise about equal proportions; amongst the older fish, it would appear that 46% were East Anglian fish, 18% were Buchan spawners and 36% were Dogger spawners. In the Shetland fishery, there are only two components, 83% Buchan spawners and 17% of Dogger spawners. On the Fladen, the method fails because of the negative year class correlation with the East Anglian fish, but the remainder can be equally divided amongst Buchan and Dogger spawners. Table V summarises these results.

Table V Estimated mixing rates derived from Table IV

	Buchan spawners	East Anglian	Dogger spawners
Buchan pre-spawners (5-7)	18%	46%	36%
Shetland	83%	-	17%
Fladen	= Dogger	?	= Buchan

This method cannot be used in the material from before the recruitment change and so we use the correlation coefficients directly, as percentages. From the treatment of the Buchan pre-spawners in Table V (compared with Table IV), it might be thought that this leads to an overestimate; but the treatment of the Shetland material shows that it might just as well underestimate the mixing rate. In the absence of data on Dogger spawners, these estimates will be used as measures of mixing.

It will be recalled that during the fifties there was no evidence of year class correlation between the spawning stocks taken separately. Nor was there evidence of year class correlations between East Anglia and the sum of Buchan and Dogger at total recruitment. This far the correlations between the spawning stock and the mixed stock is a proper estimate of mixing because the year class correlation is shown not to exist at total recruitment. However it will be recalled that a negative year class correlation is found on the Fladen when the Buchan and Dogger stocks are partly recruited. Hence the estimates of mixing of recruit fish in the northern North Sea will be underestimates. Where the data for recruit fish and older fish have been combined, the correlations will again be underestimates of the mixing rate.

So far, the catch/effort data have been used alone and although reasonable results have emerged which conflict neither with each other nor with our knowledge of the general biological trends in the northern North Sea, independent evidence of mixing rates of a quantitative nature is desirable.

The argument would be considerably strengthened if independent evidence could be found of the presence of East Anglian fish on the Fladen ground. A search was made in the distribution of maturity stages on the Fladen. The fish were separated as "recruits" or as "middle aged" fish. "Recruits" are four year old fish from 1932-49 (three year old fish were never of importance on the Fladen during this period), the sum of three and four year old fish in 1950-1 and three year old fish only from 1952-4. A break in the time series was made in 1955 because the increase in the Buchan stock starting with high year classes in 1953 (Parrish and Craig, 1961) became effective in attracting an increased fishery on the Fladen in September 1955 and in subsequent years. This increase in the magnitude of the Buchan stock during the fifties emerges quite forcibly from the catch/effort data. Figure 12(a) shows the correlation of numbers of "recruits" at East Anglia on the percentage of fish in maturity stage V on Fladen during the period 1932-54 (in black circles) and also during the period 1955-60 (in white circles). Figure 12(b) shows the correlation of numbers of "middle aged" fish at East Anglia on the percentage of fish in maturity stage IV during the period 1949-54 (in black circles) and also during the period 1955-60 (in white circles). The regressions of the percentages in maturity stage on East Anglian catches per effort are both significantly different from zero during the period 1932-54. In both regressions, the data for 1955-60 lie outside the range of error of the regressions for the period 1932-54, although it is much less obvious for "recruits" than it is for the older fish; the points for the period 1955-8 in the "recruit" regression increase the variance, but do not alter the slope. This change is probably due to the addition of Buchan

spawners in stage V, which is shown most clearly in 1959 and 1960 when the abundant 1956 year class came in. For the "middle aged" fish there is an additional effect and it is the reduction in numbers of older fish at East Anglia during the period 1955-60; there is no difference in means of the recruit catches/effort at East Anglia between the periods 1932-54 and 1955-60, but there is a marked one in the middle aged catches/effort at East Anglia between the two periods. Thus the effect of the increase in the Buchan spawning stock in maturity stages IV and V is to add to the quantity of recruits and to take the place of the East Anglian middle aged fish on the Fladen, which had by this time been reduced in numbers very markedly. It is of course likely that the East Anglian middle aged fish remained on the Fladen in low numbers.

The regressions shown in Figures 12(a) and 12(b) relate only to the East Anglian stock found on the Fladen. Figures 12(c) and (e) show the relationships between the percentages in maturity stage IV on the Fladen and the stocks of "middle aged" Dogger and Buchan spawners. For the period 1949-54, there is a significant regression of the percentage in stage IV on the stock of middle aged Dogger spawners (shown in black circles). There is a positive intercept, which implies that there is a component in stage IV in addition to the Dogger spawners; the same point can be seen in Figure 12(b) for the East Anglian "middle aged" spawners. In each figure, it is likely that the regression represents one component and the positive intercept, its complement. Using the estimate $(1 - a/\bar{y})100$ in each case, we find that 63.8% of stage IV on the Fladen in August is composed of Dogger spawners and 48.2% is composed of East Anglian spawners. The sum is 112% which implies that few Buchan spawners were found in stage IV at that period. The average mixing rates of middle aged fish on the Fladen from 1932-54 are for Dogger 56.9% and for East Anglians 43.1%. Figure 12(c) shows no relation at all between the percentage in stage IV and the stock of middle aged Buchan spawners (shown in black circles). It is not unreasonable when it is recalled that the stock of middle aged Buchan spawners on the Fladen before 1955 was a small one; in any case a large proportion of this stock would be on the spawning grounds in August.

In the period 1955-60, there is no relation between the percentage in maturity stage IV and the stock of middle aged Buchan fish on the Fladen (shown in white circles in Figure 7(e)). For the Dogger it is likely that a clear regression exists for the four points available (Figure 12(c), in white circles). It is not the case for the East Anglian middle aged fish. So it is likely that the Dogger fish are the dominant middle aged component on the Fladen in August from 1955-58. If the regression for East Anglian fish from 1932-54 were extended to the period 1955-60, the average proportion of East Anglian fish on the Fladen in August during the later period would be

something less than 5.0%. It is worth pointing out here that no correlation was found with any other combination of maturity stage and spawning stock, except one, and that therefore any complementarity (due to the use of percentages) must be found only in the relations given in Figure 7.

When we consider the distributions of maturity stage V, it appears that in August on Fladen from 1932-54 they would appear to comprise stage V recruit fish from East Anglia only, because the regression passes near the origin (Figure 12(a)). For Dogger and Buchan spawners (Figures 12(d) and (f)), the regressions are positive, but not significantly different from zero. Indeed the best fitting line to the Dogger data would imply a low rate of mixing anyway. For the Buchan spawners, the best fitting line is rather steeper from 1932-54 than from 1955-60. If anything, this would mean that they were present in smaller quantity in the later period than during the earlier, when the stock was smaller. Therefore it is concluded that the majority of stage V fish in August on Fladen are East Anglian recruits. This is perhaps not an absurd conclusion. The Buchan spawning starts in mid-August and extends to September and it might be reasonable to suggest that the Buchan spawners have spawned or are in stage V in areas closer to the spawning grounds. The proportions in stages VI and VII/II in August on the Buchan spawning ground are:-

1951	14.8%	1956	54.8%	
1952	30.8%	1957	29.2%	
		1958	32.7%	
1954	46.0%	1959	23.3%	
1955	58.6%	Average	36.3%	[Parrish et al. 1952 etc.]

The same sort of effect might account for the relative absence of Dogger spawners; they spawn in mid September and October but would have a considerable distance to travel. Tagging recoveries on the Dogger from the Scottish north-east coast in May (0.16%), June (0.13%) and July (0.07%), [Working Group Report] suggest that the majority of Dogger fish have left the Scottish north-east coast by July.

If the results in Figure 12 are used to estimate mixing, the regression $x = a' + b'y$ is uninteresting; the catch per effort of middle aged fish at East Anglia does not depend on the percentage in maturity stage IV on the Fladen. The other regression, $y = a + bx$ is used; it is worth recalling that the percentages include other maturity stages and so the percentage maturity stage is a proper estimate of mixing.

Figure 13(a) shows the time series of the percentage in maturity stage V on the Fladen from 1932-60; Figure 13(b) shows that for stage IV. The peak of stage V was reached in 1950, and from 1950-54 the proportion is much higher than in the preceding years 1932-49. There is perhaps some evidence that the increase was under way in 1949, which was the first year in which three year old fish appeared on the Fladen in quantity. This was probably the first sign of the recruitment change. It is possible that the lower values from 1955-7 reflect some retrogression of the recruitment changes (Burd and Cushing, 1962) as suggested above; in 1959 and 1960, however, the large 1956 year class in the north masked the continuance of any retrogression in these data. The same sequence of events is not shown in the distribution of stage IV, which appear to be predominantly middle aged fish of the Dogger and East Anglian stocks, presumably because the recruitment changes affected the distribution of middle aged fish only slightly. It is noteworthy that the increase in the Buchan stock by 1955 is not manifested in the time series of stage IV - which supports the result given in Figure 13(e), showing no relation between the percentage in stage IV and the stock of middle aged Buchan spawners.

In Schubert's (1961) paper a sharp increase in catch/effort on the Fladen was observed in 1951, as compared with the steady decline found in the immediately post-war years. It seems likely that it was associated with the recruitment changes, making the East Anglian recruit fish more available to capture on the Fladen. The peak in stage V on the Fladen was reached in 1950, when the recruitment change in East Anglia started, associated with the growth change in three year old recruits. It is an interesting point that the recruitment changes to the Buchan and Dogger fisheries started in 1951, not 1950. Taking the average of these values for August, we find that 35% of the Fladen catch was composed of East Anglian fish before and after the recruitment change. Before the change, the proportion was rather fewer (19%), and after it (until 1955) it was higher (42%). Hence the pre-war estimate of 27%, using the mean of $(1 - a/\bar{y})100$ and $(1 - a'/\bar{x})100$, the catches per effort of all age groups in both the East Anglian and Fladen fisheries, being corrected for changes in mortality and abundance, may not be very far wrong. It is concluded again that the negative year class correlation between the East Anglia and the sum of the Dogger and Buchan stocks had little effect on the pre-1950 data, but a destructive effect on the post-1950 data. It is also concluded that the proportion of East Anglian recruit fish on the Fladen increased after 1950 and that these contributed predominantly to the increase in catch/effort found there at the time of the recruitment change.

There are one or two biological points emerging from this analysis. The first is that the recruit fish apparently from East Anglia should be in maturity stage V when the middle aged fish are in stage IV. The second is that the recruit fish from East Anglia should be in stage V as early as August. These possibilities do not conflict with Iles' concept of a long stage V for winter spawners (in press), nor with the well-known age sequence in East Anglia of recruit fish in October and older fish in November. A third point which appears to be conflicting is that Burd (in Burd and Cushing, 1962) has presented evidence that East Anglian three year old recruits are below maturity stage IV at Shields in July. The apparent conflict can be resolved in the following way. It is well known that the larger fish of a year class in the northern North Sea lie further to the north at midsummer (Parrish and Craig, 1961). Let us suppose that the larger fish of a year class migrate further north in summer and mature earlier, then the larger East Anglian fish would be in stage V in August in the north, whereas the smaller East Anglians off Shields would still only be in stage IV in August. This supposition would make sense of an East Anglian phenomenon so far unexplained - that within a year class, the larger fish enter the fishery first and the smaller ones last.

The mixing rates as estimated by maturity stages were calculated from percentages within the stages II-V, in order to reduce some of the variance. The percentages (of total) in stages IV and V for three periods are:-

	% IV	% V
1932-49	30.4%	18.8%
1950-54	28.5%	42.3%
1955-60	34.5%	32.4%

The middle aged fish from East Anglia only comprised part of stage IV from 1932-54. The equation for the regression is $y = 15.9 + 0.8964x$; $\bar{y} = 32.6$, so $(1 - a/\bar{y})100$ is 51.2%. So the estimate of mixing of middle aged East Anglian fish on Fladen will be 51.2% of the percentage in stage IV. If the regression for 1932-54 is used for the middle aged fish from 1955-60, the likely proportion of East Anglian fish is less than 5.0%. In stage V, statistically speaking, all fish are East Anglians; this cannot be true, particularly when we see the effects of the 1956 year class, hence our estimate is then an overestimate. The results as mixing rates are:-

	% IV	% V	Σ	
1932-49	15.6%	18.8%	34.4%	
1950-54	14.6%	42.3%	56.9%)	
1955-60	<5.0%	32.4%	37.4%)	47.1%

There is no way strictly of measuring the overestimate in stage V.

We may recall that the measure of East Anglian fish on the Fladen in the catch/effort data amounted to 27%. The overestimate of East Anglian fish in stage V is not likely to be more than one third (from the best fitting lines in the data of Dogger and Buchan spawners in relation to maturity stage V) which in the sum is about 7%, the degree of difference between the maturity stage estimate and the catch/effort estimate. Indeed, it is more likely that the true estimate from the maturity stages lies between 30 and 35% and that the estimate from catch/effort is biassed downwards by a small degree of negative year class correlation. The most astonishing result is the sharp increase in the proportion of stage V on the Fladen in the period 1950-4, which must have been predominantly recruiting East Anglian fish. Therefore, it is likely that the increase in catch per effort on the Fladen in 1951 (Schubert, 1961) was largely composed of East Anglian fish. The same phenomenon was not observed amongst the middle aged fish and so we may conclude that the increase in mixing rate of East Anglian fish on the Fladen was an effect of the recruitment change.

The mixing rates derived by both methods are set out in Table VI.

Table VI Estimated mixing rates of the three spawning stocks in the northern North Sea

1930-49

Catch/effort data

Mixed fishery		Spawning fishery	
		Buchan spawners	East Anglia
Buchan pre-spawning	3-4	-	-
	5-7	43%	72%
Shetland	3-9	30%	-
Fladen	3-4	-	
	5-9	-	
	3-9	-	27%

Maturity data

Spawning fishery		
Buchan spawners	East Anglia	Dogger spawners
No estimate made		
No estimate made		
"low"	19.9%	"low"
"v. low"	14.6%	14.0%
	35%	

Table VI (continued)

1950-60

Mixed fishery		Spawning fishery		
		Buchan spawners	East Anglia	Dogger spawners
Buchan pre-spawning	3-4 5-7	50% 18%	- 46%	50% 36%
Shetland	3-9	83%	-	17%
Fladen	3-4 3-5 5-9 6-8	20.0% 31.6%	Assuming 50% East Anglian	37.2% 58.1%
	3-7			

Spawning fishery		
Buchan spawners	East Anglia	Dogger spawners
No estimate made		
No estimate made		
"low"*	37.3%	"low"
"v. low"	9.8% (5-7)	
	47.1%	

*obviously this was not low in 1959 and 1960.

The proportions of Dogger and Buchan spawners are estimated by remainder from the maturity stage estimate of the East Anglian fish; this remainder is divided in proportion to the squared correlation coefficients from the catch/effort data. The percentages in Table VI add up across the table and for the Fladen during the fifties the data have been separated into recruit and middle aged fish. The basic estimate in this period is the regression of maturity stage IV or V as East Anglian catch/effort for the period 1932-54. This relationship is extended to the whole period, assuming that the relation between East Anglian catch/effort and maturity stage IV or V remains the same. This is reasonable so long as it is assumed that after 1954, a percentage in each stage has been added to the fishery, i.e. the Buchan spawning stock has grown in abundance. The value of these estimates during the fifties is only in giving some idea of the proportions. To estimate the mixing rates of East Anglian fish on the Fladen properly the annual percentage in each maturity stage would be used.

Two methods of estimating mixing are described in some detail, that using catch/effort data and that using maturity stage data. Both methods yield results which agree within themselves; for example, if one stock appears to be absent from a fishery, the other two are present. Again in the maturity stage data, in the absence of one stock, the proportions of the other two do add up to one. When the results of the two methods can be compared, as for example in the pre-war Fladen material, they are surprisingly close. Hence, it is thought that both methods are reliable and provide estimates of mixing of East Anglian fish in the northern North Sea.

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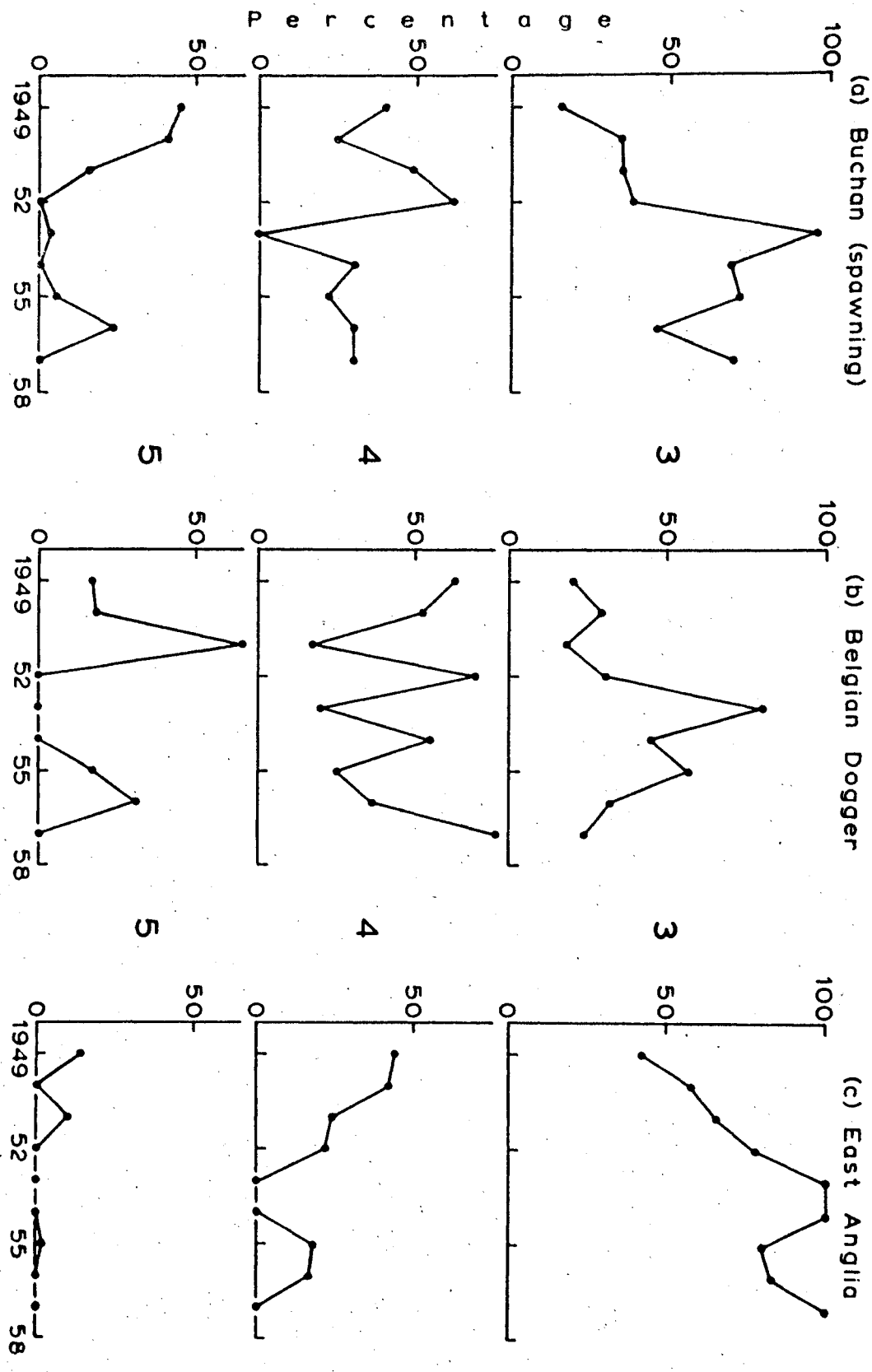


Figure 1 The percentages of total recruitment at each of the ages three, four and five in the Buchan spawning fishery, the Belgian October fishery and in East Anglia, from 1949-57. The natural mortality was assumed to be 0.2 and the total mortality was taken from Parrish and Craig (1961), Cushing (progress report, 1961) and from the data of Gilis (1956, 1957, 1958, 1959).

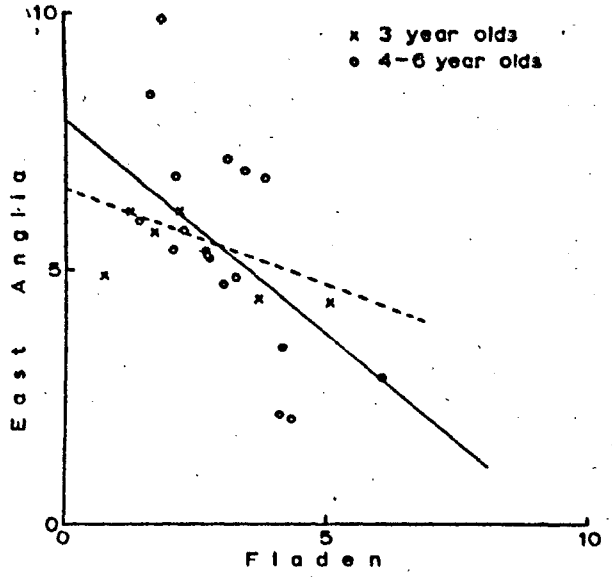


Fig. 2.

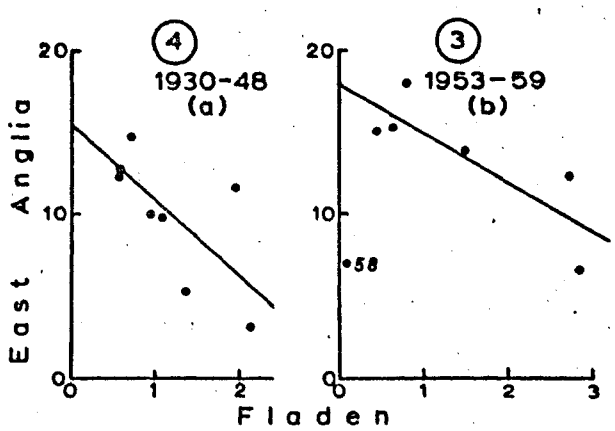


Fig. 3.

Figure 2 The negative regression of East Anglian catches/effort, corrected for differences in mortality and abundance, on the same from the Fladen, 1953-58.

Figure 3 (a) The regression of catches per effort of the four year olds at East Anglia on those on the Fladen, 1930-48; it is significantly different from zero (p.0.05).

(b) The regression of catches per effort of three year olds at East Anglia on those on the Fladen, 1953-59; it is significantly different from zero (p. 0.05). The year 1958 has been omitted from the calculation .

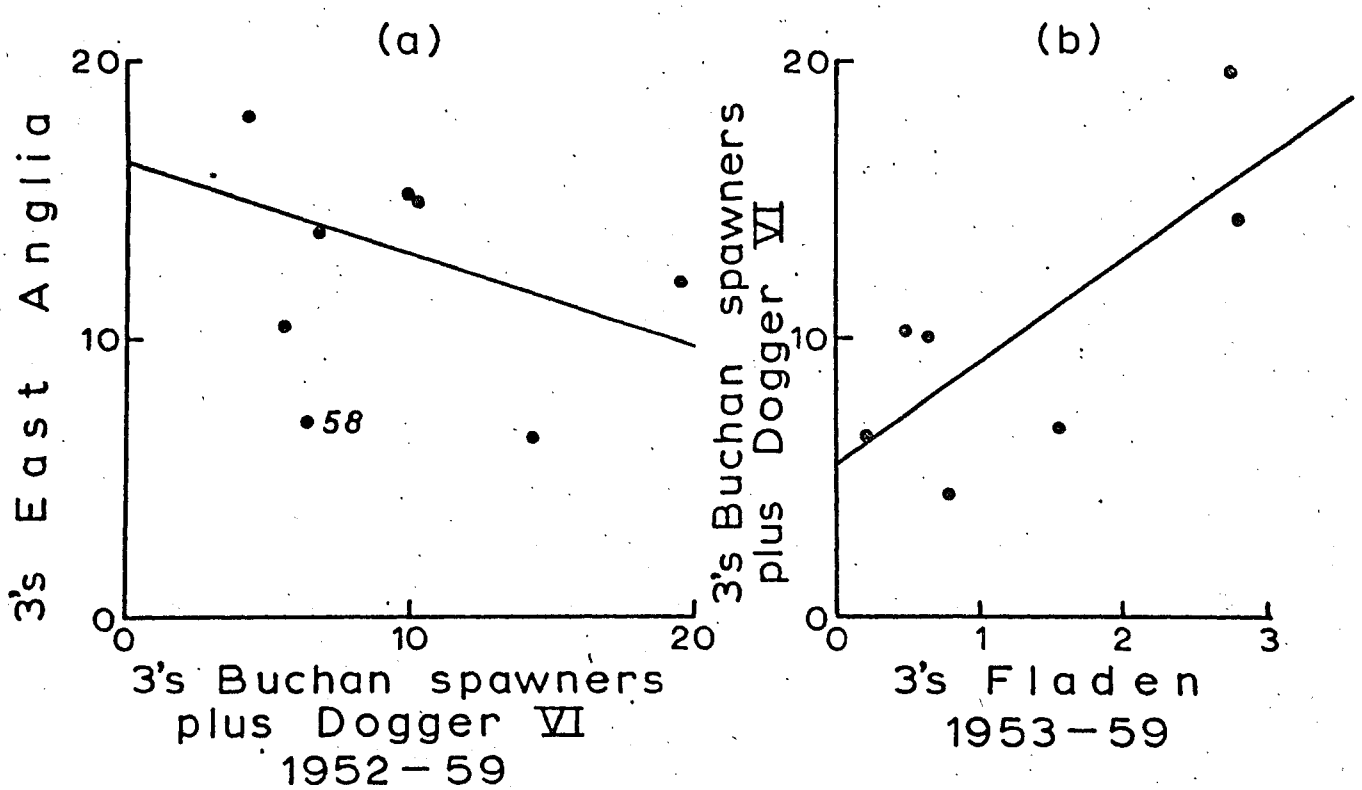


Figure 4 (a) The regression of East Anglian three year olds on the sum of Dogger and Buchan spawners of three years of age (p.0.6); it is not significantly different from zero.

(b) The regression of the sum of three year old Dogger and Buchan spawners on the three year old fish on the Fladen (p.0.05); it is significantly different from zero.

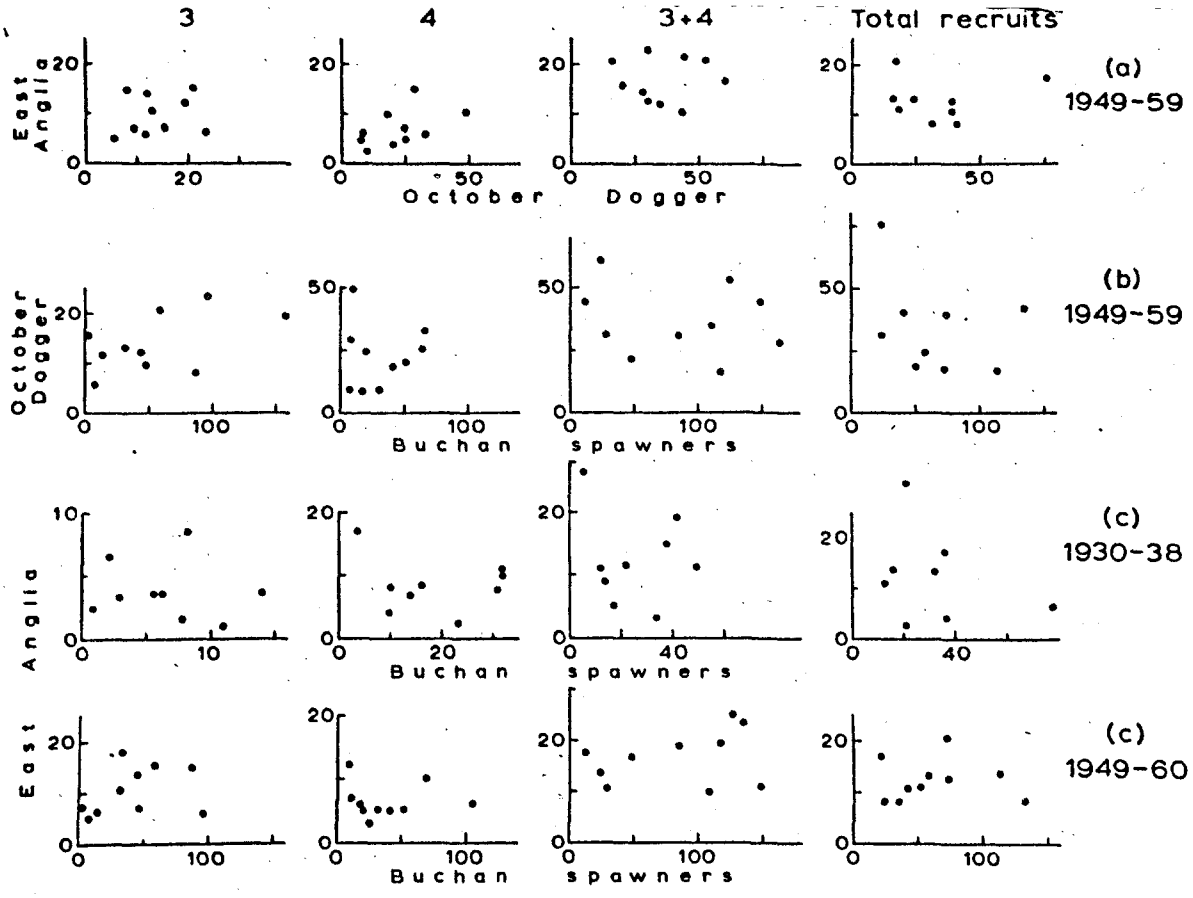


Figure 5 Year class correlation between the three autumn spawning stocks in the North Sea. In estimates of total recruitment, M was taken as 0.2 and Z from catches/effort published by Parrish and Craig (1961) and Gilis (1957, 1958 a and b, 1959, 1961).

(a) Relationships between East Anglian fish and October Dogger spawners (Belgian), at three, four, the sum of three and four year olds and as total recruitment.

(b) Relationships between October Dogger spawners (Belgian) and Buchan spawners, as three, four, the sum of three and four year olds and as total recruitment.

(c) Relationships between East Anglian fish and Buchan spawners, as three, four, the sum of three and four year olds and as total recruitment (1930-38).

(d) Relationships between East Anglian fish and Buchan spawners, as three, four, the sum of three and four year olds and as total recruitment (1949-60).

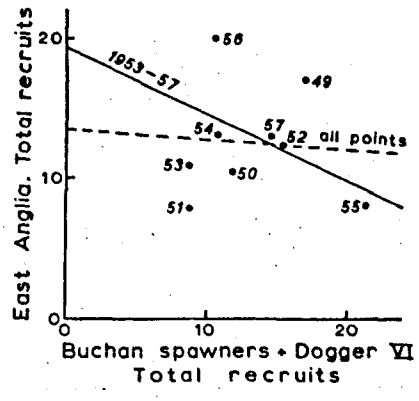


Figure 6 Relationship between total recruitment at East Anglia and the sum of total recruitments to the Dogger and Buchan fisheries.

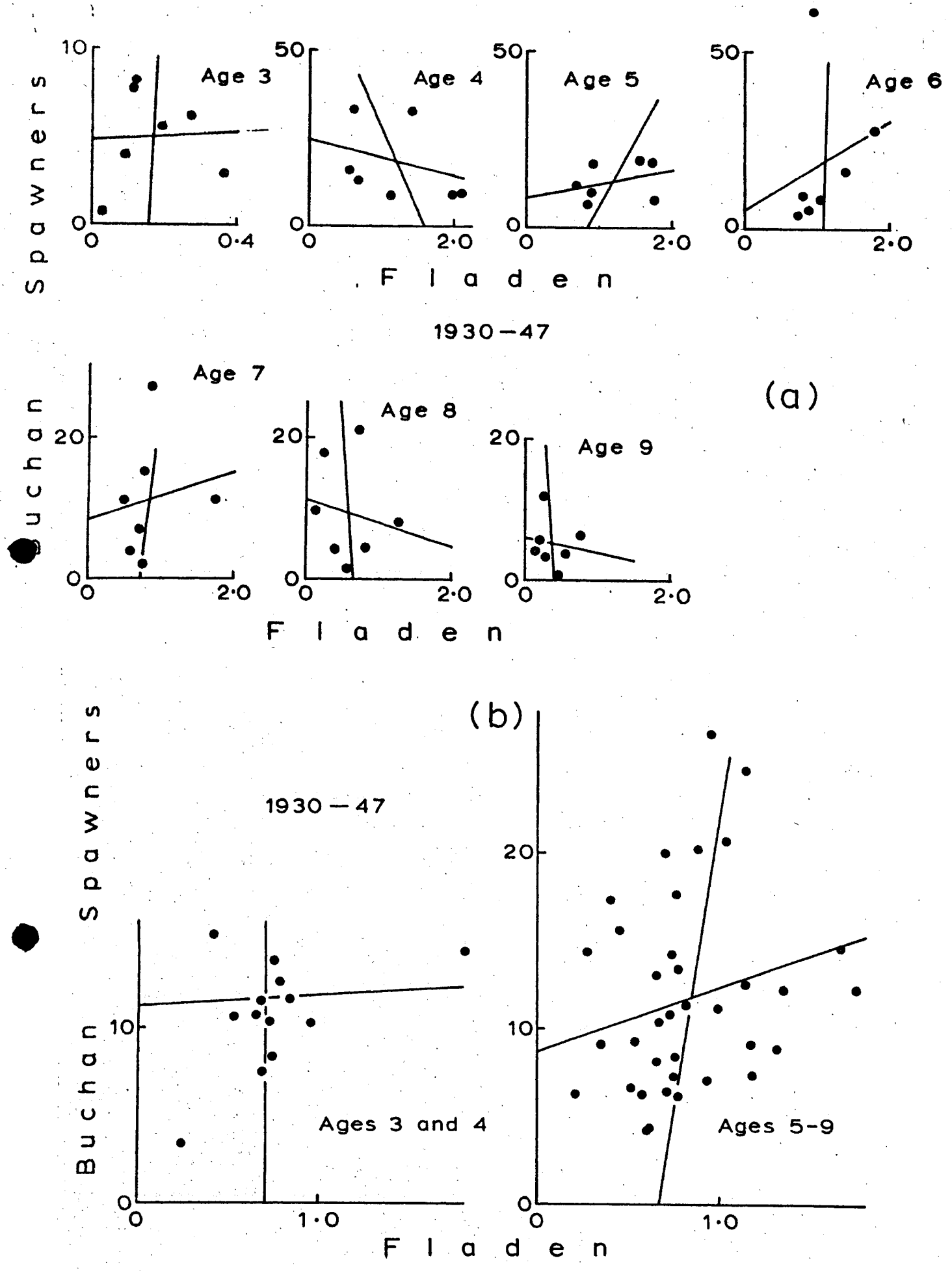


Figure 7 The relationship between Buchan spawners and the Fladen fishery in catch/effort data.
(a) Buchan spawners on Fladen, for each age separately, 1930-47.
(b) Buchan spawners on Fladen, ages 3 and 4 combined, and ages 5-9 combined and corrected for differences in mortality and abundance, 1930-47.

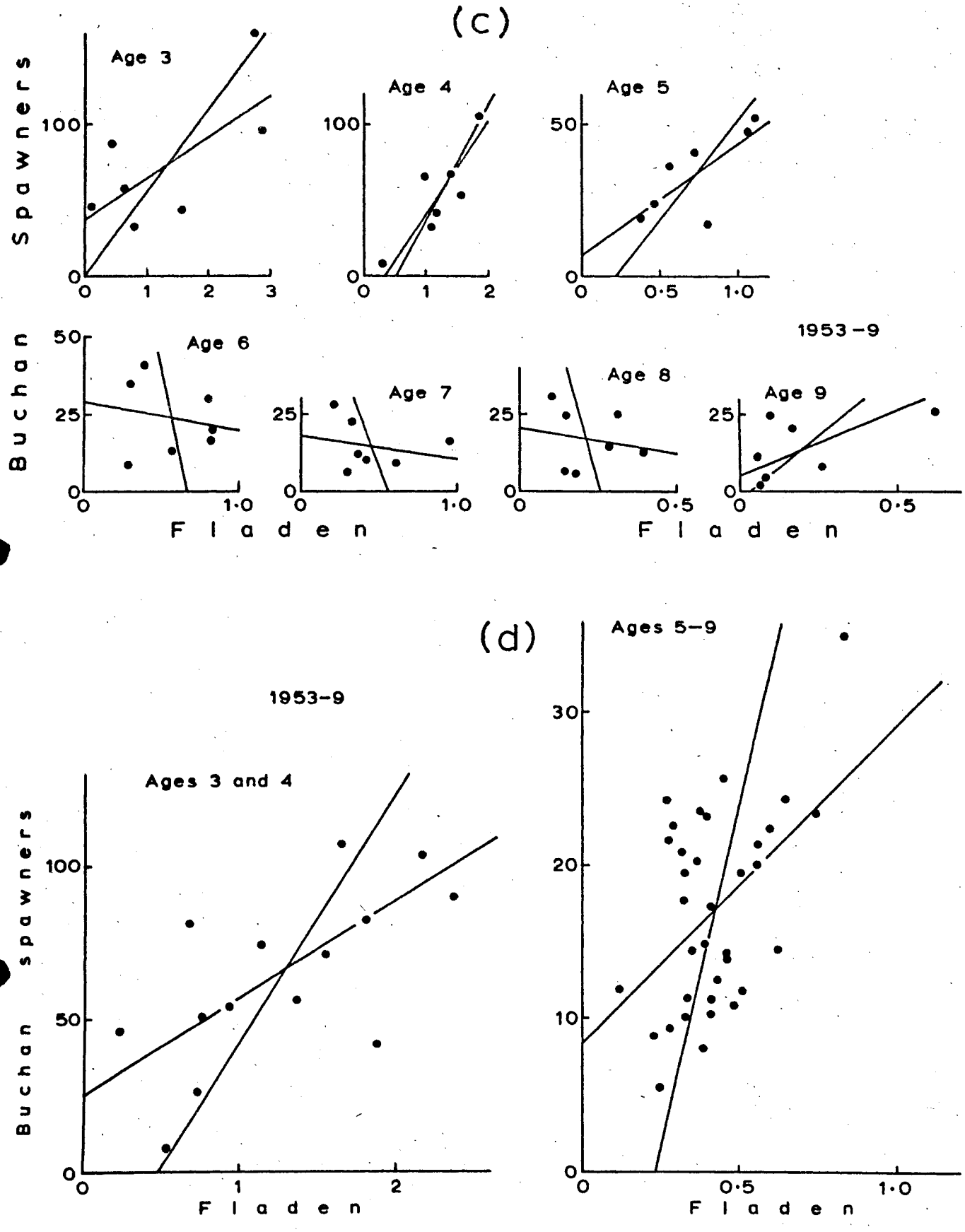


Figure 7 The relationship between Buchan spawners and the Fladen fishery in catch/effort data.

(c) Buchan spawners on Fladen, for each age separately, 1953-59.

(d) Buchan spawners on Fladen, ages 3 and 4 combined and ages 5-9 combined, corrected for differences in mortality and abundance, 1953-59.

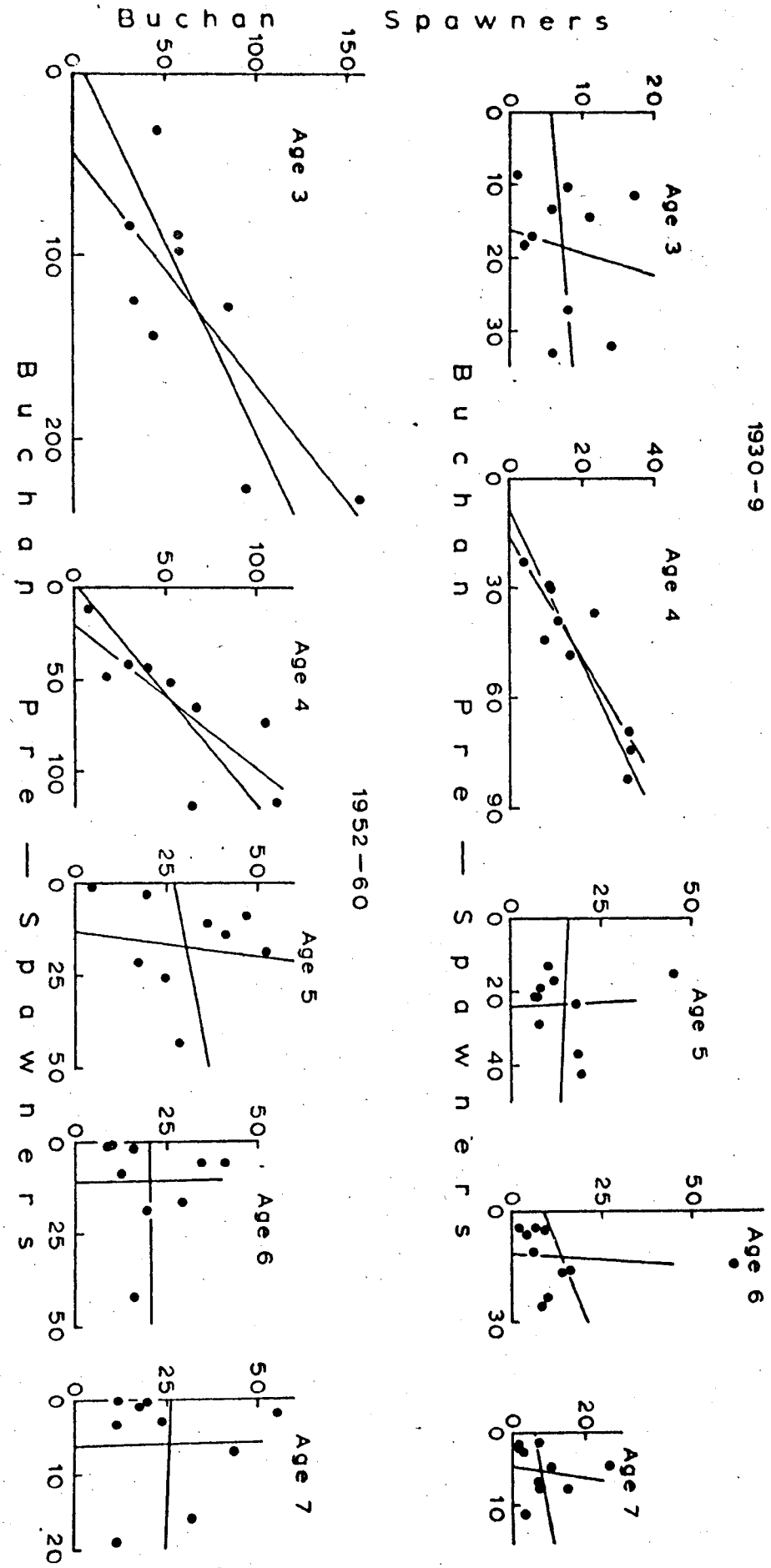


Figure 8 Relationship between Buchan spawners and Buchan pre-spawners.
(a) Buchan spawners on Buchan pre-spawners, 1930-47 and 1952-60, each age taken separately.

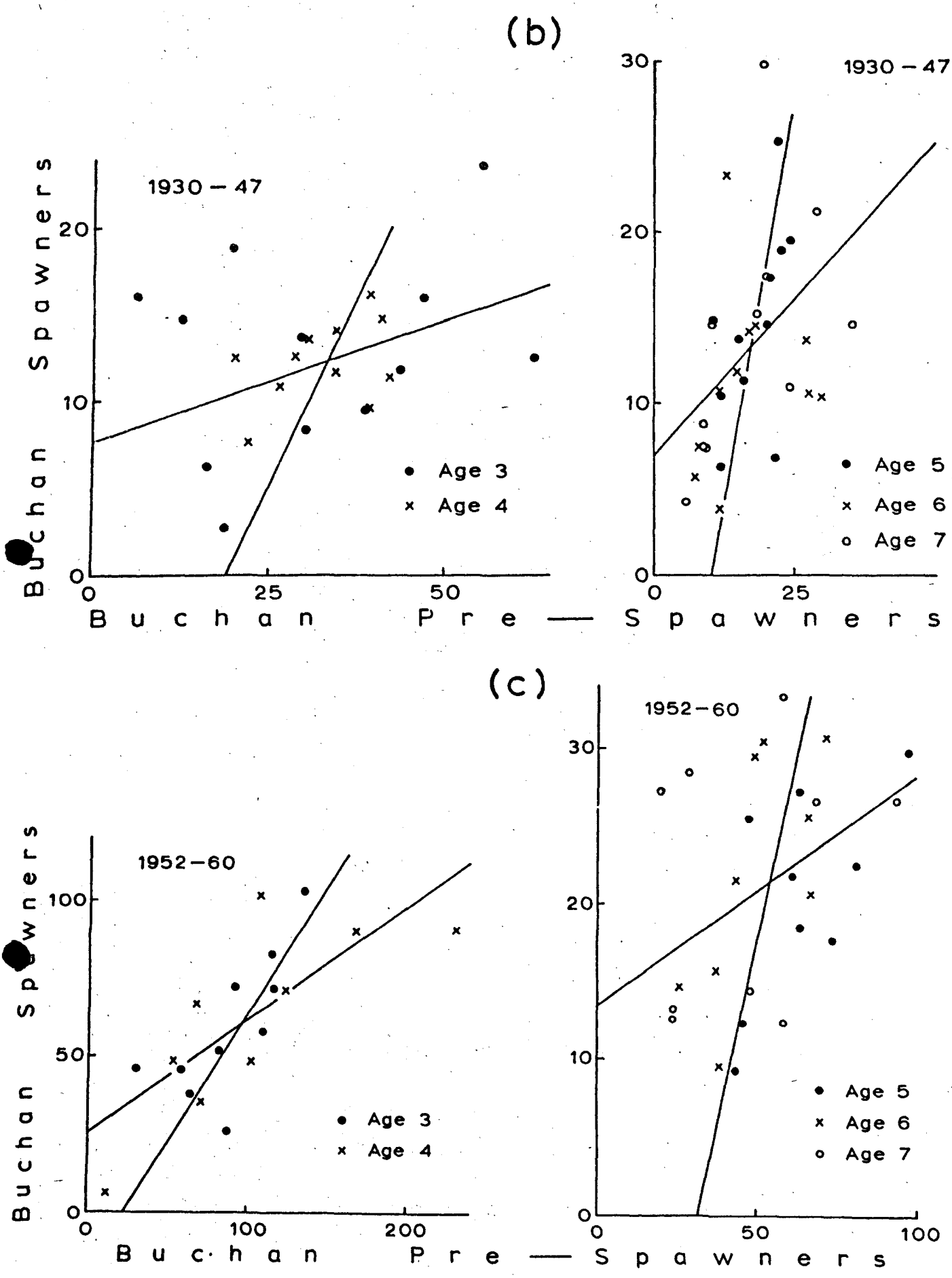


Figure 8 Relationship between Buchan spawners and Buchan pre-spawners.
(b) Buchan spawners on Buchan pre-spawners, 1930-47, (ages 3-4 and 5-7 separately), combined, and corrected for differences in mortality and abundance.
(c) Buchan spawners on Buchan pre-spawners, 1952-60 (ages 3-4 and 5-7, separately), combined and corrected for differences in mortality and abundance.

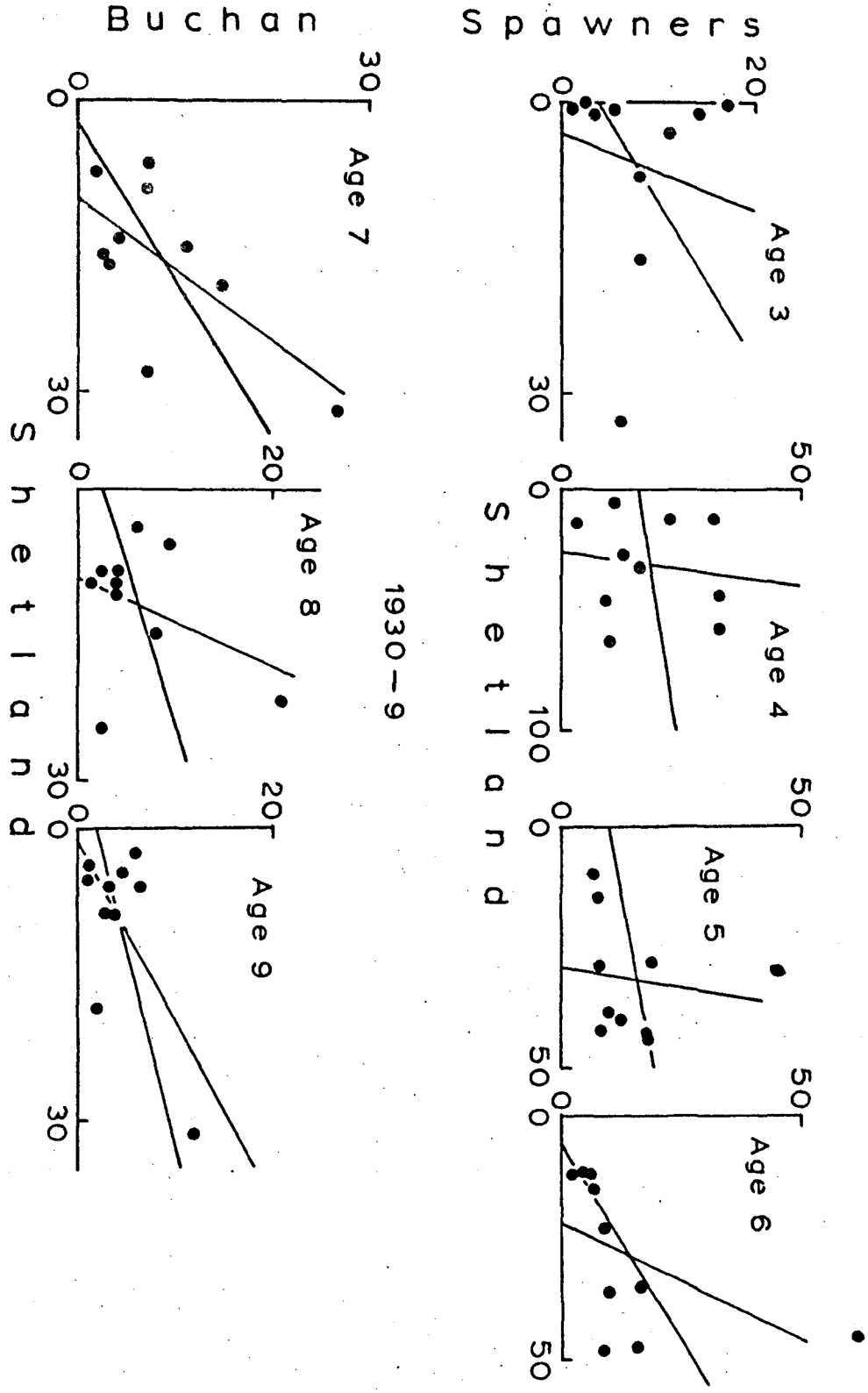


Figure 9 The relationship between the Buchan spawning fishery and the Shetland fishery in catch/effort data.
(a) Buchan spawners on Shetland, 1930-47.

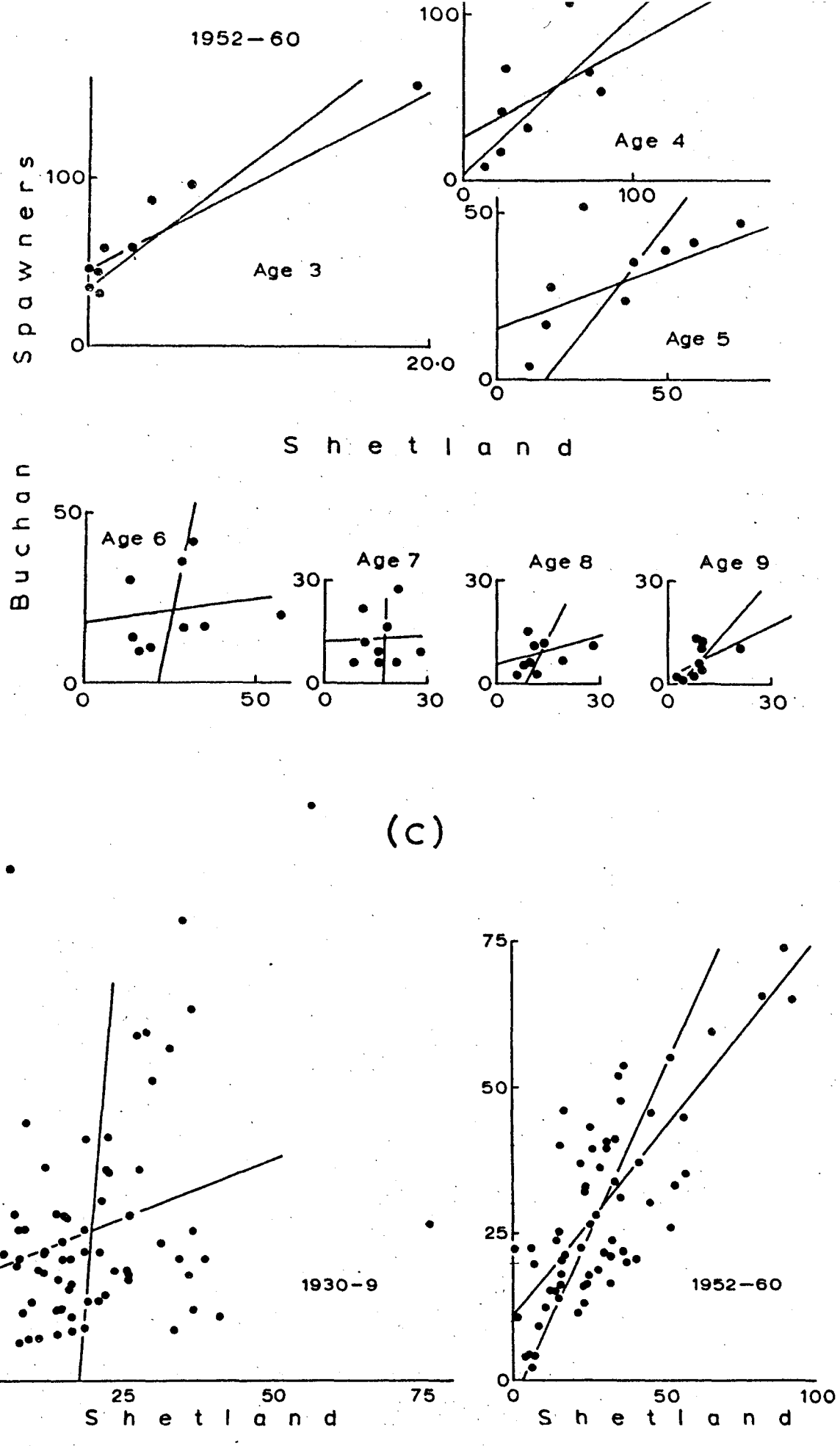


Figure 9 The relationship between the Buchan spawning fishery and the Shetland fishery in catch/effort data.
(b) Buchan spawners on Shetland, 1952-60.
(c) Buchan spawners on Shetland, combined for all ages, and corrected for mortality and abundance in both periods, 1930-39 and 1952-60.

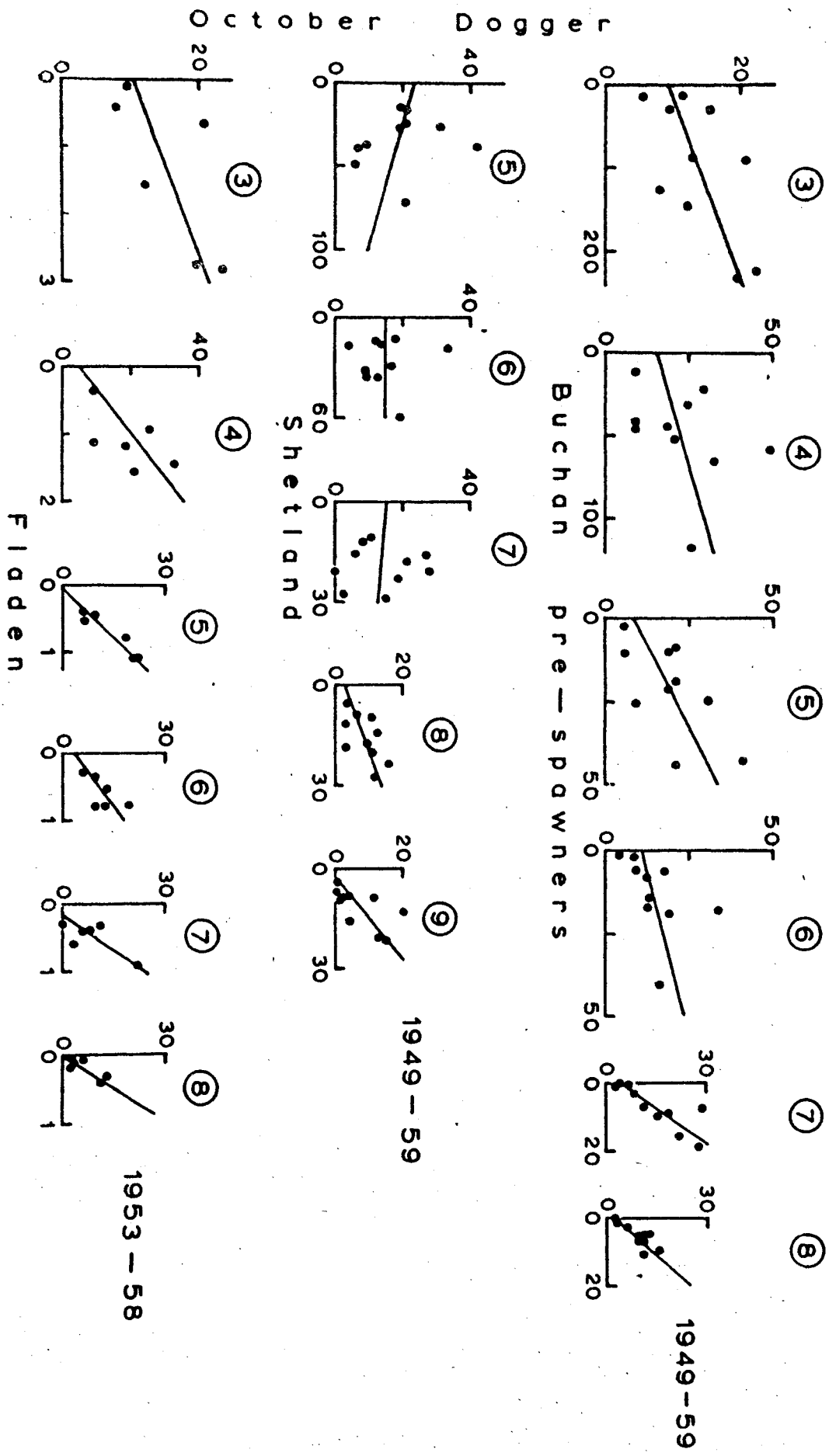
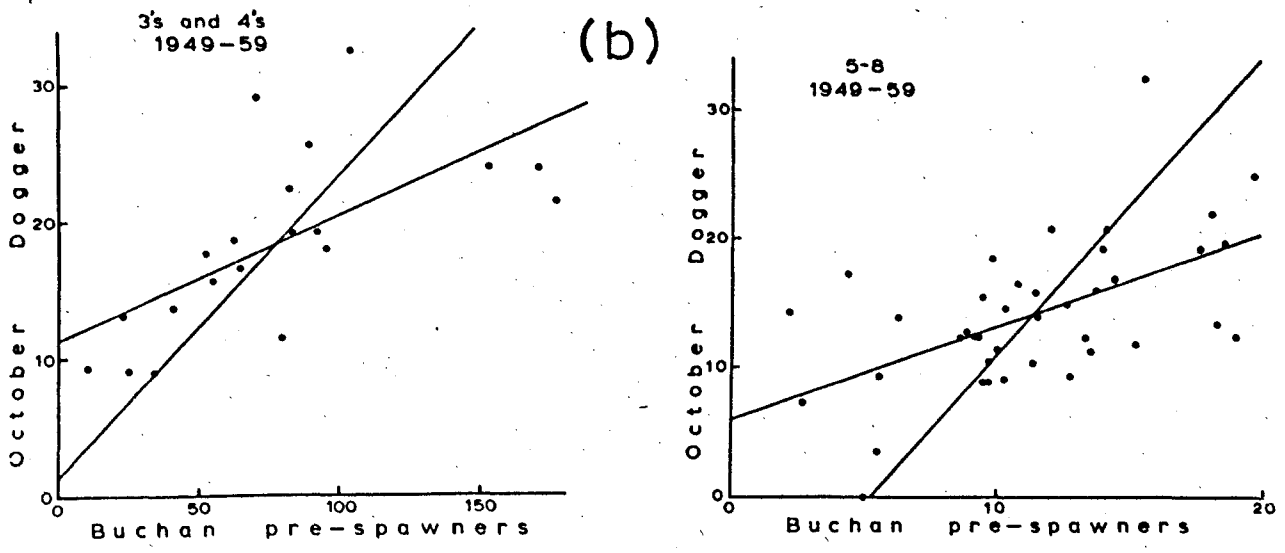


Figure 10 (a) Relationship between the October Dogger fishery and Buchan pre-spawning fishery (1949-59), Shetland (1949-59) and Fladen (1953-58), ages taken separately.



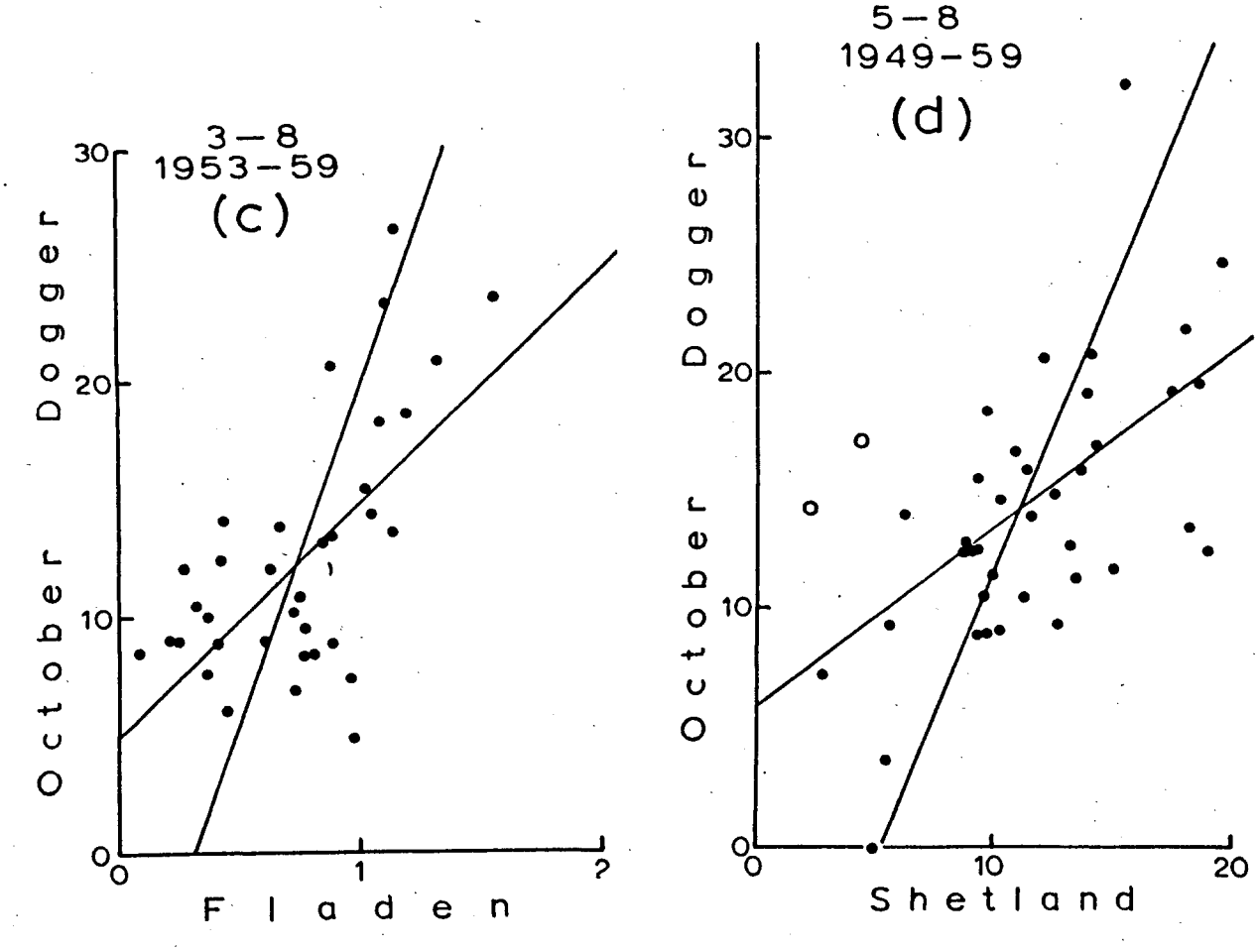


Figure 10 (b) Relationship between the October Dogger fishery and the Buchan pre-spawning fishery (three and four year olds combined; five to eight year olds combined), corrected for differences in mortality and abundance, 1949-59.

(c) Relationship between the October Dogger fishery and the Fladen fishery, all ages combined and corrected for differences in mortality and abundance, 1953-59.

(d) Relationship between the October Dogger fishery and the Shetland fishery, ages 5-8 combined and corrected for differences in mortality and abundance, 1949-59.

Ages 7 and 8 in 1959 are biassed upwards and are shown as open circles.

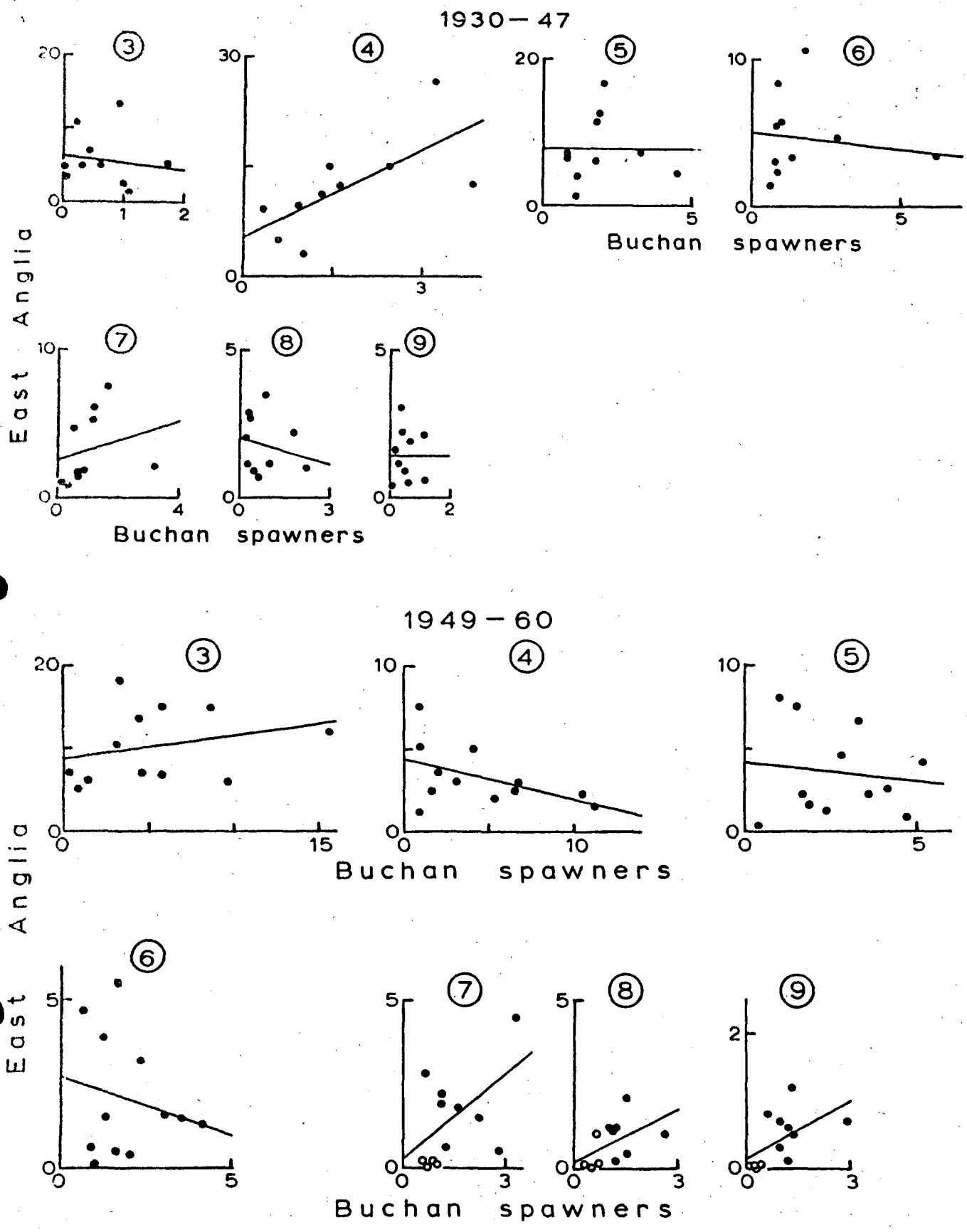


Figure 11 Relationship between East Anglia and the northern fisheries. (a) East Anglia on Buchan spawners 1930-47 and 1949-60, each age taken separately. The open circles for ages 7, 8 and 9 in the period 1949-60 refer to the years 1957-60.

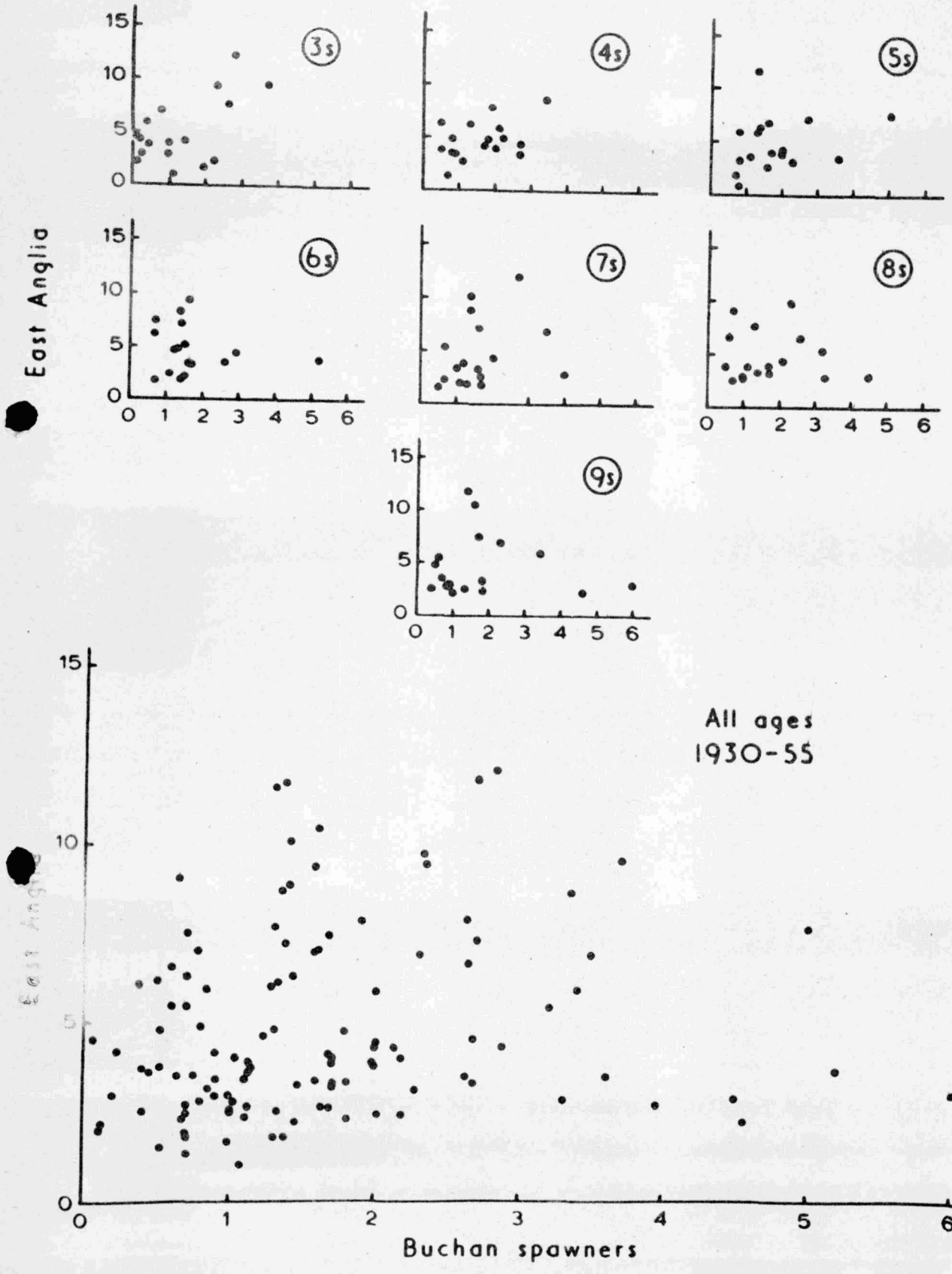


Figure 11 Relationship between East Anglia and the northern fisheries.
(b) East Anglia on Buchan spawners, data combined for the period 1930-55 and corrected for differences in mortality and abundance.

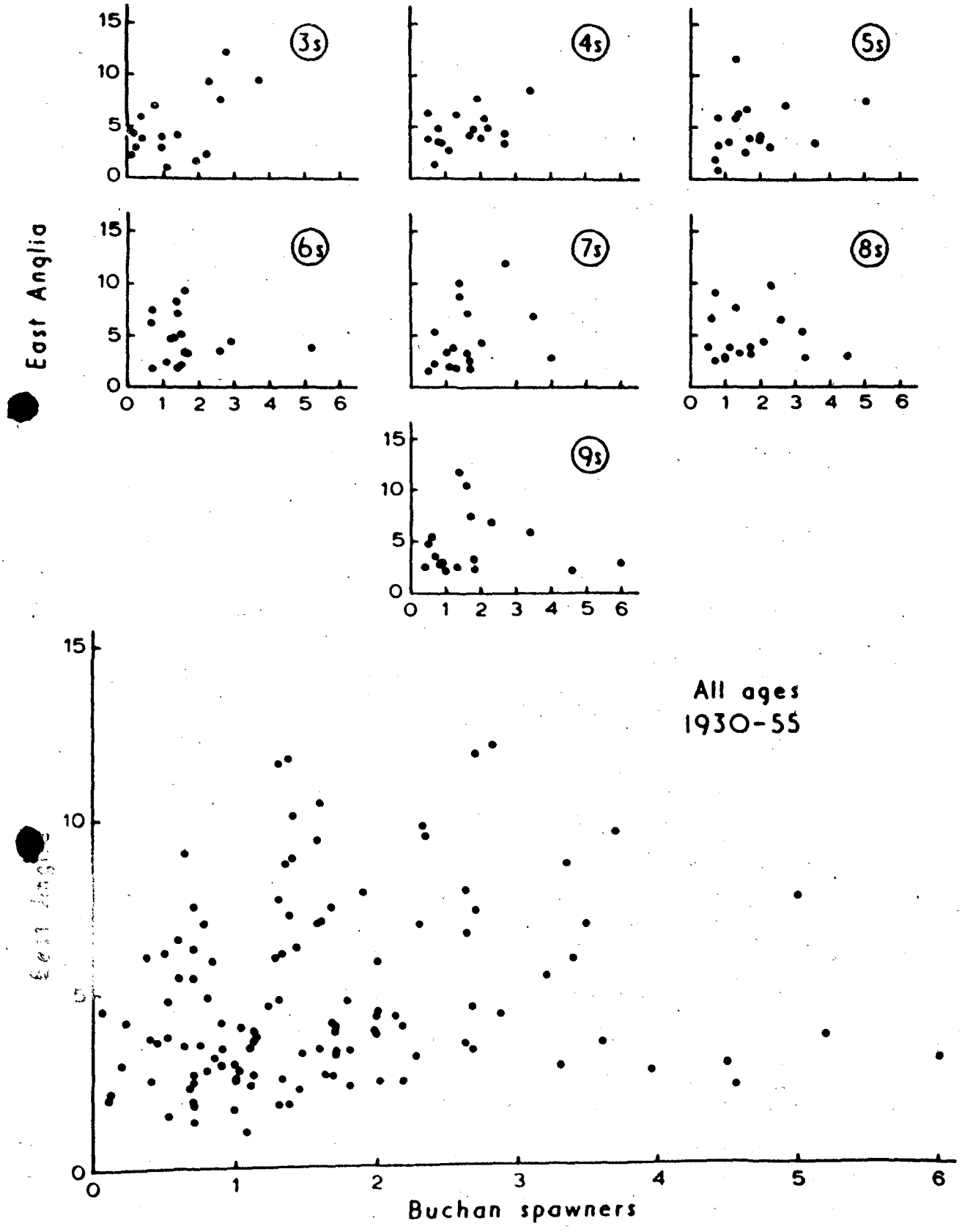


Figure 11 Relationship between East Anglia and the northern fisheries.
(b) East Anglia on Buchan spawners, data combined for the period 1930-55 and corrected for differences in mortality and abundance.

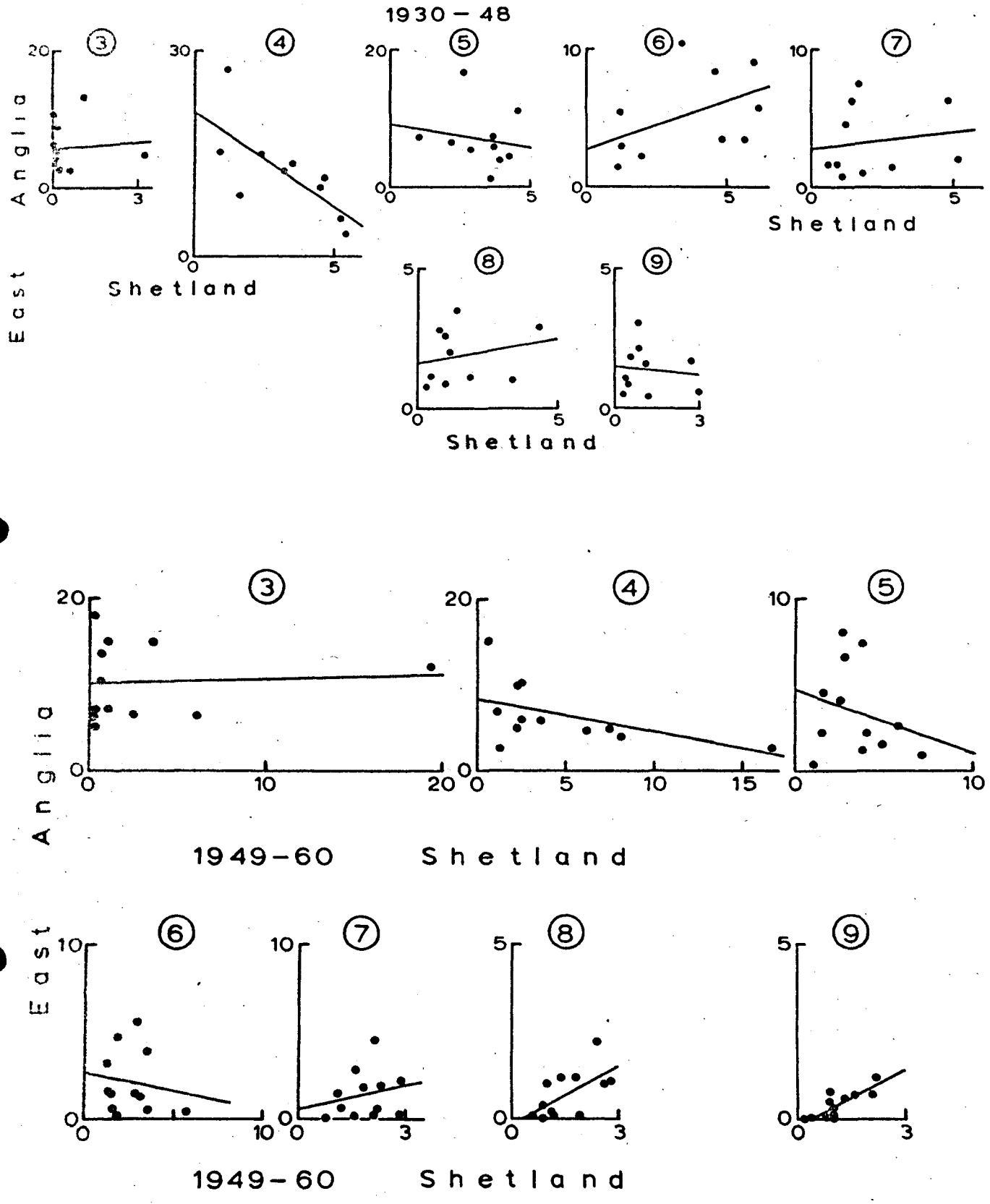


Figure 11 Relationship between East Anglia and the northern fisheries.
(c) East Anglia on Shetland, 1930-48 and 1949-60, each age taken separately.

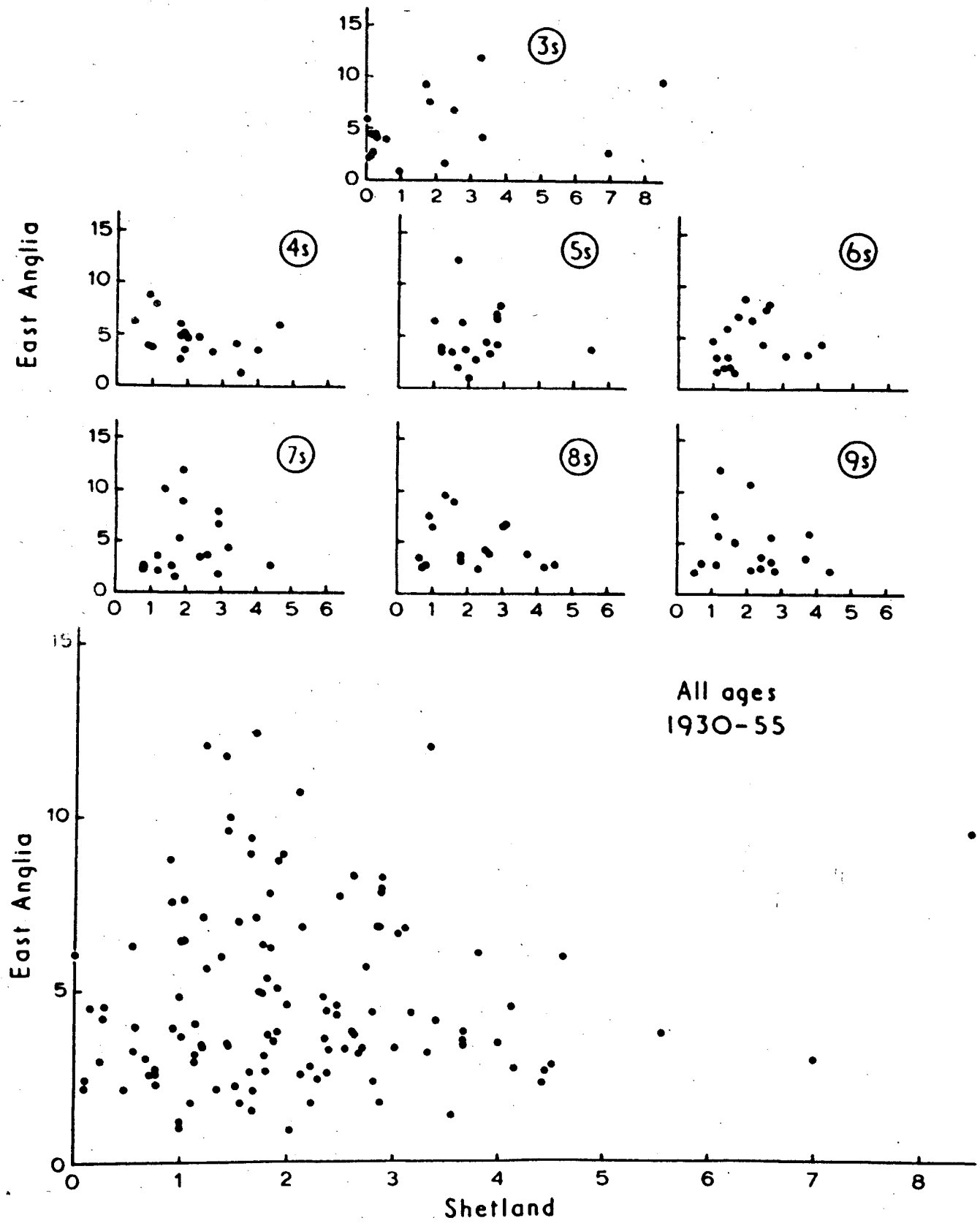


Figure 11 Relationship between East Anglia and the northern fisheries.
(d) East Anglia on Shetland, data combined for the period 1930-55 and corrected for differences in mortality and abundance.

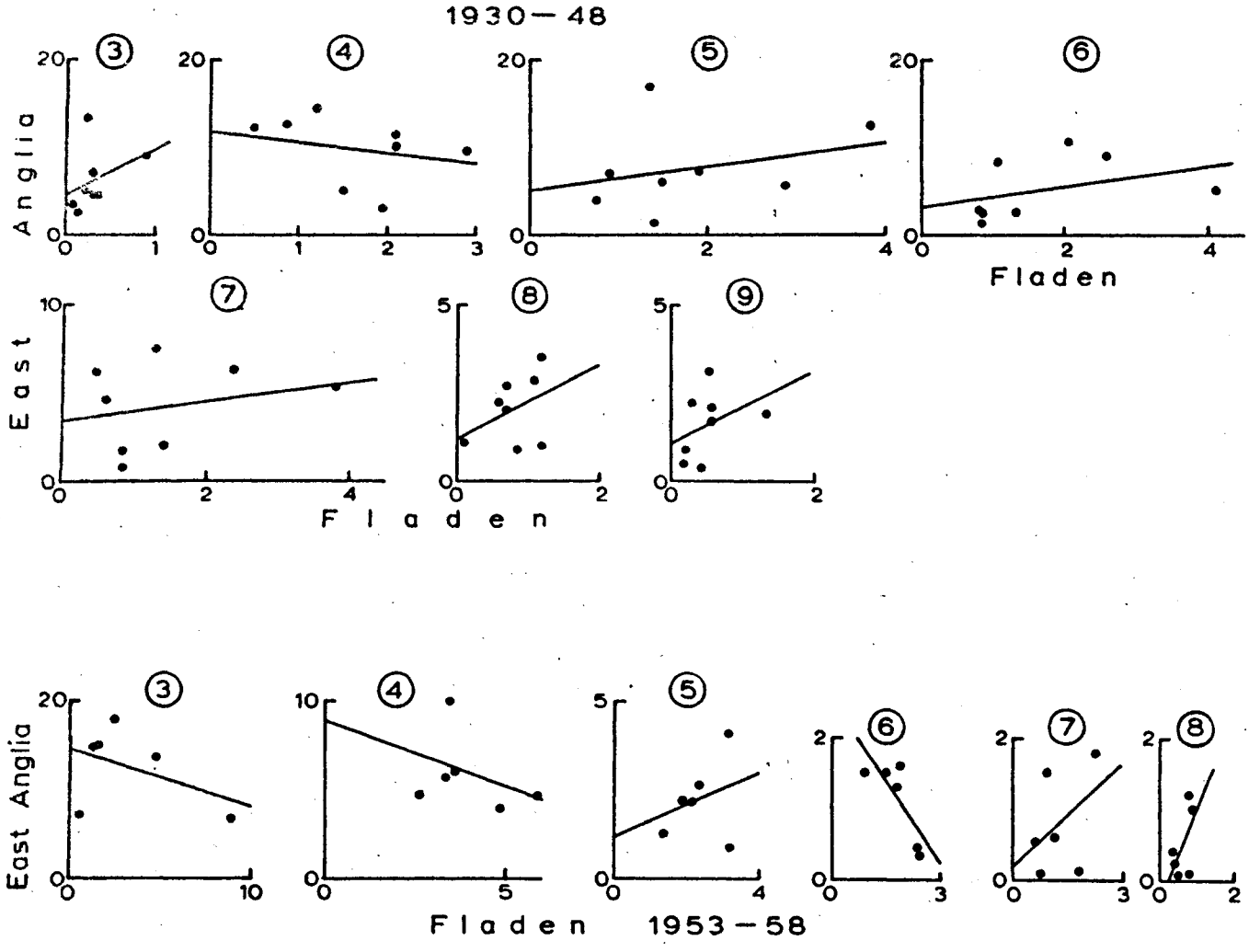


Figure 11 Relationship between East Anglia and the northern fisheries.
(e) East Anglia on Fladen, 1930-48 and 1953-58, each age taken separately.

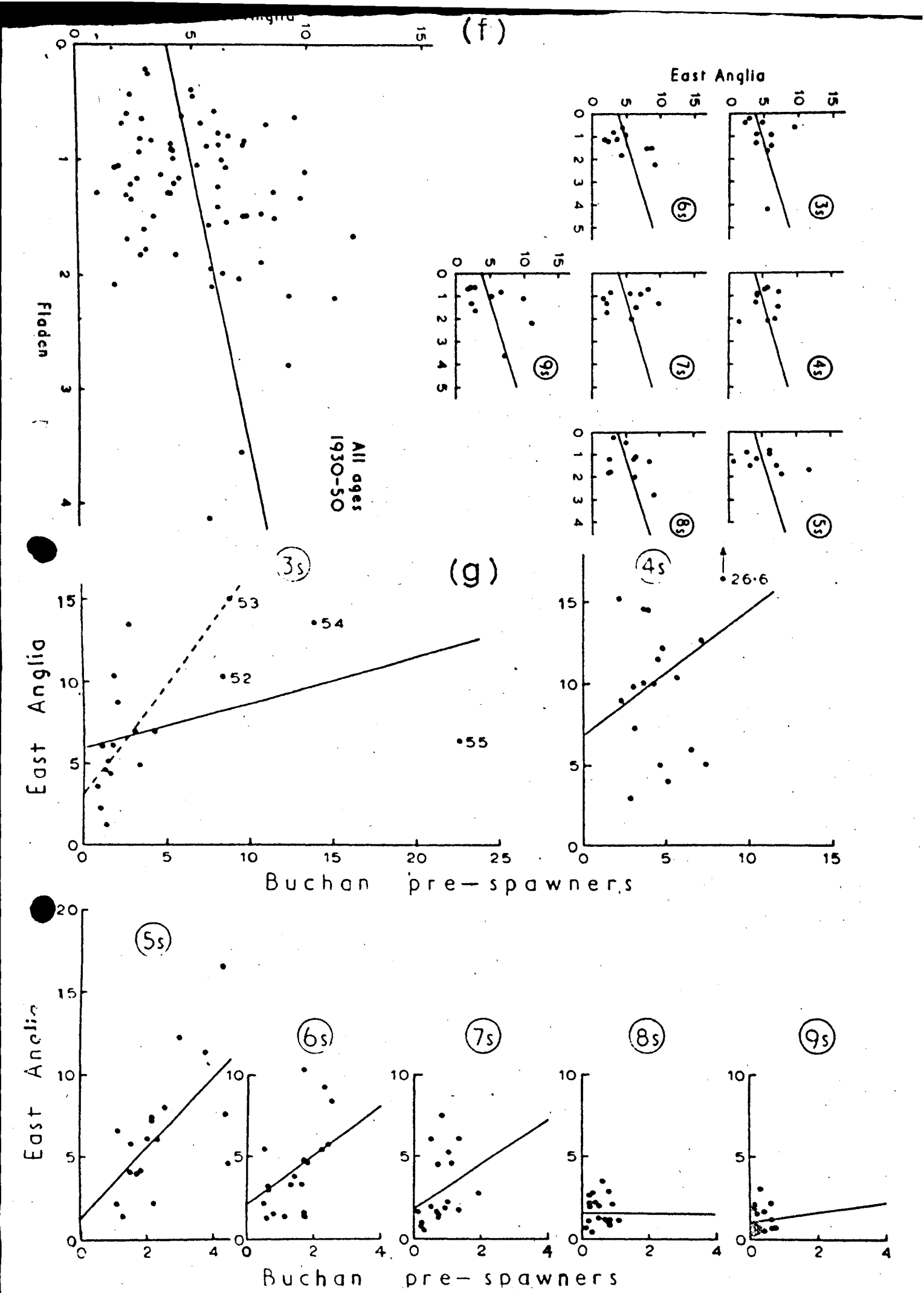
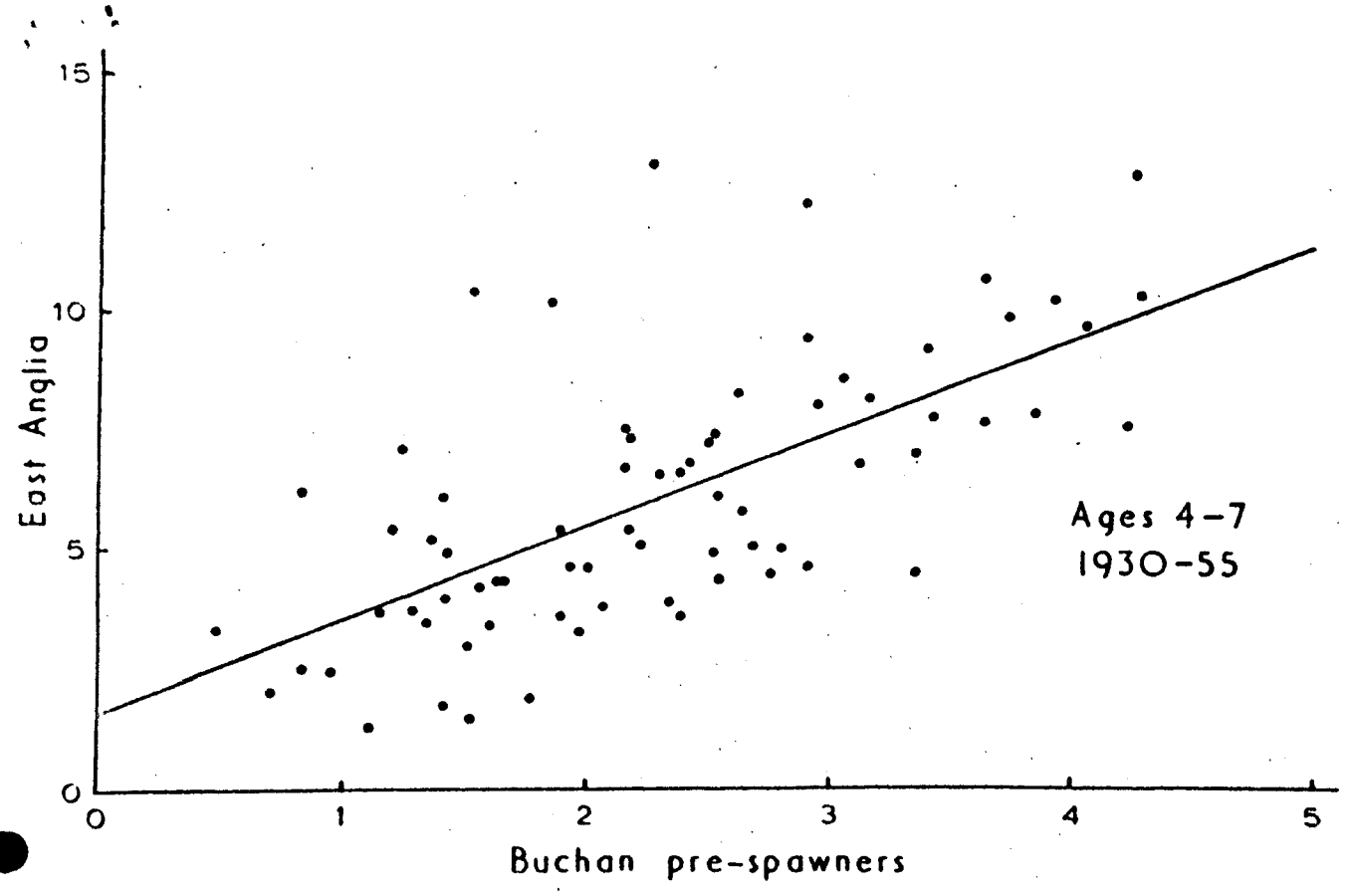


Figure 11 Relationship between East Anglia and the northern fisheries.
(f) East Anglia on Fladen, 1930-50 data combined and corrected for differences in mortality and abundance.
(g) Relationship between East Anglia and Buchan pre-spawners 1930-55, each age taken separately.

X.622850



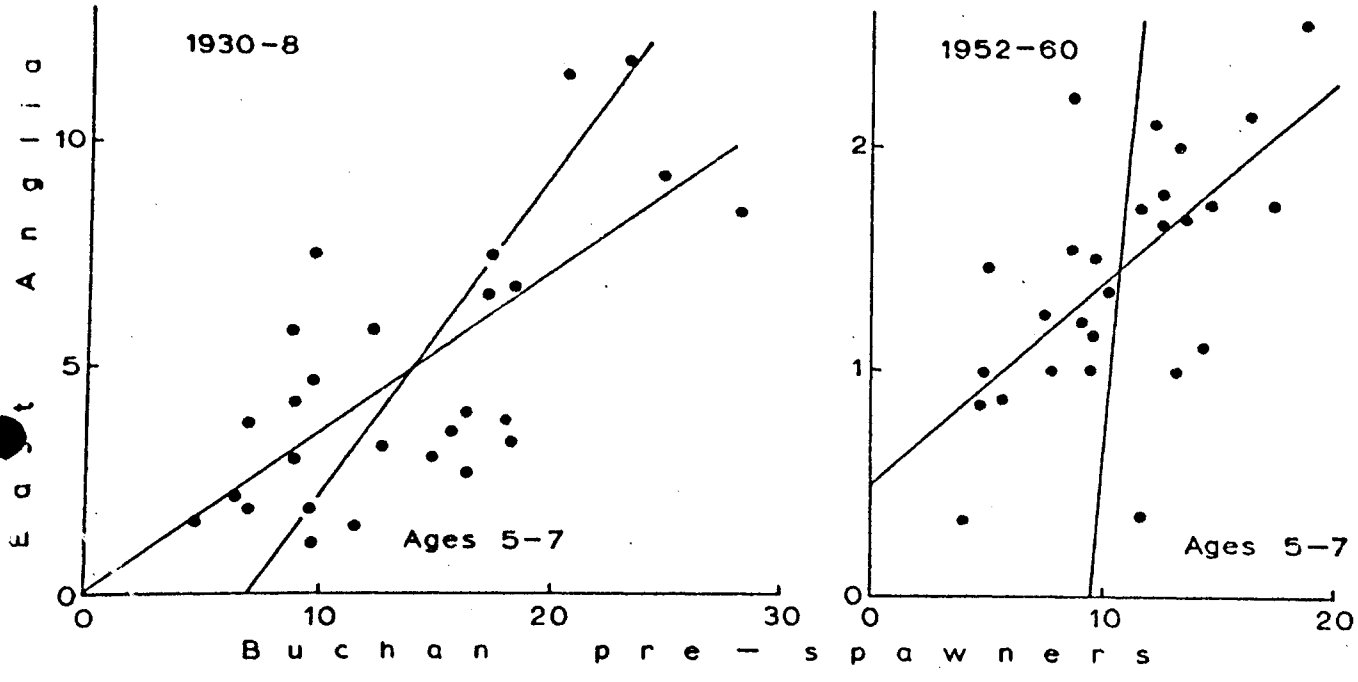


Figure 11 Relationship between East Anglia and northern fisheries.
(h) Relationship between East Anglia and Buchan pre-spawners 1930-55 (ages 4-7), combined and corrected for Differences in mortality and abundance. The figure also gives the separate regressions in combined data (for ages 5-7) for the two periods 1930-38 and 1952-60.

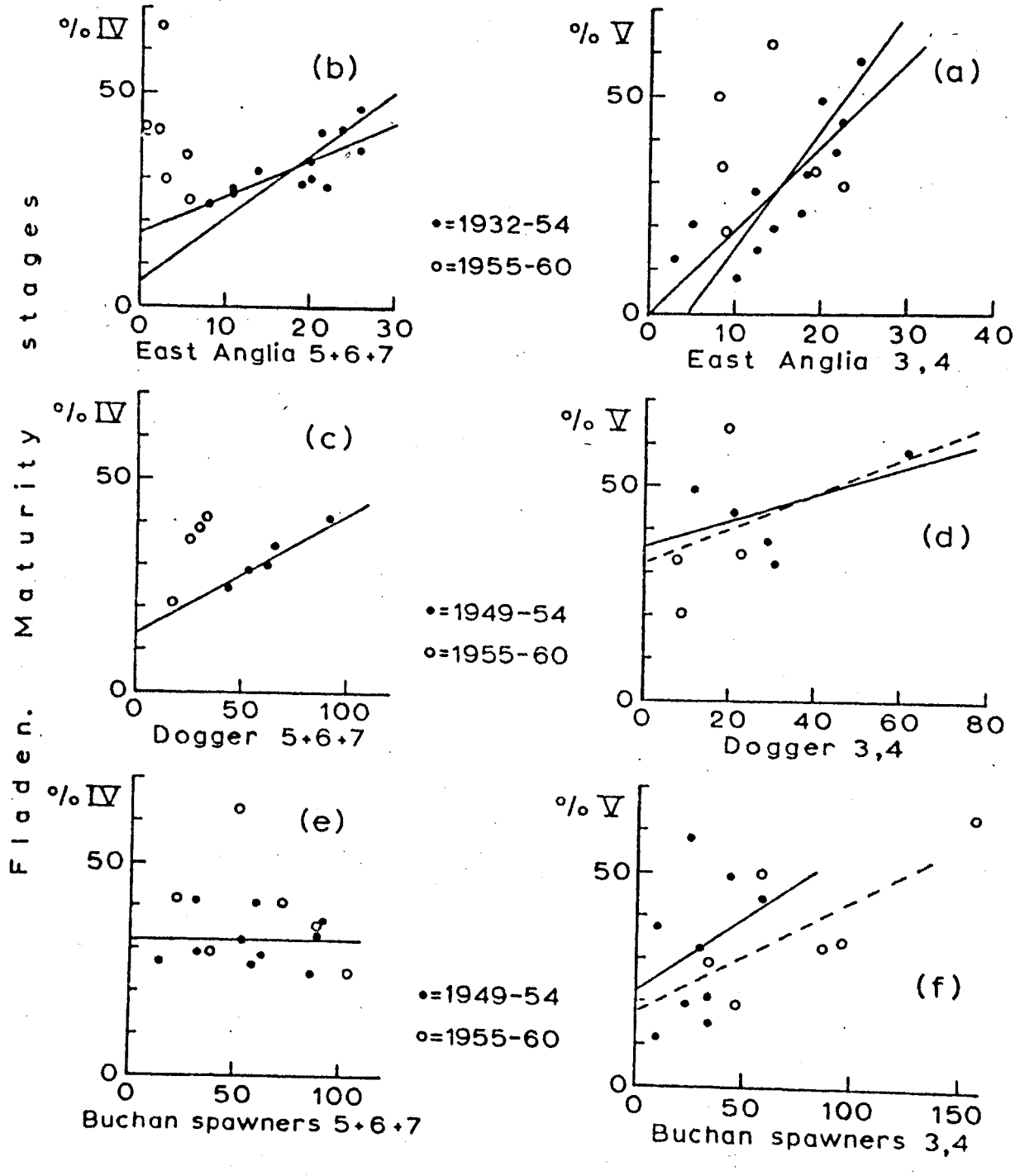


Figure 12 Relationships between the percentages in maturity stages IV and V on the Fladen and catches per effort of "recruit" (three and four year old) and "middle aged" fish (five, six and seven year old) of the three spawning stocks.
(a) East Anglian "recruits" and % stage V on Fladen;
(b) East Anglian "middle aged" fish and % stage IV on Fladen;
(c) Dogger "middle aged fish" and % stage IV on Fladen;
(d) Dogger "recruits" and % stage V on Fladen;
(e) Buchan "middle aged" fish and % stage IV on Fladen;
(f) Buchan "recruits" and % stage V on Fladen.

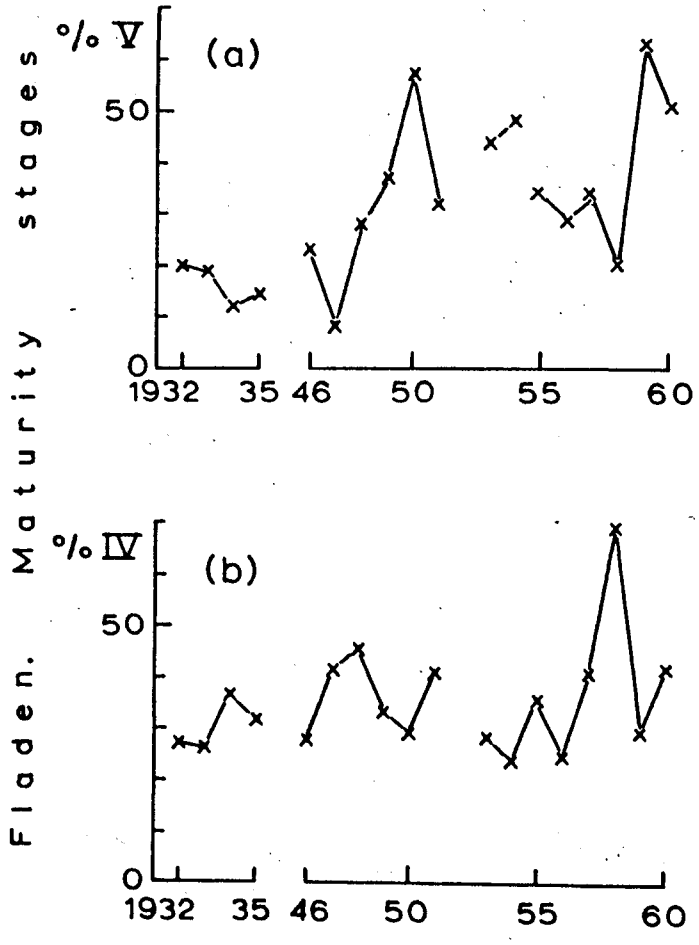


Figure 13 (a) Time series of maturity stage V, 1932-60, on Fladen;
(b) Time series of maturity stage IV, 1932-60, on Fladen.