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TREND ANALYSIS OF DISSOLVED NUTRIENTS IN THE SOUTHERN BIGHT OF THE NORTH SEA. RESULTS AND SUGGESTIONS.

by

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ABSTRACT.

The increase of nutrients in estuaries and riverplumes in the North Sea has been reported by various authors. Outside these regions an unambiguous effect of the increased discharge is more difficult to establish. Often salinity-nutrient relationships are used to "normalize" the scattered observations for one salinity. However, the conditions for which such "mixing lines" can be used are not likely to be met in open sea waters in all situations. Problems arise from the presence of different water types and from time variations, including the problem of the brief period in winter when nutrients can be considered as to be conservative.
It is proposed to consider only well-defined water masses when analyzing nutrient data sets from a number of years. This improves the homogeneity of the data set. Such an approach is applied to the Channel Water mass in the Southern North Sea.
By establishing for each set available a linear nutrient-salinity relation, the nutrient concentrations for the observation times can be assessed. Time variations in the concentrations of PO4-P, NO3-N and SiO4-Si are discussed. Indications for an increase of phosphate can be found in the Channel Water, but the variability is large. Towards the coast there are also indications for an increase of nitrate, both along the continental and along the UK coasts. But the large variability points to other effects that are of equal importance. Larger data sets are necessary to eliminate the statistical scatter, and further study of both biological effects in the winter and the role of hydrographic variations is required.

INTRODUCTION.

Different studies have shown that the nutrient load of rivers and the nutrient transport to the sea have increased since the middle of this century. For a discussion, see Dickson et al., 1988 and van Bennekom and Wetsteijn, in press. In coastal waters the effect on the nutrient conditions has been shown by different authors: by Folkard and Jones (1974), by van Bennekom et al. (1975) and by Postma (1978) for the Southern Bight, by Weichart (1986) and by Radach and Berg (1986) for the German Bight. These coastal areas are characterized by marked river plumes, extending into the sea. The question we here are facing is, whether it is possible to demonstrate this effect also for more open North Sea waters. This question was addressed by Dickson et al. (l.c.) for the waters bordering the UK east coast, and that are characterized by dispersed discharges by many smaller rivers, where river plumes of the extent found along the continental coast don't exist.In this study nutrient-salinity regression lines are used for normalization of the data.
The use of nutrient-salinity regression lines is regular practice in estuarine studies. There are some implicit assumptions connected that should be discussed when using this practice under somewhat different conditions that exist in the open sea.

THE USE OF NUTRIENT-SALINITY REGRESSION LINES.

In the case of a conservative tracer that is discharged with fresh water in sea water, we may expect a good linear tracer-salinity relation, as long as two conditions are fulfilled:
1). There are only two "watertypes" (to be defined here on the basis of salinity-tracer concentration). This is usually the case in estuaries, but may not be the case in the open sea.
2). The typical time-variations that occur in the tracer concentrations for both watertypes are short compared with the typical mixing time of the area considered. Estuarine mixing times (e.g. estimated from the quotient of the fresh water fraction in the estuary divided by the river discharge rate) vary over a wide range of values and the results of salinity/tracer studies depend very much on the right conditions.

In the case of nutrients the "tracer" is not conservative, at least not during the larger part of the year, when exchange takes place between the hydrographical compartments and the biological compartments through which the nutrients circulate. For estuaries, with usually high nutrient loads, other factors than the concentration are usually the limiting factor for plankton production, and although a strictly linear relation is not likely to be found, often there is still a consistent non-linear relation between salinity and nutrients. In those cases one applies sometimes a straight "theoretical mixing line" in order to estimate the exchange with biological compartments in the estuary from the deficit or surplus between observed and theoretical values.

PROBLEMS ENCOUNTERED IN THE OPEN SEA.

In the open sea, outside the estuaries or the river plumes (that can be considered as outward extensions of the estuaries) one meets difficulties because the assumptions here are not sure to be fulfilled. At the low-salinity

side more rivers may be discharging with different nutrient concentrations and different discharge volumes. The silicate/salinity relations from the Rotterdam Waterway (Rhine and Meuse), Scheldt and Seine rivers in the Southern Bight are discussed by van Bennekom and Wetsteijn (l.c.) as water type characteristics for discriminating different plumes.
At the high-salinity side the problems appear to be not so serious, as the differences in nutrients between the various North Sea water masses are small compared with other variations. However, if we wish to study eutrophication exactly in offshore waters, we should be concerned about such small differences, as might occur between, for instance, Channel Water and Central North Sea Water.
The North Sea boxes that are used in open-sea studies usually are large, compared with estuarine volumes. This means that variations in the input from rivers may be largely levelled-out during the relevant mixing times. In principle the long-term variations may be studied with such boxes, using data-sets from different years. However, the biological production gives complications. The open sea may become fully depleted from anorganic dissolved nutrients by plankton growth in the spring, and comparatively large deficiencies may occur over the largest part of the year. It is generally assumed that in the winter the productivity is low enough to assume that (after allowing some time interval for remineralization) the dissolved inorganic nutrients are quasi-conservative. However, the length of this winter period might be shorter than often assumed. It is shown by van Bennekom and Wetsteijn (l.c.) that in the eastern Southern Bight plankton growth is locally significant even in february. So, quasi-conservative behaviour of dissolved nutrients may be found for only two months. As this period becomes comparable or even shorter than the mixing time of an open-sea box, we may expect complications. Local concentration differences have no time to become levelled-off, and year-to-year differences may occur.
Concluding, we are left with the problem that the physical significance of a nutrient-salinity relation for the open sea as used by Dickson et al. is not very clear.
In the following we have attempted to follow a slightly different approach in order to tackle the same problem.

WATER MASS APPROACH.

Instead of combining all data from a large geographical box, we prefer to restrict ourselves to the data that can be assumed to belong to a selected water-mass.
Water masses in the North Sea are characterized by their salinity range and their geographical setting. We here deal with the water mass "Channel Water", entering the North Sea via the Straits of Dover, having salinities >34.75 (Lee, 1980), with typical maximum values of 35 psu. This water mass itself is admixture of oceanic water entering the Channel in the west and water from the English and French coasts. We therefore may expect two nutrient-salinity relations, one for the eastern and one for the western flank of the water mass.
The data used are from the sets collected in the winter months (january and february) by the Netherlands Institute of Sea research (years 1968,'69,'74,'75,'76 and '78) and by the Fisheries Laboratory at Lowestoft (years 1961,'62,'74,'75,'76 and '77). Data were selected from latitudes between 51°06' (Straits of Dover) and 51°48' (South of the Rhine plume) and with salinities of 33 psu and higher, in order to have only one well-mixed low-salinity water mass

at either side (see fig.1). The area covered is rather small, and it is assumed that during the short winter period of quasi-conservative behaviour of dissolved nutrients over an area of this size the largest time-variations are levelled-off. These assumptions therefore allow the application of regression lines to this data set.

ANALYSIS.

From these observations, for each set separately, data were selected from only one (usually near-surface) depth, in order to avoid bias towards deeper series. These data were divided into three groups: the central group (salinity above a variable limit S) and the eastern and western groups (salinities between 33 and S), according to their geographic position with respect to the central group. The limiting salinity S was chosen on the following criteria: if the maximum observed S(max) was higher than 35 psu, S = S(max)-0.5 ; if S(max) was 35 psu or less, S(max) was fixed at 34.5 psu. It is clear that with these rules the number of data per group is faily reduced, compared with the purely geographic criterium. The central group was always present in the sets, the western group sometimes was not represented at all, or only with just one data point (in which case this group was disregarded). The eastern group was always present, but on one occasion with just one point. In that case, again, the data were not used.
Taking each set separately (thus each year separately), for the central and eastern groups combined an eastern nutrient salinity line was calculated, and for the central and western groups (when present) a western regression line. The results are given in Table 1 for phosphate, nitrate and silicate.

DISCUSSION.

Taking a salinity of 35 psu as representative for the Channel Water in the Southern Bight, we can investigate the variations in the dissolved nutrients in the course of the period 1960-1980. The results are plotted in fig.2 - fig.4, discarding the results with a too low reliability (exceedance more than 5%). These results are marked with an asterisk in Table 1.
The relatively large statistical margin of 5% means that the estimates for concentrations in the Channel Water may have rather wide limits of uncertainty. Yet the values found do vary appreciably, and reflect, at least partly, real variations.
The phosphate values show a tendency to increase, but in the years 1974 to 1979 along with high values also low values do occur. The nitrate values show minimum values in the data from 1968, 1969 and 1974. Silicate (apart from the low value in 1968) is more stable over the period considered. It should be noted that the anthropogenic silicate discharge has not been increasing recently, like the phosphate and nitrate. If we may consider the silicate variations found here as (at least partly) due to "natural" causes (consumption or hydrographic variations) it is possible that similar effects can occur in the phosphate and nitrate values. Note that the low values in 1968 and 1969 have been observed in february. Dickson et al. also suggested relatively low values for nitrate in these years. However, whether these low values are part of a long-periodic oscillation, as suggested in that publication, or are just incidental (as is the case if consumption in februari is the cause) we are unable to decide.
One furthermore may presume that for open North Sea waters the influence of variations in water circulation becomes relatively important, compared with the

river discharge. This effect is not fully reduced by the water mass approach used here. However, as long as there are no more data available, it will be difficult to come to firm conclusions.
The trends outside the axis of the Channel Water are illustrated by the extrapolated concentrations at a salinity of 33 psu. and by the slopes of the regression lines.
The numbers in Table 1 show also a rising trend for nitrate and phosphate, both for the eastern and the western flanks.
Variations in silicate are more irregular, in accordance with the findings for the axis of the Channel Water.
Again, we only can find indications of trends and variations and cannot attain firm conclusions. More data are required. Given more data, it is believed that, where possible, an approach based upon water mass characteristics should be preferred. It is likely, however, that variations found not only will reflect anthropogenic effects but that also variations in the circulation of the North Sea will be of importance for the difference from one year to the other.

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Explanation to Table 1

n(e), n(c), and n(w) are the numbers of data points from the eastern, central and western groups respectively.
R is the correlation coefficient. The number of data points for the eastern and western flanks are n(e) + n(c) and n(c) + n(w), respectively.
Non-significant (5%) results indicated with an asterisk (*)
P(33), N(33) and Si(33) are the calculated values for the concentration of phosphate, nitrate and silicate at a salinity of 33 psu.
P(35), N(35) and Si(35) are equally the concentrations for 35 psu.
P(ch), N(ch) and Si(ch) are the weighted averages of the latter values for the combination of eastern and western water, and is taken representative for Channel Water values.
The slope of the regression lines is given in column b.
Concentrations in µmol / litre.

TABLE 1

PHOSPHATE

year	m	n(e)	n(c)	n(w)	eastern flank R	P(33)	P(35)	b	western flank R	P(33)	P(35)	b	P(ch)
1961	j	2	3	3	.82	.67	.44	−0.11	.98	.88	.42	−0.23	.43
1962	j	2	7	1	.36*	.80	.66	−0.07					–
1968	f	6	1	–	.81	.85	.45	−0.20					.45
1969	f	3	3	–	.86	.87	.55	−0.16					.55
1974	j	4	4	–	.97	2.53	.98	−0.77					.98
1974	f	1	3	1	data not used				data not used				–
1975	j	3	5	2	.91	2.11	.70	−0.70	.96	2.07	.70	−0.69	.70
1975	j	23	2	–	.88	1.66	.48	−0.59					.48
1976	j	2	3	8	.86	1.38	.57	−0.40	.66	2.08	.49	−0.79	.51
1976	j	5	6	–	.86	1.53	.66	−0.43					.66
1977	j	4	15	4	.98	2.31	.93	−0.69	.99	3.11	.98	−1.07	.96
1978	j	6	5	–	.89	1.30	.70	−0.30					.70

NITRATE

year	m	n(e)	n(c)	n(w)	eastern flank R	N(33)	N(35)	b	western flank R	N(33)	N(35)	b	N(ch)
1961	j	2	3	3	.92	24.4	7.7	− 8.4	.98	22.5	7.6	− 7.5	7.6
1962	j	2	7	1	.96	21.7	7.4	− 7.2					7.4
1968	f	6	1	–	.91	23.9	3.4	−10.2					3.4
1969	f	3	2	–	.72	9.8	1.6	− 4.1					1.6
1974	j	4	4	–	.98	20.9	2.9	− 9.0					2.9
1974	f	1	3	1	data not used				data not used				–
1975	j	3	5	2	.78	30.1	8.2	−11.0	.96	36.2	8.2	−14.0	8.2
1975	j	22	2	–	.93	28.2	4.2	−12.0					4.2
1976	j	2	3	8	.94	21.8	4.1	− 8.8	.65	23.3	5.7	− 8.8	5.3
1976	j	5	6	–	.95	28.5	5.7	−11.4					5.7
1977	j	4	15	4	.98	39.7	11.7	−14.0	.97	56.9	12.7	−22.1	12.2
1978	j	3	5	–	.96	49.4	6.2	−21.6					6.2

SILICATE

year	m	n(e)	n(c)	n(w)	eastern flank R	Si(33)	Si(35)	b	western flank R	Si(33)	Si(35)	b	Si(ch)
1961	j	2	3	3	.97	11.1	4.4	−3.4	.99	12.8	4.2	−4.3	4.3
1962	j	2	7	1	.97	14.9	4.8	−5.0					4.8
1968	f	11	1	–	.78	9.4	1.4	−4.0					1.4
1969	f	6	5	–	.67	11.2	5.3	−3.0					5.3
1974	j	4	4	–	.91	16.2	7.8	−4.2					7.8
1974	f	5	4	3	.47*	8.5	6.4	−1.0	.82	9.8	6.0	−1.9	6.0
1975	j	3	5	2	.87	22.6	5.8	−8.4	.59*	17.6	6.4	−5.6	5.8
1975	j	29	6	–	.96	16.4	4.5	−5.9					4.5
1976	j	2	3	8	.79	11.6	6.5	−2.6	.61	12.3	7.4	−2.4	7.2
1976	j	5	6	–	.88	14.5	5.1	−4.7					5.1
1977	j	4	15	4	.98	19.2	5.8	−6.7	.98	17.5	5.9	−5.8	5.8
1978	j	9	7	–	.99	18.3	5.0	−6.8					5.0

Figure captions.

fig. 1
Area of the Southern Bight from which the data are analysed. Mean isohalines are shown. In synoptic measurements the Channel Water tongue is usually narrower than appears from the mean conditions.

fig. 2
Variation of the calculated concentration of PO_4-P in Channel Water of 35 psu. Closed dots: january observations. Circles: february observations.

fig. 3
As fig. 2, for NO_3-N concentrations.

fig. 4
As fig. 2, for SiO_4-Si concentrations.

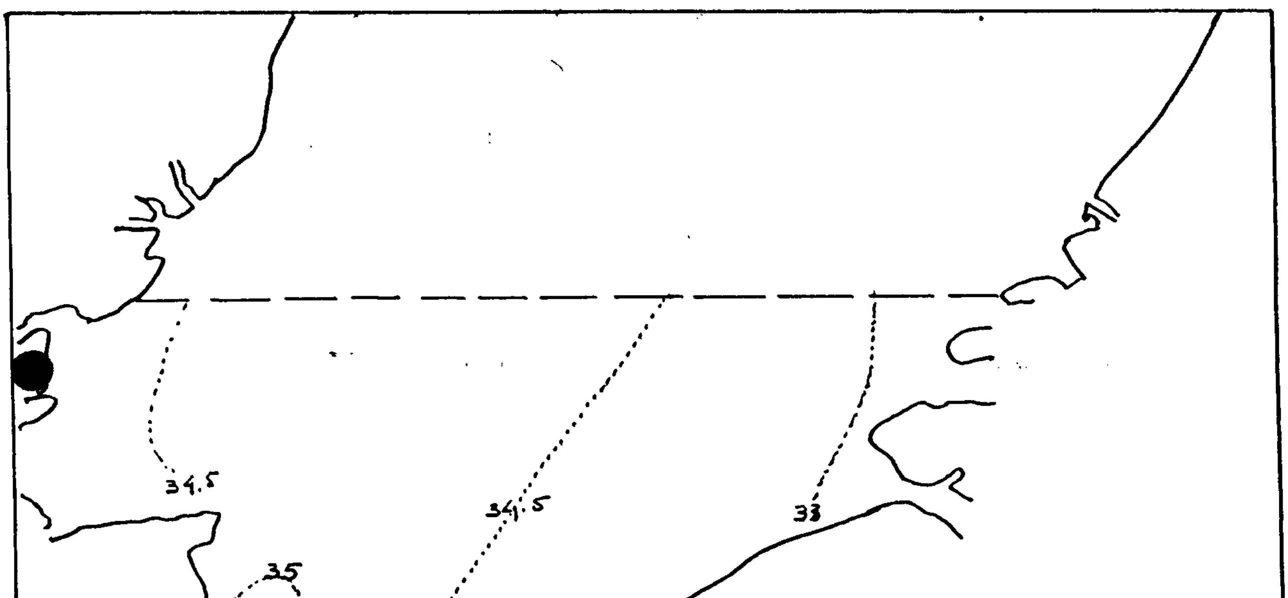

fig. 1

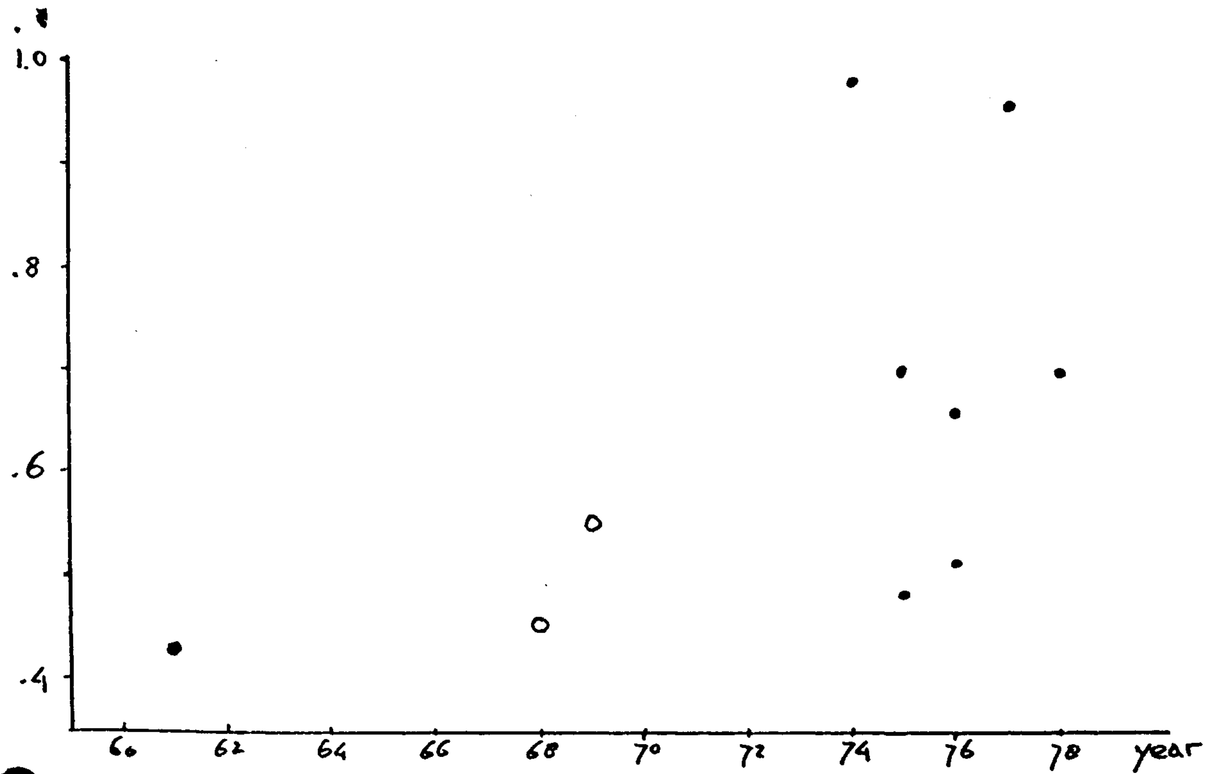

fig. 2

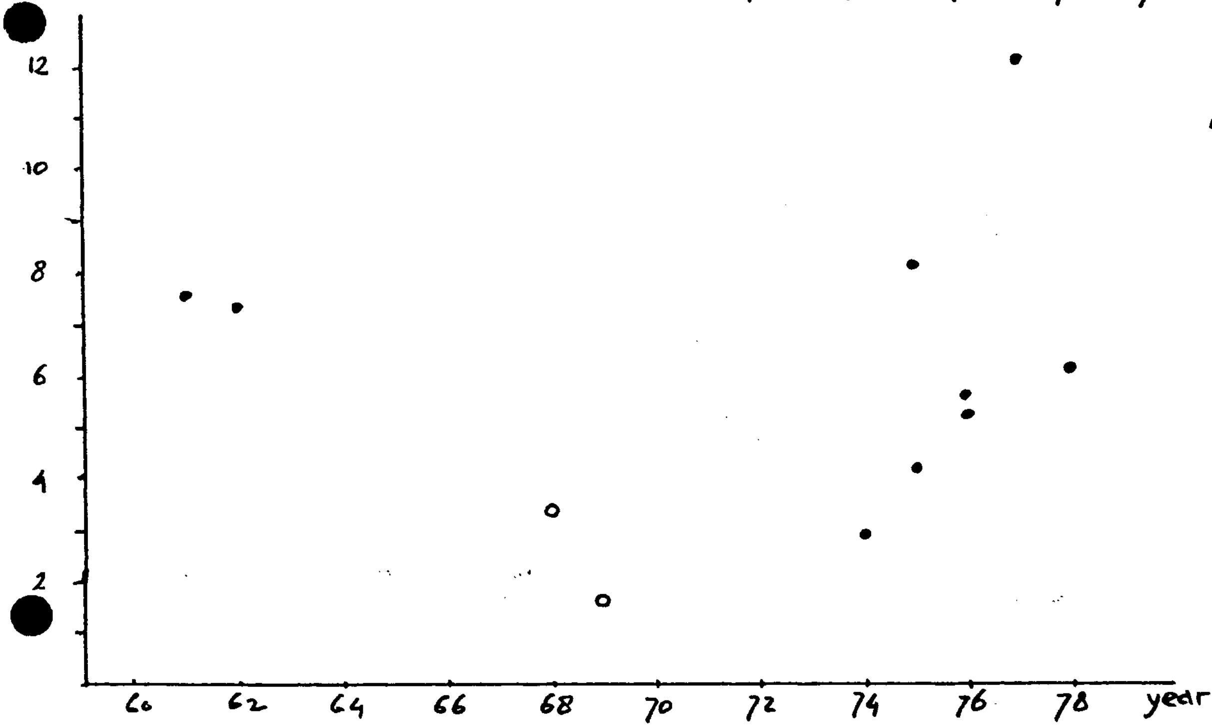

fig. 3

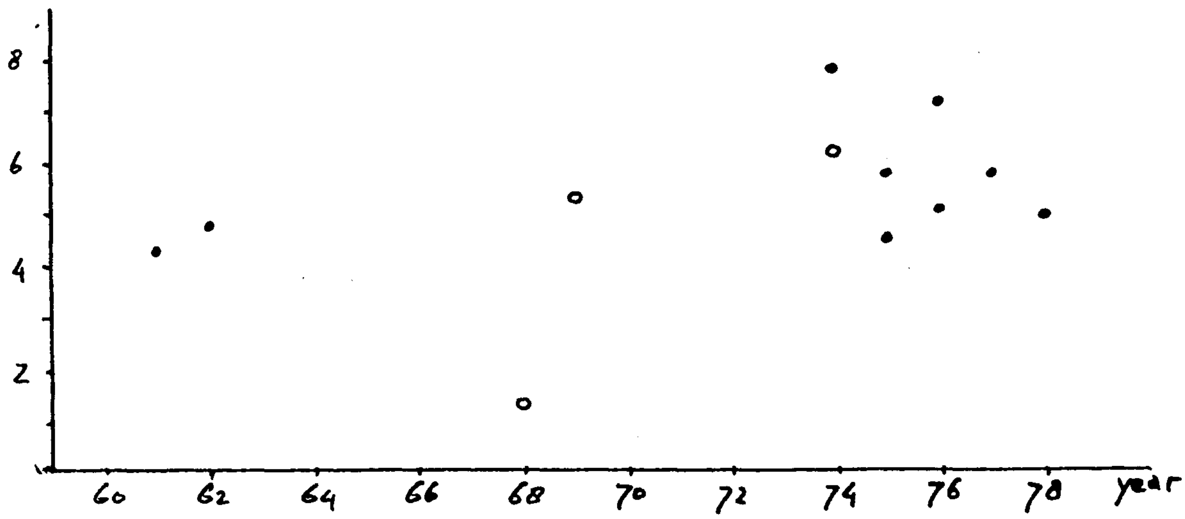

fig. 4