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INTERNATIONAL COUNCIL FOR THE EXPLORATION OF THE SEA

C.M. 1977 B:36
GEAR AND BEHAVIOUR COMMITTEE

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ANALYSIS OF CATCHING EFFICIENCY AND FISH BEHAVIOUR BY MEANS OF THE SIGMA FUNCTION

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Summary

The sigma function describes the relation of the standard deviation s_x from the average $\bar{x}$: $s_x = f(\bar{x})$ as it frequently occurs in biological data. It is brought about by (a) multiplicative correlations of individual events, (b) the time-series character of biological data and (c) regulation of processes. The interpretation of the sigma function on the basis of this set of causes has prooved to be effective. This is demonstrated by giving two examples:
(a) On the basis of monthly catches conclusions can be made with regard to the behaviour of the caught flat fish and fishing power of trawls; (b) By comparing the efficiency of two bottom trawls used under normal fishery conditions quantitative estimates can be made of the differences of herding by means of the gear of differing types of trawls.

Résumé

La fonction sigma décrit la dépendance de l'écart type s_x de la moyenne $\bar{x}$ qui existe souvent dans les données biologiques: $s_x = f(\bar{x})$. Elle résulte a) des liaisons multiplicatives des événements individuels, b) du caractère de séries temporelles des données biologiques et c) des procédés de régulation. En fonction de ce complexe de causes, l'interprétation de la fonction sigma s'avère très capable ce qui a été montré sur deux exemples: a) A partir des captures mensuelles il est possible de déduire des conclusions relatives au comportement des plies capturées et à la capacité captive du chalut, b) pour une comparaison de la capacité captive de deux chaluts de fond utilisés normalement en pêche, il est possible de quantifier les différences dans l'entassement des poissons à la zone du gréement avant du chalut en fonction du type du chalut.

1. Introduction

SOLLBERGER(1960) described the relation of the standard deviation s_x from the average $\bar{x}$ as common for time series as the sigma line: $s_x = f(x)$. It is the direct expression of the time-series character of a data series: "A biological variate may move (changing its value with time) and that its velocity may be uniform, accelerating or decelerating. The probability of observing a certain value of a variate during a given short space of time will be inversely proportional to its velocity ... Individual moving variate paths may differ with regard to the shape of the curves. The resulting divergence or convergence of the paths will give rise to a correlation between the average and dispersion characteristics of the variate" (SOLLBERGER 1960, pp. 15 and 18).

In naming the relation $s_x = f(x)$ we follow SOLLBERGER although he derived the term "sigma line" from the symbol σ for the standard deviation of an empiric distribution as it was commonly used in the past and is used in more recent publications for describing the standard deviation of a parent population. We think, however, that it would be more sensical to speak of a <u>sigma function</u> in order to avoid that the name of a phenomenon of an objective correlation between averages and dispersions be limited to its purely graphic representation.

2. Causes, properties and interpretation of the sigma function

Frequency of occurrence, causes and possibilities of interpretation of the sigma function are of basic interest with regard to two aspects: (a) Variance stability is an important precondition for many parametric methods; (b) deviations from the "normal" condition can be used for diagnostic purposes taking causes and interpretation of a given sigma function into account.

In continuation of the investigations carried out in the field of bio-indication of conditions and disturbances in ecosystems (HERING 1976 a, b) we have investigated the frequency of occurrence, properties and causes of the sigma function (HERING 1977):

1. Contrary to the majority of textbooks on biological statistics variance instability and, thus, sigma function appear regularly in biological data. Skewness and sigma function are correlated both by cause and by formula (KAPTEYN and VAN UVEN 1916, HOTELLING and SOLOMONS 1932, SOLLBERGER 1960).

2. Sigma functions (and, simultaneously, skew frequency distributions) occur if the different variates are correlated with each other non-additively. This is true both for the effects of the stochastic influences combined in the "error component" e and for the relations between stochastic and deterministic components. The common biostatistical models of the additive basal type

$$y = f(x) + e$$

(y - dependent variable; e - stochastic error component; x - independent variable) must, when establishing the occurrence of a sigma function empirically, be replaced by model arrangements of the following types:

$$y = f(x) \mathbin{\stackrel{\times}{=}} e \quad \text{or}$$

$$y = f(x \stackrel{+}{\times} e)$$

3. Sigma functions, furthermore, result from the fact that biological processes proceed in a regular manner (i.e. represent time series) and that only a finite number of relevant causes is involved. KAPTEYN and VAN UVEN, therefore, proposed to estimate the quantity of relevant causes through the term $(\bar{x}/s_x)^2$. In the case of time series the effect of a random variation from the formerly established quantity is particularly severe, if the quantities in question are correlated multiplicatively (SACHS 1968). The proof of the presence of a sigma function involves the necessity of investigating the problem by chronobiological methods.
4. The sigma function is also an expression of biologically controlled processes. Organismic (i.e. self-maintaining and optimizing) systems show stabilisation of variability. Dispersion is, as a rule, smaller at the system outputs as compared with system inputs. At the same time, however, a definite "rest" dispersion forms the basis for optimum adaptation. The stabilisation of dispersion is usually related to the mean level of a given process, i.e. $s_x = f(\bar{x})$.

5. Insofar as a linear relation is present between dispersion and mean value, the regression parameters a and b of the regression function $y = a + bx$ can be interpreted specifically. In accordance with SOLLBERGER the following possibilities of interpretation are possible:

a) $b = 0$ no sigma function because there is no time dependence, but identical (level-dependent) individual variability;

b) $b > 0$ positive sigma function:
- variability disappears together with the variabl
- increase of difference at high values;

c) $b < 0$ negative sigma function:
- variability is inversely proportional to the mean values;
- there is an upper threshold value;

d) $a > 0$
- the measured variable can become negative;
- the biological factors of variability remain effective (possibly fulfilled by other functions) even if the variable approaches zero.
- A measuring error (in the broadest sense of the word) is involved to the effect that the measured values of the variable remain below the actual ones. The mean deviation between measured and actual values amounts to the value of a (see also below)

e) $a < 0$ At zero dispersion the mean value ("basal value") of a given biological process becomes positive. This "basal value" is to be interpreted in the sense of the normal "basal state".

f) $b_1 \neq b_2$ Data sets I and II are heterogeneous. In particular, the time dependence is different (the larger b the more explicit is the time dependence of a given process).

g) The skewness is calculated in the usual way
$S = (\bar{x} - D)/s_x$ (D - mode)
The linear sigma function of type $s_x = a + b\bar{x}$
can be transformed to become $1/b = (\bar{x} - (-a/b))/s_x$.
Thus $S = 1/b$ and $D = -a/b$ and it is possible
to determine the parameters of the sigma function
through skewness and mode on the basis of one
series of measurements.

On the basis of this system of interpretation in the following two examples are given of fish behaviour analysis and assessment of fishing power.

3. Fishing power analysis and interpretation of behaviour

MEEK (1905) has published catches per unit effort (unit catches) stating species of fish, year, month and fishing region. By compilation of the values for the species of dab (presumably yellowtail flounder, Limanda ferruginea (STORER) and plaice (presumably American plaice, Hippoglossoides platessoides (FABRICUS)) it was possible to determine mean values including appropriate standard deviation. The time-series structure of the original data was lost, however. The linear sigma functions shown in table 1 were obtained.

Table 1: Sigma functions of unit catches expressed as linear regressions $s_x = a + b\bar{x}$. Original data acc. to MEEK (1905)

No.		a	b	r		α_r%	α_t%	α_F%
1	2	3	4	5	6	7	8	9
	Dab, all months							
1	Alnmouth Bay	4.98	-0.03	-.118	4	-	-	-
2	Dunridge Bay	1.31	0.26	.376	7	-	-	50
3	Cambois Bay	1.84	0.31	.559	4	-	-	50
4	All stations	1.22	0.41	.645	7	5	5	2.5
	Plaice, all months							
5	Alnmouth Bay	16.80	-0.46	-.311	4	-	-	-
6	Dunridga Bay	-3.04	0.55	.657	7	5	5	25
7	Cambois Bay	3.23	0.002	-.005	6	-	-	-
8	All stations	-33.44	2.79	.979	-7	0.1	0.1	0.1
9	Dab and plaice all stations	0.54	0.36	.580	32	0.1	0.1	0.1
	Dab and plaice all fishing regions							
10	January	7.20	-0.39	-.756	4	5	5	25
11	February	-1.34	0.54	.699	6	5	5	25
12	March	3.42	0.11	.566	5	5	5	50
13	April	0.33	0.32	.773	4	5	5	25
14	May	-0.51	0.60	.981	6	0.1	0.5	0.1
15	June	1.60	0.24	.410	5	5	5	50
16	All months	-0.29	0.44	.673	30	0.1	0.5	0.1

The coefficient a or the values of x_0 (i.e. the mean unit catch at a standard deviation of zero) can be interpreted as follows:

1. Positive values of a (i.e. negative values of x_0) occur as a result of low efficiency. By far less fish is cought than is present in the region, many escape before or out of the trawl. The value x_0 is a direct expression of the fish escape and, thus, of the efficiency of the fishing gear.

2. Negative values of a (i.e. positive values of x_0) show that successful hauls are always characterized by a certain minimum catch ($x_0 > 0$). Mean unit catches between zero and x_0 are not possible. This phenomenon can be explained by the effect of herding. The fish concentration in the fishing region can continuously vary between zero and a maximum value. The gear of the trawl causes primary herding into the way of the trawl. This effect is often increased by facilitation (originating from the fish herded by the gear and influencing other fish which, though in the area of the head gear would normally not become primarily herded or herded into the wrong direction) (HERING 1969). The trawl will catch either nothing (if there is no fish) or a quantity of fish corresponding to the original fish concentration increased by the quantity resulting from the herding effect.

The x_0-values for dab and plaice show a remarkable movement over the year (fig. 1). It corresponds in an almost ideal manner to the general biology of both species. This correspondence is remarkable, because, among other things, the figures used for the calculation of the x_0-values are extremely rough (monthly mean values of the unit catches from different, not always successive years). The circannual cycle of fish behaviour relative to the fishing gear can be explained as follows: In January the fish is situated in the cold water in the depth when no food is taken. It reacts to the gear of the trawl in the form of herding. In March to April the flat fish moves into warmer water near the surface to form there pre-spawning and spawning concentrations. Taking the x_0-values as a basis, the migrating motivation can be established already in February (the increased motoric activities prevents directed herding in the trawl way). This motivation, in March, obviously causes clear reactions of escape in relation to fishing gear and thus the x_0-values to become negative. The formation of pre-spawning and spawning concentrations leads to a reduction of the activity and thus also to reduced reactions of escape without a directed herding occurring in the sense of positive x_0-values. The dissolution of the pre-spawning and spawning concentrations, i.e. the transition to the feeding period is, as could be expected, characterised by a reduction of efficiency caused by non-directed reactions of escape.

In the case of efficiency analyses on the basis of data from the fishing log-book the sigma function will also supply valuable informations.

In the first quarter of 1971 a flotilla comprising 3 to 7 side trawlers and the factory main vessel "Martin Andersen Nexö" (ROS 315) fished off the Norwegian coast on pre-spawning concentrations of Saithe (Pollachius virens L.). The classical 140-feet-trawl and a newly developed bottom trawl with a largely increased opening were used. The experimental trawl was more effective only in the case of very uniform fish concentration. On days with a high standard deviation, i.e. on days on which fish schools were formed the 140-feet-trawl was more effective (experience-optimated herding effect of the gear of the trawl acc. to HERING, see fig. 2).

Unit catches related to trawl types indicate the presence of a clear sigma function (fig. 3). For all days on which the experimental trawl was fishing better or worse the following sigma functions were calculated:

$s_{cpue} = -8.35 + 1.39$ cpue [basket/h]
$cpue_o = 6.02$ baskets/h $r = 0.89$ ($p < 0.1$ %)
$s_{cpue} = -4.89 + 1.07$ cpue [basket/h]
$cpue_o = 4.67$ baskets/h $r = 0.79$ ($p < 0.27$ %)

The $cpue_o$-value can, in accordance with the explanations made on the sigma functions of the MEEK data (see above), be interpreted as a quantitative measure of the herding effect. Days with low catches by the experimental trawl are not only characterised by a dispersion which is less dependent upon the mean value (small b-value), but also by a lower $cpue_o$-value.

The two examples given furnish, in our opinion, a convincing proof of the efficiency of the sigma function. Particularly the analysis of MEEK's catch statistics shows that it is possible on the basis of very rough ecological data to draw conclusions with regard to the biological behaviour and to the fishing gear. It is true, however, for the sigma function as well as for all other mathematical syllogisms that they are only formal logic deductions bearing hypothetical character. Their final verification is only possible by appropriate experiments.

4. References

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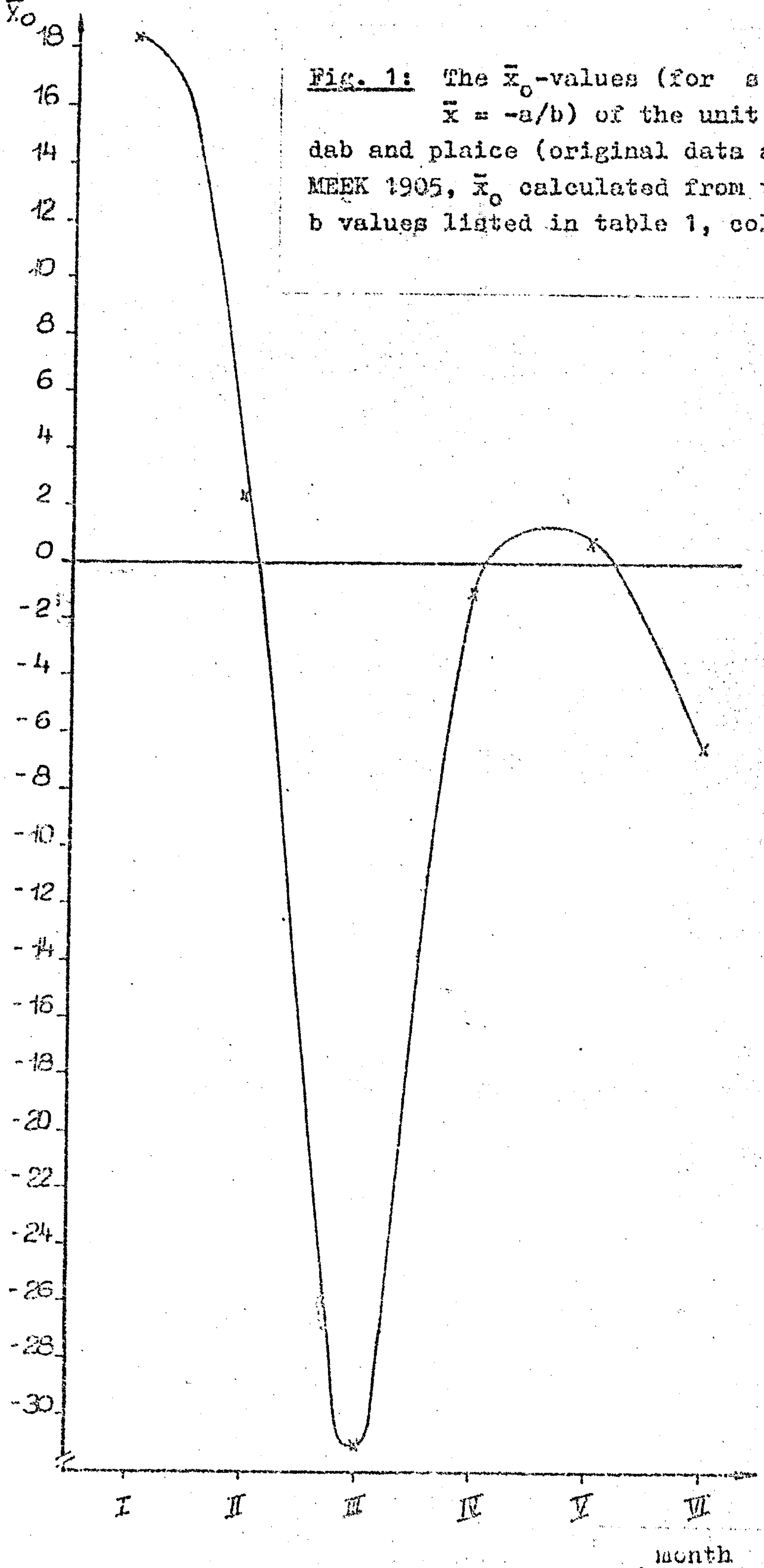
Fig. 1: The $\bar{x}_o$-values (for $s = 0$, i.e. $\bar{x} = -a/b$) of the unit catch of dab and plaice (original data acc. to MEEK 1905, $\bar{x}_o$ calculated from the a and b values listed in table 1, column 11-16)



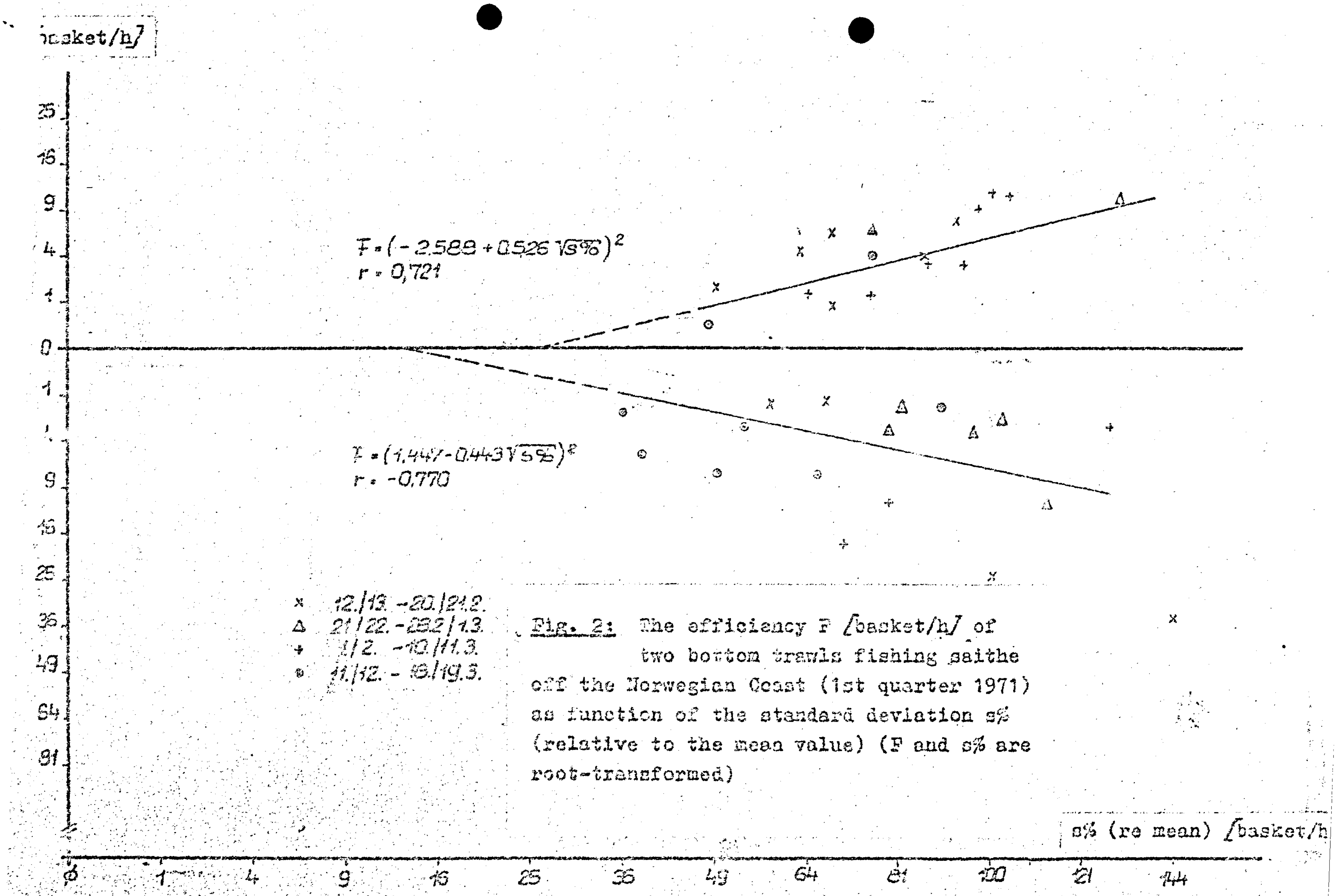


Fig. 2: The efficiency F /basket/h/ of two bottom trawls fishing saithe off the Norwegian Coast (1st quarter 1971) as function of the standard deviation s% (relative to the mean value) (F and s% are root-transformed)

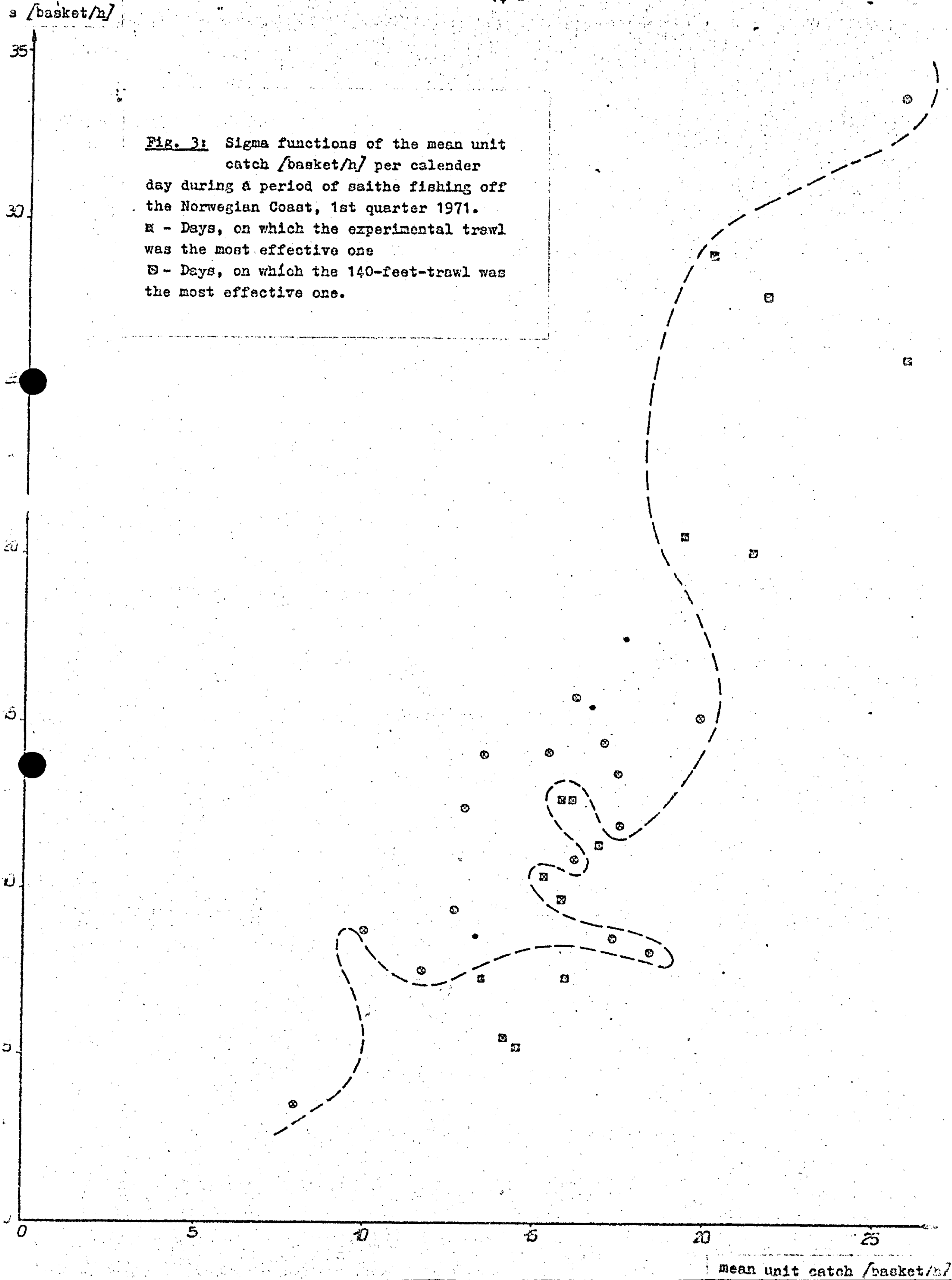


Fig. 3: Sigma functions of the mean unit catch /basket/h/ per calender day during a period of saithe fishing off the Norwegian Coast, 1st quarter 1971.
⊠ - Days, on which the experimental trawl was the most effective one
⊡ - Days, on which the 140-feet-trawl was the most effective one.