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International Council for the
Exploration of the Sea

With collaboration of
FAO and ICNAF

Symposium
on
"Stock and Recruitment"
NO.20

RELATIONSHIP OF PARENT STOCK SIZE AND YEAR-CLASS STRENGTH IN NORWEGIAN SPRING SPAWNING HERRING

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INTRODUCTION

The attempt to gain a better understanding of the recruitment problem of marine fishes has been approached in several ways. Theoretical contributions to the study of the inter-relationship between the size of the parent stock and recruitment have been published (e.g. Ricker 1954, Beverton and Holt 1957, Cushing 1968), and extensive larval studies have been carried out at several laboratories (e.g. Blaxter 1965, Hempel and Blaxter 1963, Ahlstrom 1954,1965) in order to elucidate the fluctuations in year-class strength. Factors controlling the recruitment mechanism in the adult stocks and the effect of fisheries on immature fish are problems frequently being investigated (e.g. Cushing 1962, Zijlstra 1963, Anon.1965).

The annual number of fertilized eggs and the subsequent number of young fish (the recruits)are related in some way to the abundance of the spawning stock. The nature of this relation is not known. A marked relationship between the annual number of eggs produced (the spawning potential of the parent stock) and the number of subsequent recruits is demonstrated for some species of fish with low fecundity, e.g. spurdog (Holden 1968). Similarly an indication of such a relationship is found in some relatively small stocks of Pacific herring (Clupea pallasii Valenciennes) in British Columbia (Taylor 1963) and in the Downs stock of herring in the North Sea (Burd and Holford 1968), but no trend of decreasing recruitment with decreasing spawning stock has as yet been demonstrated for the other major stocks of herring in the North Sea (the Buchan and Bank stocks) and in the Norwegian Sea (the Norwegian spring spawning herring). However, within the range of population sizes for which data have been available for these stocks, a relationship between the spawning potential of the parent stock and subsequent year-class strength is difficult to trace due to the variation in the normally high natural mortality of the very young stages.

In the present paper year-class strength as adults and before the herring are subject to fishing (at about six months of age) is compared with the parent stock size. The spawning potential of the parent stock is compared with subsequent larval abundance and figures of mortality for larvae collected in spring of 1968 and 1969 are presented. The predator effect during the egg stage and early larval development is discussed, and some concluding remarks are given on the probability of the spawning stock to produce numerous year-classes when the stock size fluctuates at the present low level.

MATERIAL AND METHODS

The major part of the data are obtained from:

1) tagging experiments carried out in 1952-1965;
2) samples of herring collected during the Norwegian winter herring and young and adolescent herring fisheries in 1947-1970;
3) O-group fish surveys carried out in 1959-1969;
4) surveys conducted during and subsequent to spawning and hatching in 1968-1970;
5) official fishery statistics.

Adult herring

Results of the extensive tagging experiments conducted by the Fisheries Research Institute, Reykjavik and Institute of Marine Research, Bergen are published by Fridriksson and Aasen (1950,1952), Dragesund and Jakobsson (1963), Dragesund (1970a). The method used to estimate the adult stock size from tagging experiments has been described by Dragesund and Jakobsson (1963). Estimates available for the period 1952-1965 are given by Dragesund (1970a).

In order to analyse the year by year variations of the spawning potential, the stock size in tons in different years were converted to numbers of fish by length (Dragesund 1970a). With data on fecundity by length (Baxter 1959, Parrish and Saville 1965) the number of eggs deposited each year could be calculated. The sampling procedure for age, length and weight determination of adult herring during the Norwegian winter herring fishery(the spawning season) is described by Dragesund (1970a).

Young and adolescent herring

The material of young and adolescent herring includes data from acoustic surveys and herring samples. The method used for estimating O-group abundance at about six months of age is described by Dragesund (1970b), where estimates of the year-classes 1959-1965 are also given. For those of 1966-1969 data are available from the international O-group fish surveys (Anon. 1966,1967,1969a,1969b).

The age compositions of young and adolescent herring are from reports published by Dragesund (1963,1970b) and from unpublished records available at the Institute of Marine Research, Bergen.

Herring eggs and larval herring

Herring eggs and larvae were collected on surveys covering the coastal banks from Stad to Lofoten. Eggs were collected with dredge or obtained from stomach content of haddock and saithe fished with bottom trawl. In 1968 four and in 1969 five successive larval surveys were carried out from hatching and during the following five to six weeks. The material of herring larvae collected in 1970 is not yet worked up and can not be included in this report.

Oblique hauls were taken with Clarke-Bumpus plankton samplers equipped with silk nets of mesh size 0.50 mm. The sampling depths were 25-5 m, 50-30 m and 75-55 m. The total towing time was 20 minutes, and the towing speed between 1.5 and 2.0 knots. All samples were preserved. The larvae were counted and measured to the nearest mm below, and sorted into larvae with and without yolk sac, the results being expressed as the number of larvae below 1 m^2 of surface (Dragesund 1970a).

Echo counting

Counting of fish (mainly haddock and saithe) was carried out in 1970 within a limited area off Møre. The Simrad echo integrator (QM) in conjunction with a 38 kHz Simrad Scientific sounder was applied. When possible the integrator was calibrated by paper counts. The method applied is described by Midttun and Nakken (1968). The integrator readings were converted to fish densities and the number of fish was found by area integration of the densities.

RESULTS

Stock size

Estimates of the absolute size of the spawning stock of Norwegian spring spawning herring are available for a series of sixteen years. In the present paper the series is extended with another eight years. The estimates for the period 1953-1968 are based on tagging experiments (Dragesund and Jakobsson 1963, Dragesund 1970a) and combined acoustic surveys and underwater photography experiments (Fedorov, Truskanov and Yudanov 1963, Anon. 1969c). The absolute size of the spawning stock during the period 1947-1952 has been derived from catch per unit effort data(the drift net fishery) given by Østvedt (1963). The abundance indices showed that stock size remained at about the same level during this period and was somewhat lower than that which occurred in the mid-1950s. The average abundance figure for the stock size during the period 1947-1952 was about 85 per cent of the average figure for the years 1954-1956. The spawning stock sizes for 1969 and 1970 are derived from data in the report of the Atlanto-Scandian Herring Working Group (Anon. 1969c) applying a total mortality coefficient of Z=0.44. Figures of the absolute size of the spawning stocks for the period 1947-1970 are given in Table 1.

Table 1. Spawning stock size in millions of metric tons during the period 1947-1970.

Year	Tagging experiments	Acoustic surveys, underwater photography	Deduced figures	Mean
1947			10.7	10.7
1948			10.7	10.7
1949			10.7	10.7
1950			10.7	10.7
1951			10.7	10.7
1952			10.7	10.7
1953	12.5			12.5
1954	12.2			12.2
1955	13.9			13.9
1956	12.0			12.0
1957	9.4			9.4
1958	6.6			6.6
1959	5.0	6.0		5.5
1960			4.5	4.5
1961			3.5	3.5
1962		2.5		2.5
1963		2.9		2.9
1964	5.0	3.3		4.3
1965	7.7	6.8		7.3
1966		6.5		6.5
1967		4.0		4.0
1968		2.0		2.0
1969			1.3	1.3
1970			0.9	0.9

The stock size was on a relatively high level in 1947-1956. From 1957 onwards a decrease in the stock took place and this continued until 1962 when it was about 2.5 million tons. In the following three years the stock increased from 2.9 million tons in 1963 to 7.3 million tons in 1965. From 1966 to 1970 a rapid decrease in stock size took place. The estimates for 1963-1965 do not include the component spawning at Lofoten, and the total spawning stock these years, therefore, is underestimated.

The spawning potential of the stock is a function of the size of the spawning stock. However, fecundity increases with length and weight of the fish (e.g. Parrish and Saville 1965, Jakobsson et al. 1969) and thus the spawning potential of the stock is a function both of the number and the length distribution of fish. Preliminary figures of the spawning potential for the spawning seasons 1947-1969 are given in Figs. 2 and 3.

Year-class strength

Estimates of year-class strength for adults are complicated by the wide range of ages over which individuals of a given year-class attain sexual maturity. However, knowing the size of the spawning stock, an estimate of year-class strength can be obtained by calculating the abundance of the year-class at six years, when most of the year-class has entered the adult stock (Østvedt 1958, Dragesund 1970a). The 1965-1969 year-classes had not reached the adult stage (six years of age) in 1970 and cannot be compared with the previous year-classes in the adult stock.

By calculating year-class strength at an age of six years the effect of fishing on the immature herring is not measured in the year-class strength estimates. A fishery which is of considerable importance to the population dynamics of the Norwegian spring spawning herring is carried out on young and adolescent herring in Norwegian coastal waters. This fishery is divided into two components, (1) that based on the small-herring, i.e. mainly 0- and I-group with the former predominating and (2) that based on the fat-herring, i.e. I- to IV-group herring with the II- to III-group predominating. The effect of these fisheries on recruitment to the adult stock has been discussed by several authors (e.g. Marti and Fedorov 1963, Devold 1963, Dragesund 1970b). Dragesund concluded that the fishery for 0- and I-group herring (the small-herring fishery) carried out in the Norwegian fjords in 1959-1964 did not have a primary effect on the recruitment to the year-class strength as adults. This is mainly due to the fact that the fjord population is only a part of the total 0- and I-group population. However, in the period 1965-1968 a considerable increase in the exploitation of both small- and fat-herring took place as the fishery was extended into the open sea. This resulted in a marked reduction of the 1963 and 1964 year-classes before they entered the adult stock. The effect is also expected to be significant for the 1965-1968 year-classes, though it should be stressed that these year-classes were extremely poor at the 0-group stage.

Investigations carried out by Dragesund (1970b) showed that a close correlation existed between the abundance of 0-group herring (at about six months of age) of the 1959-1962 year-classes and subsequent abundance. 0-group abundance estimates are available for the 1959-1969 year-classes, whereas direct estimates of year-classes prior to these are lacking. Assuming that a correlation exists between the abundance of 0-group herring and subsequent year-class strength, a back calculation can be made for the 1950-1958 year-classes, provided the exploitation is known for the year-classes as small-herring.

The variation in exploitation of small- and fat-herring can be measured by taking the ratio between catch at different stages during the young and adolescent phases and the total echo abundance of 0-group herring (Dragesund 1970b). In Fig.1 is shown the variation of exploitation of small-herring for the 1959-1968 year-classes and of fat-herring for the 1959-1964 year-classes. It is clearly demonstrated that poor year-classes were more heavily exploited than the rich ones as small-herring. The major reason for the higher exploitation of poor year-classes (e.g. those of 1961 and 1962 compared with those of 1959 and 1960) is ascribed to the different distribution pattern. In 1959 and 1960 0-group herring had an oceanic distribution and only a minor part of the 0-group population entered the fjords of northern Norway. In 1961 and 1962 the distribution was more restricted to the coastal areas, and a greater portion of the total 0-group population was present in the fjords. It is assumed, therefore, that in most of the years during the 1950s, when poor year-classes occurred these had a coastal distribution comparable with those of 1961 and 1962, whereas that of 1950 had a similar distribution to the year-class of 1959.

When back calculating the abundance of 0-group herring, therefore, the average ratio between the catch of small-herring and echo abundance for the 1961 and 1962 year-classes (equal to 5.43) was applied to the 1951-1958 year-classes.

$$\frac{\text{Catch}}{\text{0-group abundance}} = 5.43 \qquad (1)$$

and the 1959 year-class (equal to 0.85) to that of the 1950 year-class

$$\frac{\text{Catch}}{\text{0-group abundance}} = 0.85 \qquad (2)$$

Knowing the catch as small-herring the abundance is estimated from expressions (1) and (2). The results are given in Table 2. It is reasonable to assume that the abundance of the 1950 year-class is underestimated compared with that of 1959 by using this method. This is indicated by the higher abundance at six years of age and by the fact that the catches in tons subsequent to the small-herring stage was about 1.5 times greater for the 1950 year-class.

Table 2. Catch of small-herring for the 1950-1968 year-classes and estimated abundance of 0-group herring(explanation in the text)

Year-class	Catch in thousands of tons	0-group abundance
1950	270	318
1951	175	32
1952	215	40
1953	180	33
1954	135	25
1955	90	17
1956	127	23
1957	115	21
1958	117	22
1959	277	326
1960	267	147
1961	169	38
1962	94	15
1963	121	54
1964	102	75
1965	30	9
1966	136	23
1967	12	4
1968	9	2
1969		5

Stock and recruitment

In Fig.2 is plotted the spawning potential of the parent stock for the period 1947-1964 against the resulting year-class strength at six years of age. Similarly the spawning potential for the period 1950-1969 is plotted against year-class strength at the 0-group stage (Fig. 3).

No firm conclusions can be drawn from the diagrams about the relationship between parent stock size and the abundance of the resulting year-class. They may indicate that in some years within the period considered year-class strength was affected by the parent stock. However, in most of the years, year-class strength was determined by other factors which completely ruled out the effect of the parent stock. Thus, in at least twelve of twentythree years during the period 1947-1969 the size of the parent stock has apparently not been the primary factor controlling subsequent year-class strength. In years when abundant year-classes were produced as in 1950 and 1959 other factors may have given rise to favourable conditions of the progeny.

Different factors considered to be of importance in determining year-class strength of Norwegian spring spawning herring have been discussed by Dragesund (1970a). Strong year-classes seemed to occur when a combination of the following conditions existed:

1) widespread distribution of spawning;
2) long duration of the spawning period;
3) a rapid dispersion of larvae from the spawning grounds.

The coincidence in time between the occurrence of suitable food and hatching of herring larvae is assumed to be the most important environmental factor controlling year-class strength during the early larval development. The gradual northward displacement of the main spawning centre during the last decades probably has increased the importance of the timing factor, since only two definitely rich year-classes occurred during the period 1947-1965, namely those of 1950 and 1959.

At present the spawning stock size is at a very low level and some further considerations concerning the stock size and the abundance of the resulting year-classes of 1967-1969 are given in the following chapters.

Stock size and larval abundance

Although no exact estimates are available for the size of the spawning stocks in 1969 and 1970, it is obvious that the size continued to decrease from 1968 onwards due to lack of recruits. It is reasonable to assume that the stock sizes in 1969 and 1970 were of the order of 1.3 and 0.9 million tons respectively (Table 1).

Larval abundance estimates of the 1959-1965 year-classes just after hatching suggest that the variation in the size of the spawning stock was reflected in the larval abundance figures (Dragesund 1970a). However, the sampling procedure was not satisfactory for reliable abundance estimates during that period. In the years 1967-1970 much greater effort was devoted to sampling of herring larvae and the quantitative distributions according to length in the different periods for 1968 and 1969 are shown in Figs 4 and 5. The results of the investigations carried out in 1967 are published in a previous report (Dragesund and Nakken 1970). In contrast to the years of 1963-1966 no major spawning was observed in the Lofoten region in 1967-1969. The spawning took place off Møre-Trøndelag with the centres off Ona-Grip and Halten. The main spawning occurred 10-15 March, corresponding to a peak of hatching in the first week of April (Figs. 4 and 5).

In Fig. 6 is shown the abundance of larvae in the different periods of sampling by integrating the density of larvae within the isolines of larval abundance drawn in Figs. 4 and 5. The diagrams show two striking features, namely an unexpected low abundance of hatched larvae in 1969 compared with 1968 and a significant lower larval mortality in 1969. The reduction in spawning potential from 1968 to 1969 was in the order of 30 per cent, whereas the reduction in number of newly hatched larvae was 85-90 per cent. This might be explained by a markedly higher mortality during the incubation period in 1969 than in 1968, or the stock might have spawned in other areas. The former explanation is the most reasonable.

Lea (1930) showed that thick egg layers on the Norwegian spawning grounds resulted in high mortality. According to Dragesund and Nakken (unpublished) no such thick layering of eggs could be found in 1967-1970 and the layering was probably of significant importance to the mortality. Also few unfertilized eggs were found during the same period.

During the spawning seasons in 1967-1970 the relative importance of the predator effect seemed to have increased. Gadoid fishes (haddock and saithe) have been feeding heavily on herring roe. In Table 3 some preliminary figures for the number of eggs observed in the stomachs of haddock and saithe are shown.

Table 3. Number of herring eggs in stomachs of haddock and saithe in 1969 and 1970*.

Year	Haddock			Saithe		
	No. of fish invest.	Length range (cm)	Average no. of eggs	No. of fish invest.	Length range (cm)	Average no. of eggs
1969	20	46-60	34200	2	50-80	49000
1970	13	40-70	24200	7	49-86	21100

* The figures are preliminary.

In the winter of 1970 the number of fish present within a limited locality in the main spawning area off Ona-Grip was counted. It is assumed that the survey grid covered about one third of the spawning centre off Ona-Grip (Fig.7). Provided that a similar or somewhat smaller area was located off Halten (say two third of that off Ona-Grip) and that the density of fish were the same, a total number of $2.10^7 \times 5$ was feeding on herring roe in 1970. About 80 per cent of the haddock and 15 per cent of the saithe in the trawl catches had herring roe in their stomachs. The number of fish counted was splitted in haddock and saithe according to the ratio of the two species in the trawl catches within and just outside the grid of counting, i.e. 83 per cent of the fish were haddock and 17 per cent saithe. Assuming that the fishes are filling their stomachs once per 24 hours during the incubation period (i.e. about 20 days) a total number of 3×10^{13} herring roe was eaten by haddock and saithe. This corresponds to about 40 per cent of the spawning potential in 1970.

Investigations carried out in 1968-1970 showed that spawning took place almost in the same areas these years. Thus, provided that a similar quantity of eggs were consumed by haddock and saithe in 1968 and 1969 this corresponds to about 15 and 20 per cent of the spawning potential respectively. It is reasonable to assume that the reduction in number of eggs spawned in 1969 was even greater than indicated in the present estimates. In addition to the larger fishes a significant number of I- and II-group haddock and saithe was feeding on herring roe both in 1969 and 1970. These are not included in the counted number of fish above.

Larval mortality

The size of a larval stock at a given time t can be expressed as

$$N(t) = N_{l_o}(t) + N_{l_1}(t) + N_{l_2}(t) + \ldots\ldots \quad (3)$$

where l_o is the length at hatching and l_1, l_2.. etc. are the subsequent length groups in millimeter.

When sampling is carried out at different time intervals t_1, t_2, t_3... etc., the following expressions according to length are established

$$\begin{aligned} N(t_1) &= N_{l_o}(t_1) + N_{l_1}(t_1) + N_{l_2}(t_1) + \ldots\ldots \\ N(t_2) &= N_{l_o}(t_2) + N_{l_1}(t_2) + N_{l_2}(t_2) + \ldots\ldots \qquad (4) \\ N(t_3) &= N_{l_o}(t_3) + N_{l_1}(t_3) + N_{l_2}(t_3) + \ldots\ldots \\ &\vdots \end{aligned}$$

The time variation of the number of larvae within one length group is determined by:

1) the rate of hatching;
2) the growth rate (k);
3) the mortality (m).

It is assumed that spawning is taking place in a limited area within a certain time interval. After an incubation time of, say, three weeks the larvae start to hatch. The duration of hatching and the growth rate will determine the time interval larvae of length l_o, l_1, l_2 etc. occur.

When larval sampling starts at the time when the first larvae are hatched and continues until hatching is finished, expressions (4) will have the following form

$$
\begin{array}{llllll}
N(t_1) = & N_{l_o}(t_1) & + \quad 0 & + \quad 0 & + \ldots\ldots\ldots\ldots & \\
N(t_2) = & N_{l_o}(t_2) & + N_{l_1}(t_2) & + \quad 0 & + \ldots\ldots\ldots\ldots & \\
N(t_3) = & N_{l_o}(t_3) & + N_{l_1}(t_3) & + N_{l_2}(t_3) & + \ldots\ldots\ldots\ldots & \qquad (5) \\
N(t_4) = & 0 & + N_{l_1}(t_4) & + N_{l_2}(t_4) & + \ldots\ldots\ldots\ldots & \\
\vdots & \vdots & \vdots & \vdots & &
\end{array}
$$

At the time t_4 all the larvae are hatched.
From expressions (5) it is possible to obtain figures of both growth rate and mortality. The growth rate can be estimated from the distance between the peaks of the length distributions according to time.
The mortality can be found from the reduction in number from one length group to the next

$$m = \frac{\int_0^T N_{l_1}(t)dt - \int_0^T N_{l_2}(t)dt}{\int_0^T N_{l_1}(t)dt} \qquad (6)$$

where the integration interval T is large enough to ensure that $N_{l_1}(0) = 0$ and $N_{l_2}(T)=0$. Then expression (6) gives an average mortality between length groups. Usually the survey time is limited and the observation series too short to get $N_{l_2}(T)=0$ at least for the larger length groups. However, when the growth rate is known the mortality can be estimated by using the growth rate to determine the integration limits.

$$m = \frac{\int_{t_1}^{t_3} N_{l_1}(t)dt - \int_{t_2}^{t_4} N_{l_2}(dt)}{\int_{t_1}^{t_3} N_{l_1}(t)dt} \qquad (7)$$

where t_2 and t_4 are determined from

$$(t_4 - t_3) = (t_2 - t_1) = \frac{1}{k}(l_2 - l_1) \qquad (8)$$

when l_2 and l_1 are two successive mm groups.

A similar method was used by Dragesund and Nakken (1970) for estimating larval mortality in 1967. It should be noted that a series of mortality estimates is obtainable by this method when successive and frequent synoptic larval abundance figures are available.

The number of larvae according to length and time in 1968 and 1969 is given in Table 4. The numbers are calculated from the density charts in Figs. 4 and 5.

Table 4. Number of larvae x 10^{-8} according to length and time

Year	Period	8	9	10	11	12	13	14	15	16	17	Total
1968	3-8 Apr.	11	711	475	82							1279
	17-21 "			1	2	61	85	31	8			188
	21-24 "					10	28	38	33	2		111
	24-29 "							6	14	7	1	28
1969	2-5 Apr.	4	32	15	1							52
	7-15 "	3	7	31	18	9	1	1				70
	15-19 "		2	4	1	13	5	1				26
	20-26 "		1	0	3	1	12	6	16	1	1	41
	28.Apr.-7 May				0.29	0.42		0.29			0.32	2

Due to the gap in observations between 5 and 19 April in 1968 no mortality between length group can be estimated. An average growth rate (k) of 0.29 mm per day between 9 and 13 mm is found for this year applying expression (8), where l_1 and l_2 refer to 9 and 13 mm respectively and t_1 and t_2 to 5 and 19 April. The reduction of total number of larvae from 5 to 19 of April is estimated from Fig. 6 and amounted to 86 per cent. This figure can be taken as a minimum figure of larval mortality (m) between 9 and 13 mm, as hatching obviously occurred also later than 5 April.

Fig. 8 shows the number of larvae according to length and time in 1969. An average growth rate of 0.29 mm is found between 9 and 14 mm. Mortality estimates were obtained from equation (7) by area calculation in Fig. 8. The results are given in Table 5.

Table 5. Mortality estimates of herring larvae between different length groups in 1969.

Length in mm	Relative figures of larval abundance	Mortality between 10 mm and successive groups in per cent
10	100	
11	49	51
12	38	62
13	32	68
14	16	84

DISCUSSION

The survival of eggs spawned and of larvae hatched in 1967-1969 is illustrated in Fig. 9. A reduction of $\geq$95 and $\geq$99 per cent respectively took place in 1967 and 1969 from spawning to hatching. Figures on mortality of herring eggs during the incubation period are given by Runnstrøm (1941), Baxter (1968), Hempel and Hempel (1968). The mortality was low and varied mainly between 4 and 12 per cent. Similarly Dragesund and Nakken (unpublished) observed few dead and unfertilized eggs on a spawning site near Grip in 1968. None of these results include mortality at the hatching stage and mortality caused by predation.

During the spawning seasons in 1967-1970 the predator effect was most likely by far the most important factor and the relative importance of this effect has increased during this period (Fig. 9 A). The echo counting in 1970 was carried out within a very limited area during one night and the results are probably inaccurate. In addition to the larger fish a significant number of smaller haddock and saithe was feeding on herring roe both in 1969 and 1970. These are not included in the number of fish counted, and the result of the echo counting is therefore most likely an underestimate. The counting indicates that the number of eggs consumed by the fishes might be of the magnitude of half the spawning potential and suggests that the large mortality found during the incubation period was reasonable. A further reduction of the larval population of the order of 70-95 per cent during the early larval development (9-13 mm) will add to this effect.

To discuss the possible obtainable magnitude of year-class strength from the larval populations in 1967, 1968 and 1969 the number of larvae four to five weeks after hatching is compared with the number of herring at different stages from six months onwards for the 1959 and 1963 year-classes. Tentative estimates for the abundance (converted to number of herring) at different ages for the 1959 and 1963 year-classes are obtained from data given by Dragesund (1970b). In these estimates the loss due to fishing during the young and adolescent phases is taken into account (Fig. 9 B). The following annual instantaneous natural mortality coefficients have been used: M_1= 2.76 from October in the 0-group to April in the I-group stage, M_2= 0.69 from May in the I-group to April in the II-group stage and $M_3 \ldots M_6$ = 0.24 from May in the II-group to 1 January in VI-group stage.

It is obvious that the abundance of the larval populations present in the sea four to five weeks after hatching in 1967-1969 were too low to produce a numerous year-class of the magnitude of that spawned in 1959. Even a year-class like that of 1963, which was in order of one tenth of that in 1959 (Table 2), is unlikely to occur.

The number of larvae hatched in 1970 was negligible and the predator effect in 1970 was probably even greater than in 1969 (Dragesund and Nakken unpublished). It is therefore possible that with the present high predator effect and the low spawning stock size the larval population may be too low to produce numerous year-classes.

The diagrams of Figs. 2 and 3 may be used to discuss the probability of obtaining numerous year-classes with the present parent stock size. During the period 1947-1969 it is likely that the best survival conditions for eggs, larval and postlarval herring existed in 1959. This can be seen by taking the ratio between year-class strength and spawning potential. Grouping these ratios in four taking that of the 1959 equal to one, an illustration of the distribution of the survival ratios during the period 1947-1969 is obtained (Fig. 10).

In eighteen of twentythree occasions the ratios between year-class strength and spawning potential fell in the group 0-0.25, and only in one of twentythree in the group 0.75-1.0. The probability, therefore, in the following years to obtain survival conditions as favourable as those in 1959 seems low. Even if survival conditions like those in 1959 occur in all of the years 1971-1973 this would result in a spawning stock size (excluding fishing during the young and adolescent phases) of the magnitude of only 2-3 million tons in late 1970s. With the present low spawning potential and the high predator effect the probability of rebuilding the spawning stock in near future, therefore, seems low. However, better survival conditions than those experienced in the period of observations may of course occur.

SUMMARY

1. Estimates of the size of the spawning stock of Norwegian spring spawning herring for the period 1947-1969 are presented. The spawning stock size varied between 13.9 and 2.0 million tons in the period 1947-1968. From 1966 to 1970 a rapid decrease has taken place from 6.5 million tons to about 0.9 million tons.
2. The parent stock size is compared with subsequent abundance of the resulting year-class at six years of age for the 1947-1964 year-classes and at six months of age for the 1950-1969 year-classes. The results indicated a relationship between the parent stock size and subsequent abundance of the resulting year-class when favourable condition for spawning and hatching existed. However, in most of the years, year-class strength was determined by other factors which completely ruled out the effect of the parent stock size, when this was above a certain level.

3. The spawning potential of the parent stock for the years 1967-1969 is compared with subsequent larval abundance at hatching. A reduction of ≥95 and of ≥99 per cent respectively took place in 1967 and 1969 from spawning to hatching. Most of this reduction is ascribed to predation by haddock and saithe.
4. Estimates of larval mortality during the early larval development (9-13 mm) are given. These varied between 70-95 per cent.
5. With the present low spawning potential and the high predator effect the probability of rebuilding the spawning stock in near future seems low.

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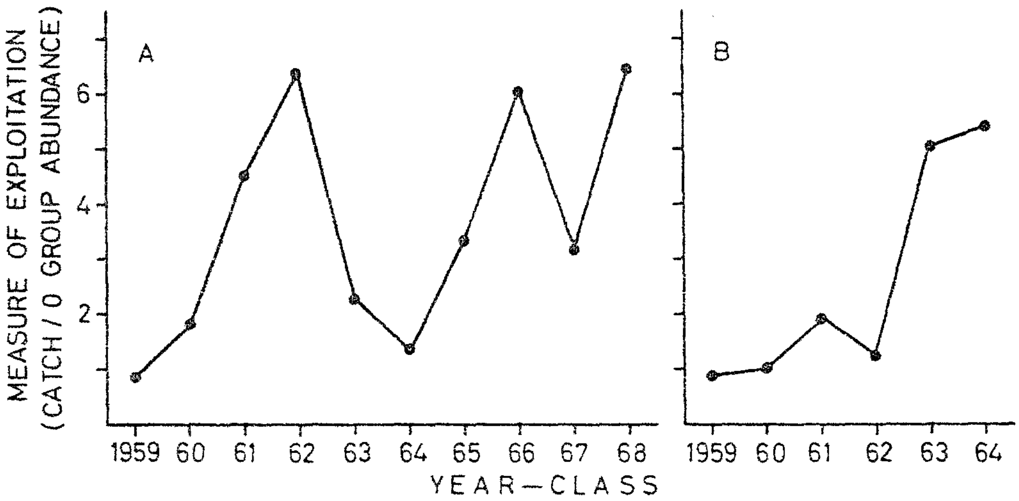


Fig. 1. Measure of exploitation indicated by the ratio of catch in tons/0-group echo abundance (A) during the small-herring stage for the year-classes 1959-1968 and (B) during the fat-herring stage for the 1959-1964 year-classes.

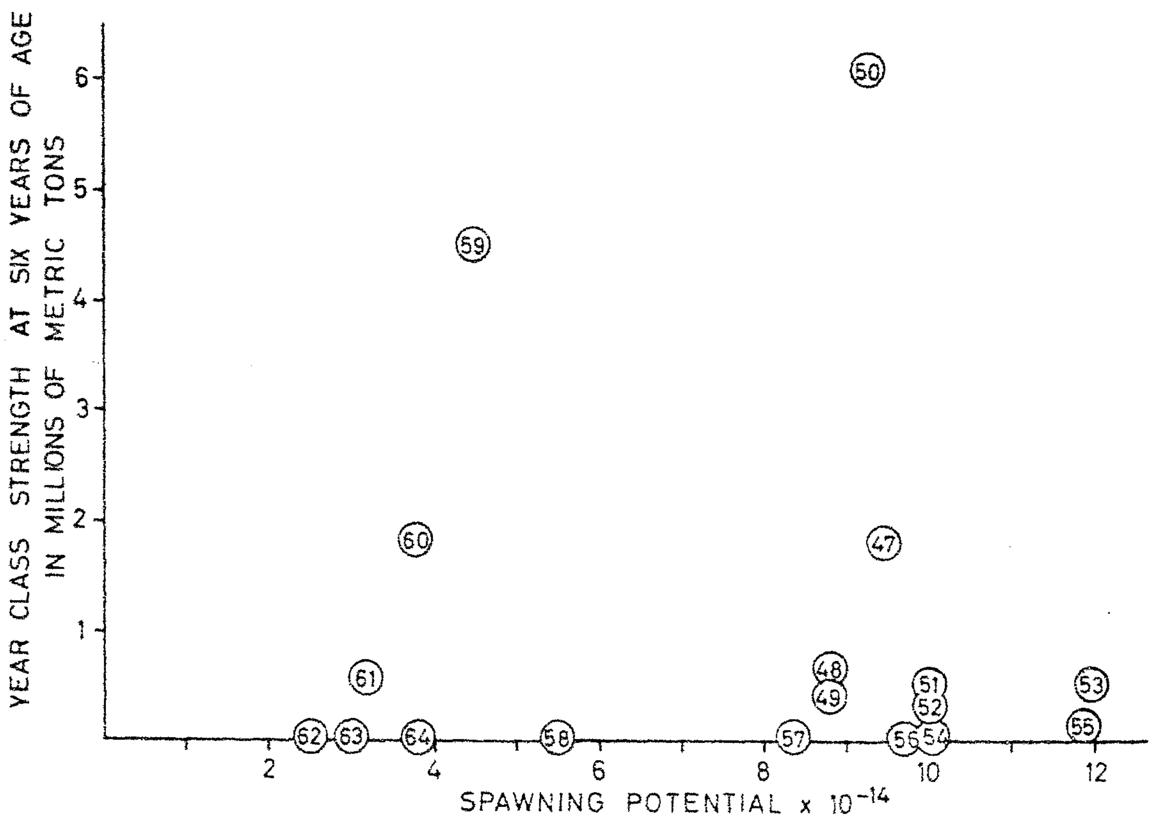


Fig. 2. Relationship between the spawning potential of the parent stock and the subsequent year-class strength at six years of age for the 1947-1964 year-classes. The respective year-classes are indicated inside each circle.

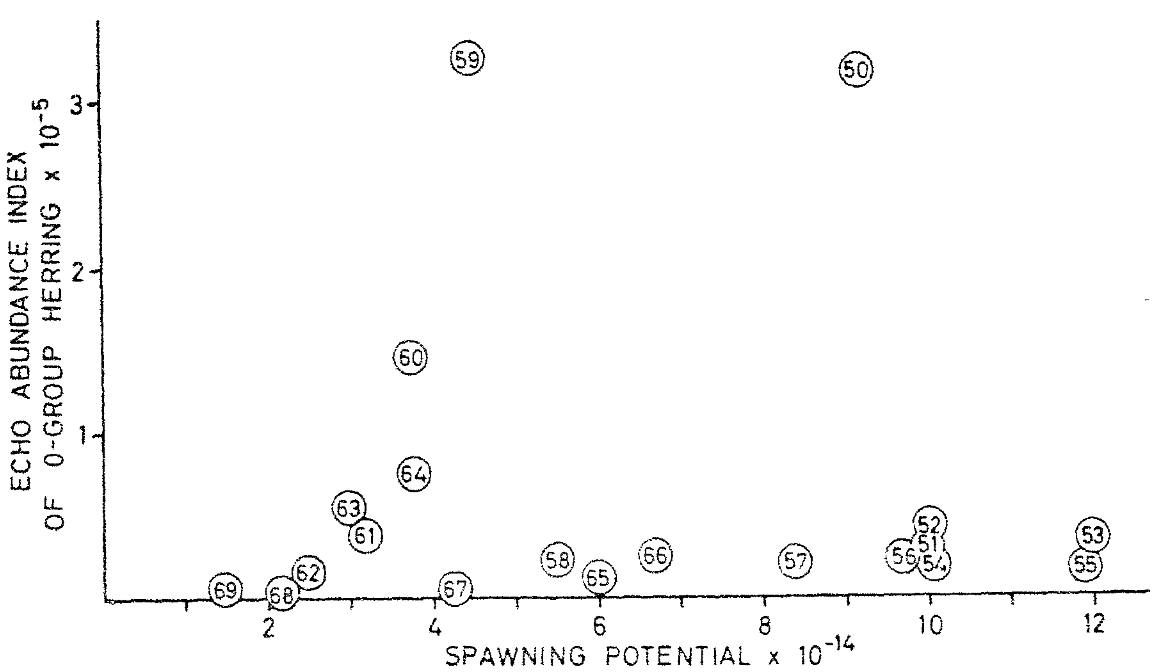


Fig. 3. Relationship between the spawning potential of the parent stock and the subsequent year-class strength at about six months of age for the 1950-1969 year-classes. The respective year-classes are indicated inside each circle.

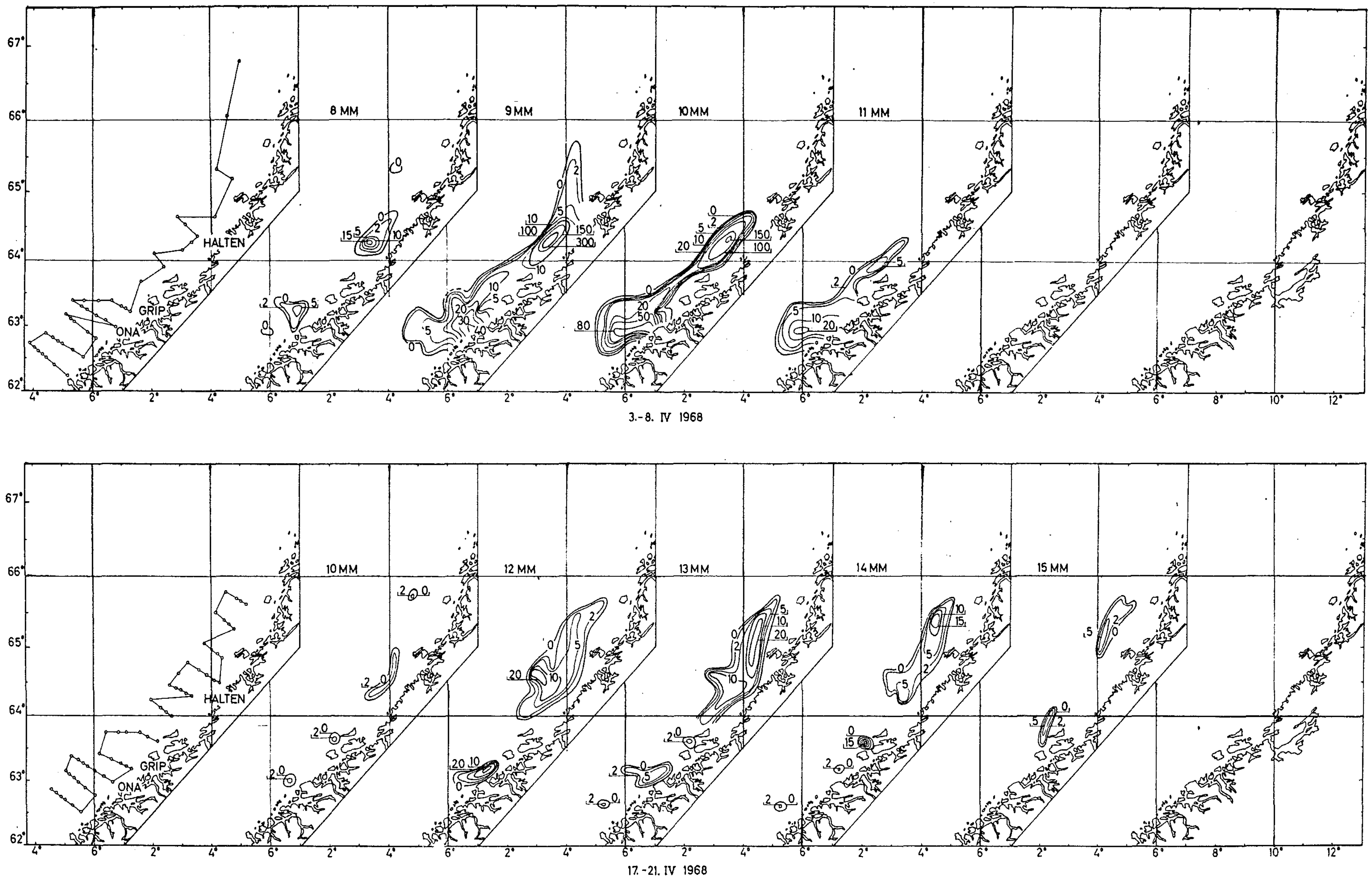


Fig. 4. Grid of stations (left) and quantitative distribution of larvae according to length during the different survey periods in 1968. Equal levels of larval abundance are indicated by isolines. The figures represent number of larvae below 1 m^2 surface.

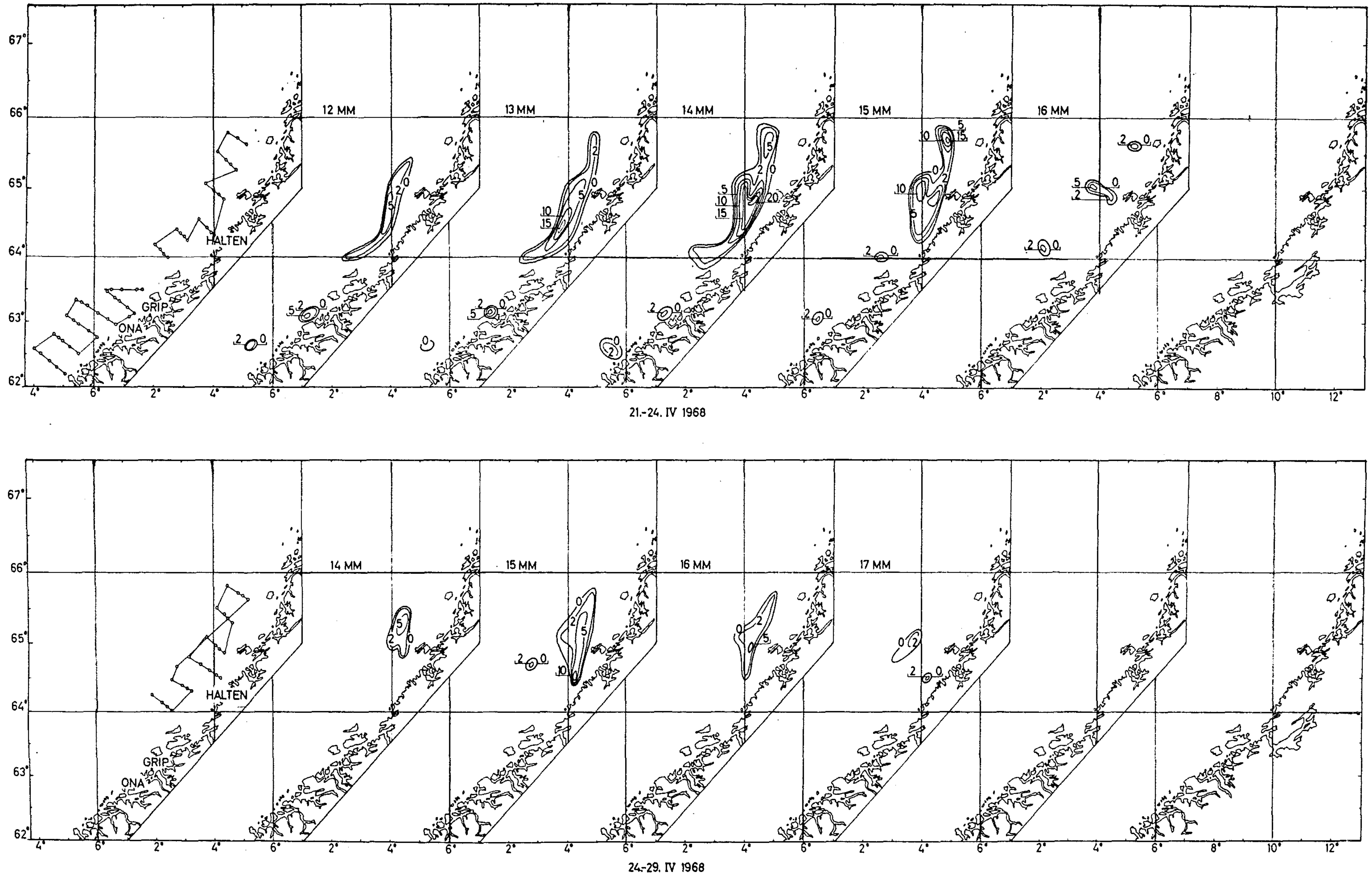


Fig. 4 (continued)

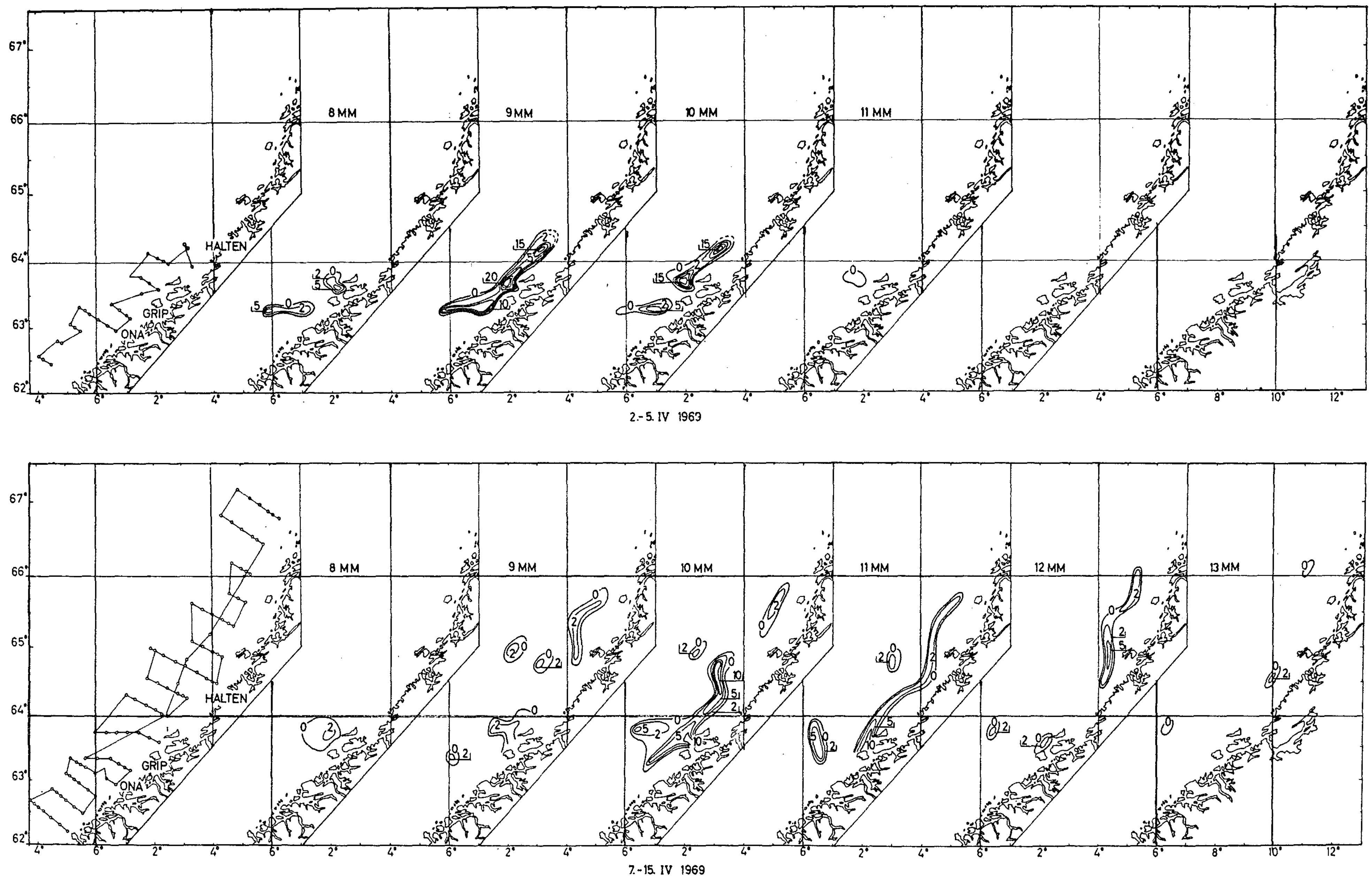
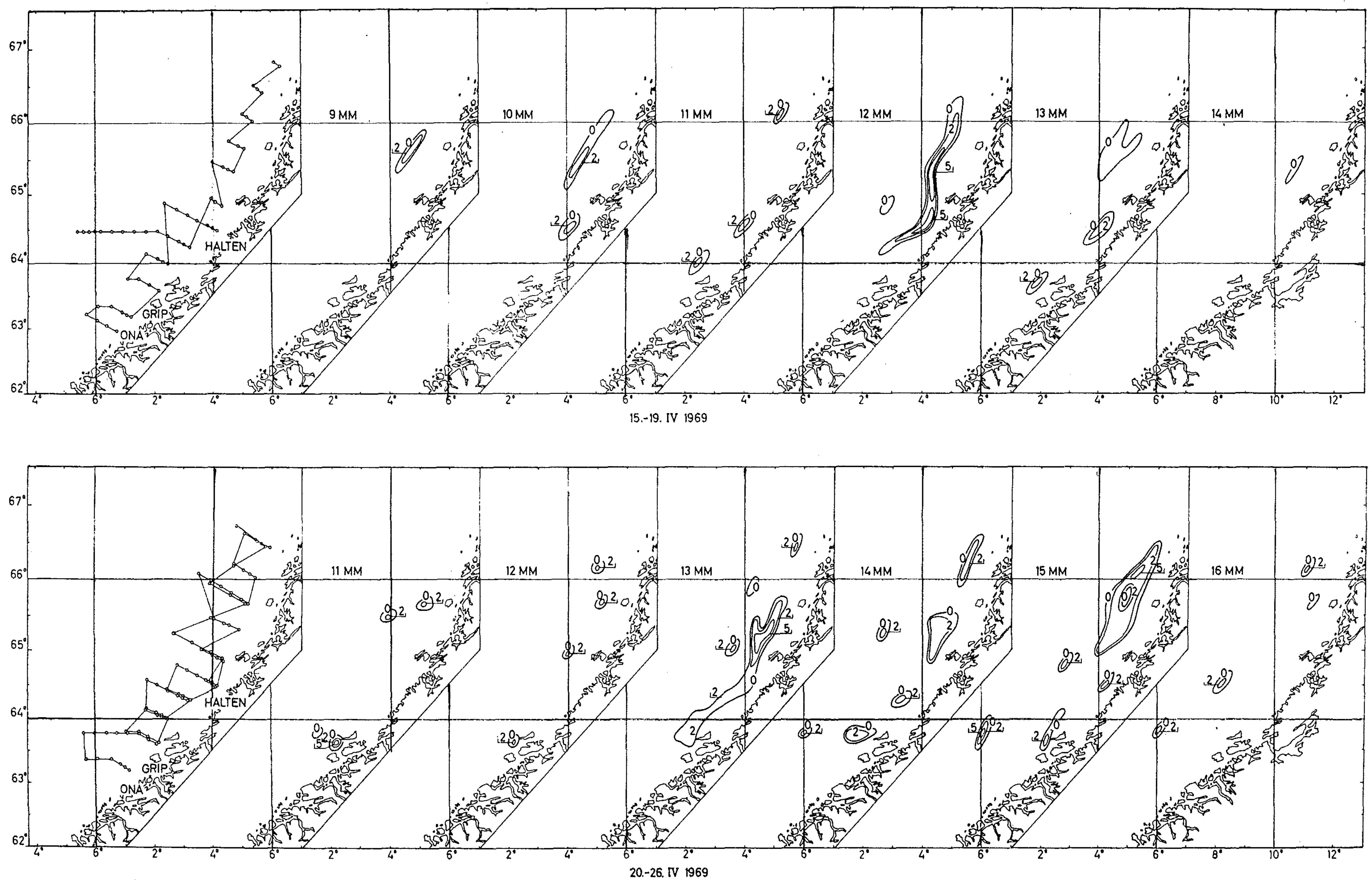


Fig. 5. Grid of stations (left) and quantitative distribution of larvae according to length during the different survey periods in 1969. Equal levels of larval abundance are indicated by isolines. The figures represent number of larvae below 1 m^2 surface.



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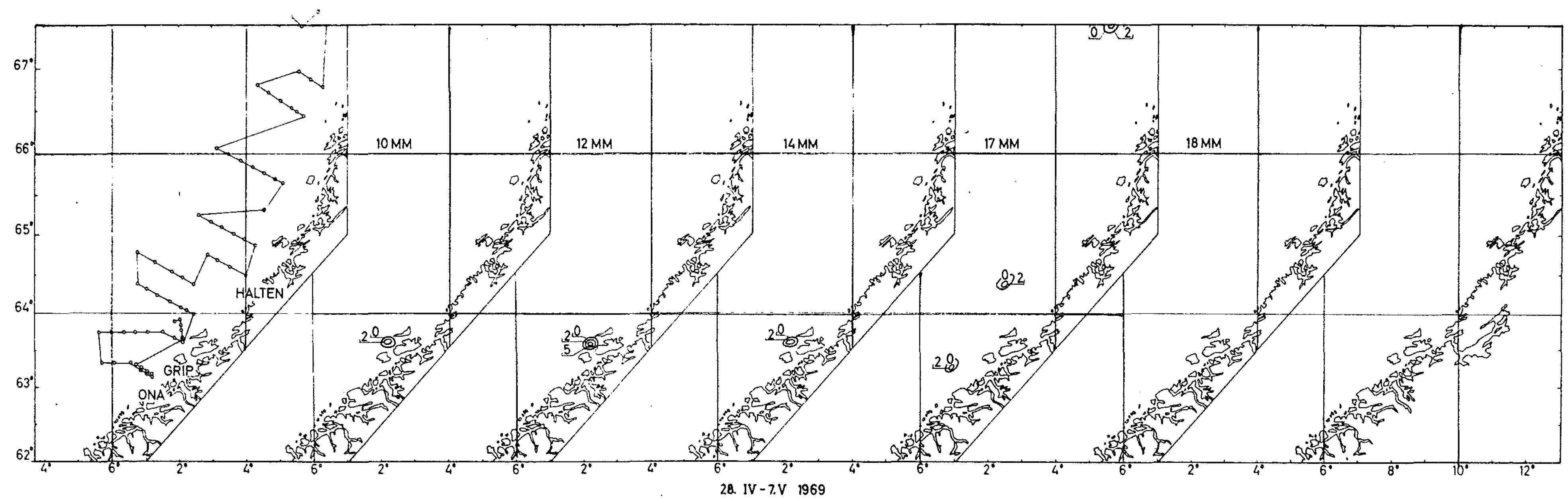

Fig. 5 (continued)

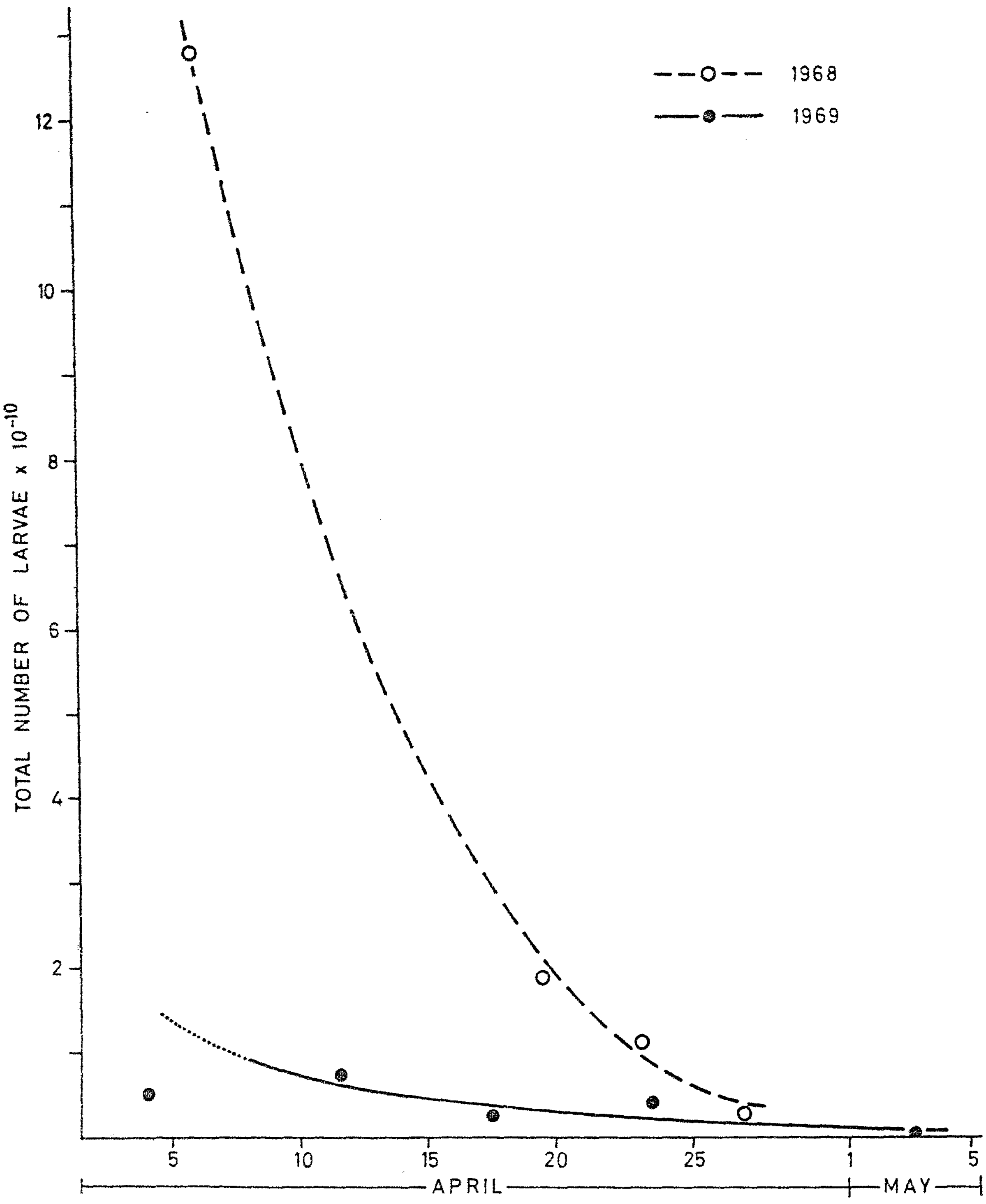

Fig. 6. Estimated total number of larvae during different periods of sampling in 1968 and 1969.

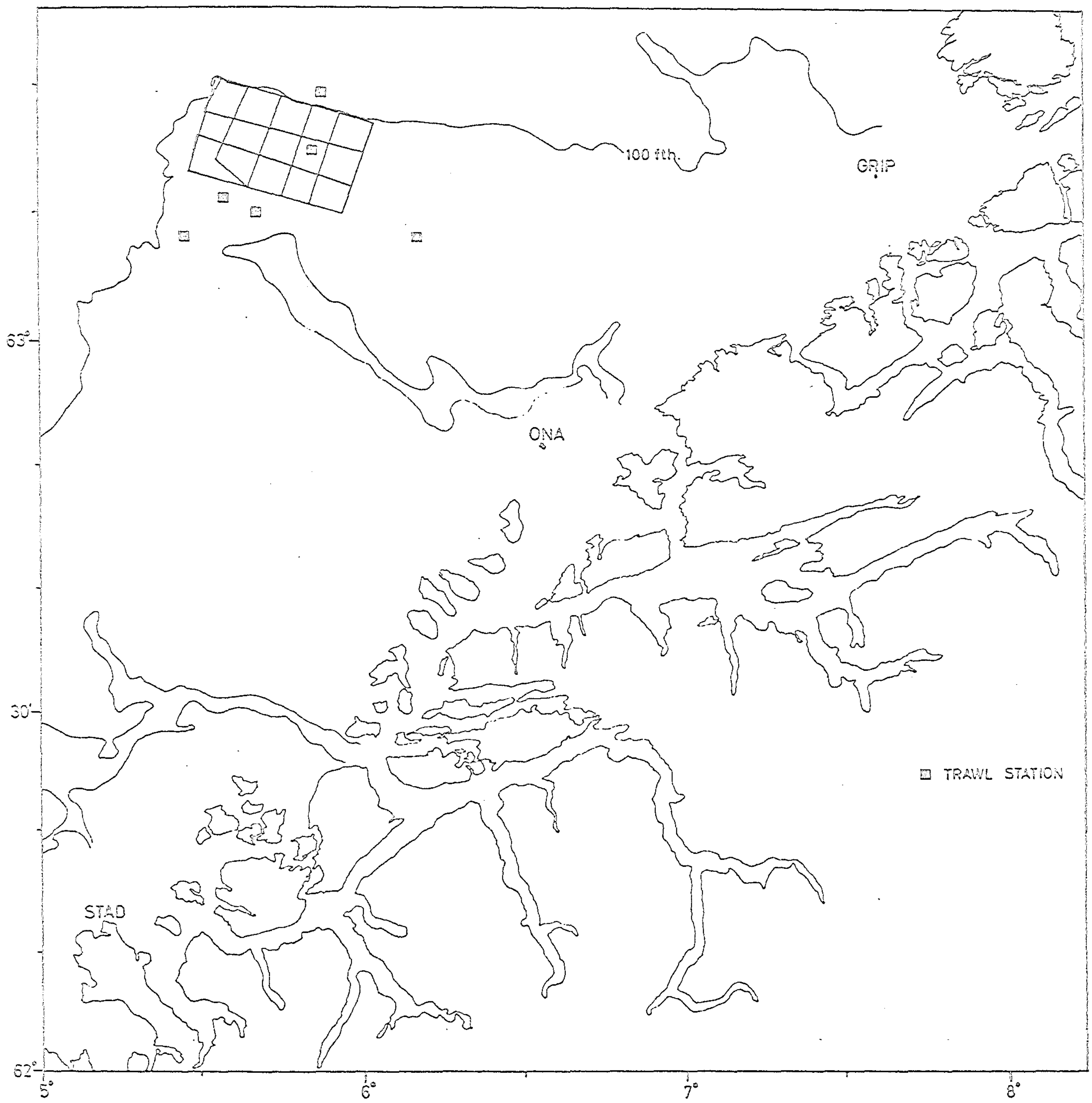

Fig. 7. Echo survey grid where counting of fish was carried out in 1970. Bottom trawl stations are indicated.

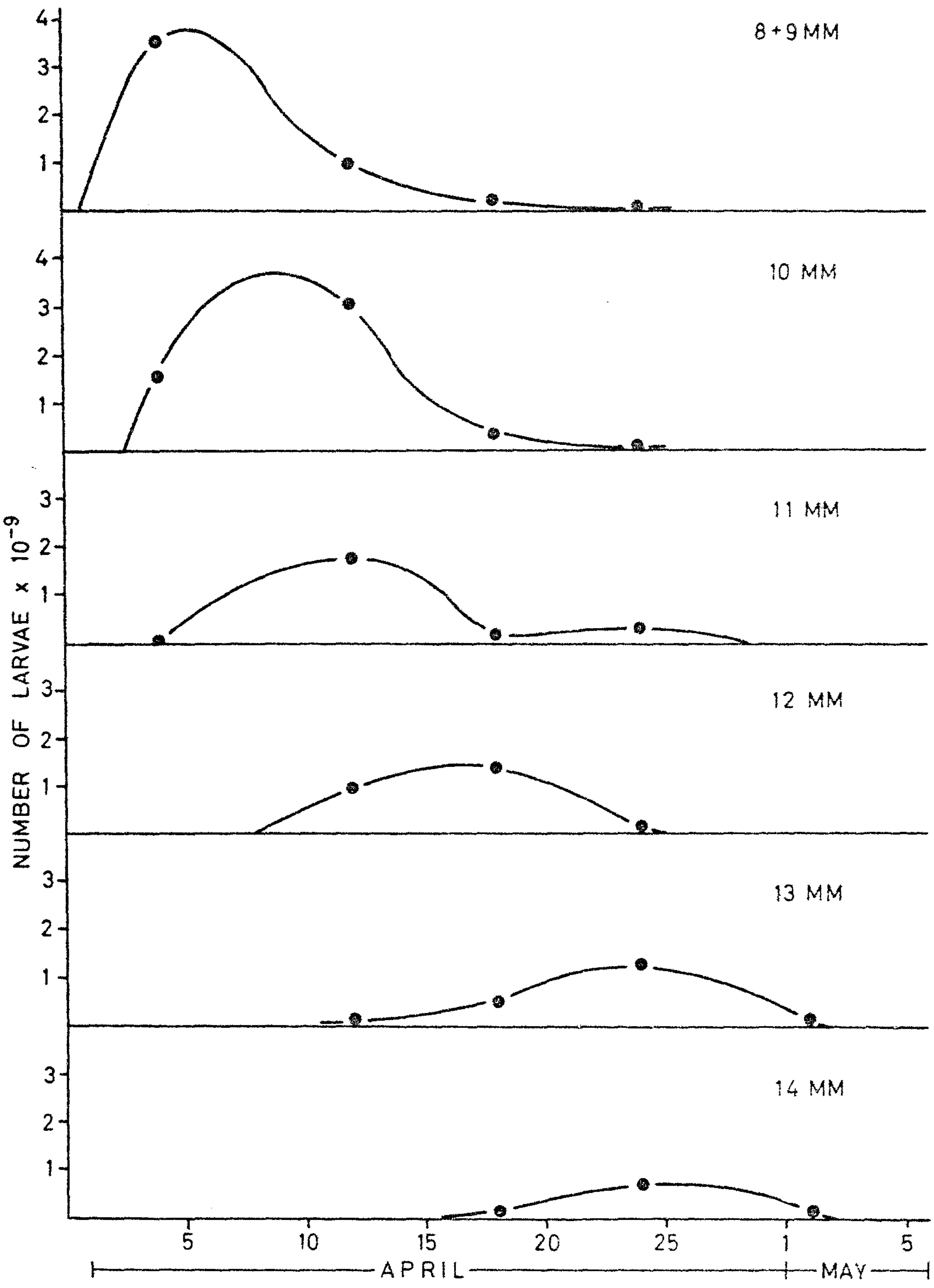

Fig. 8. Number of larvae in each mm group as a function of tim(
in the area surveyed in 1969. The 8 and 9 mm group are
pooled.

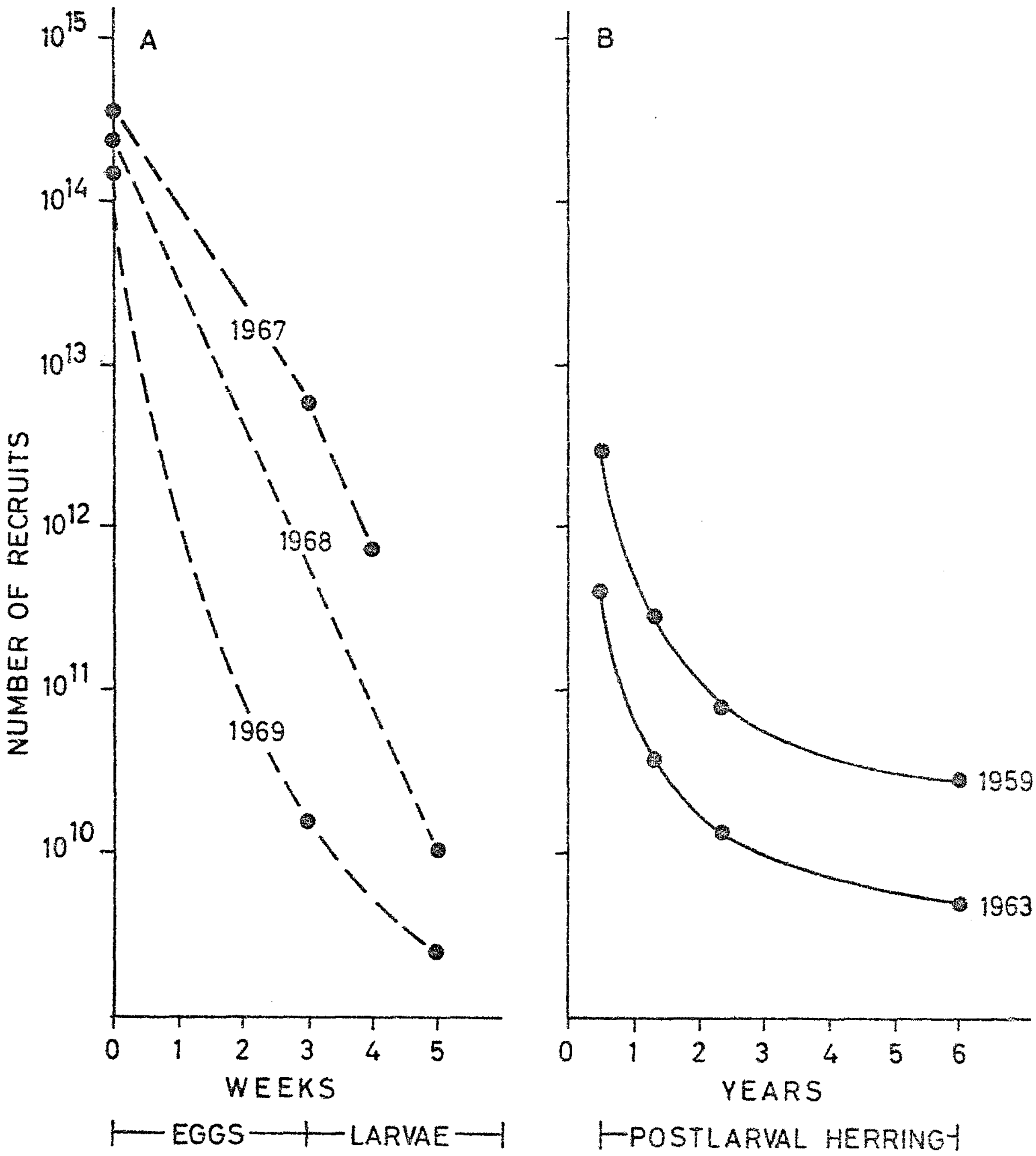

Fig. 9. Survival of recruits (A) during the incubation period and early larval development in 1967-1969 and (B) of the 1959 and 1963 year-classes from six months to six years of age.

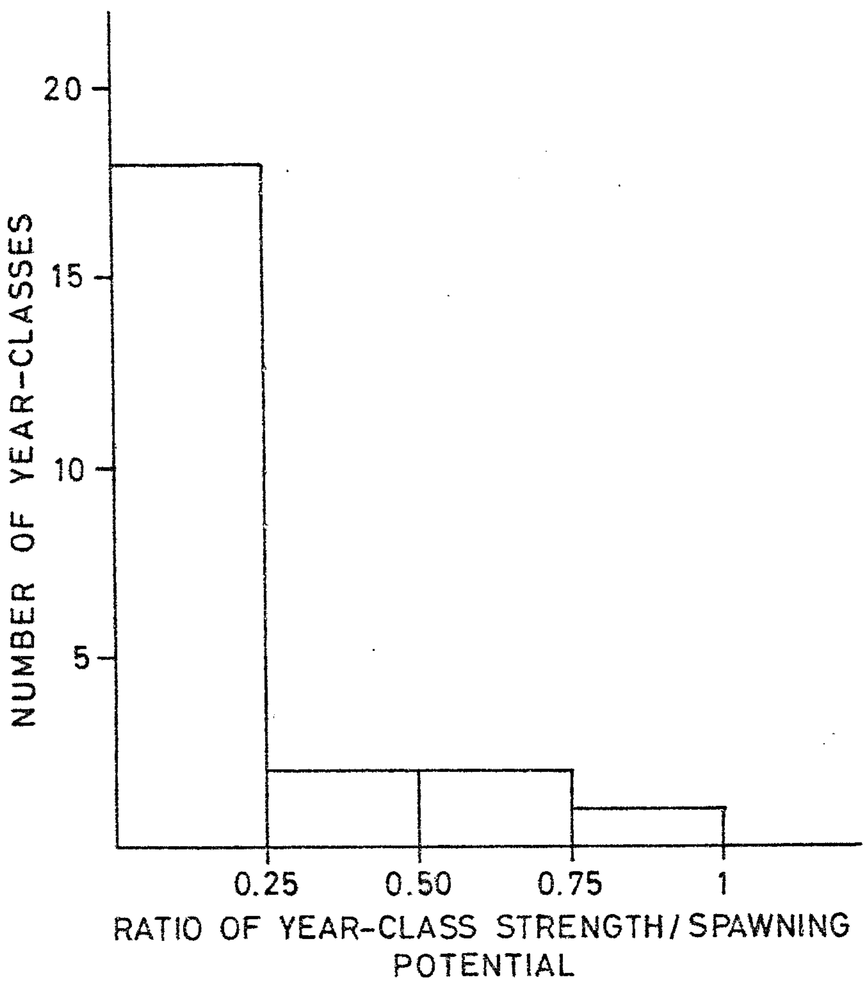

Fig. 10. Histogram showing the frequency of the ratio between year-class strength (measured at six years of age for the 1947-1950 year-classes and at six months of age for the 1951-1969 year-classes) and spawning potential.