HOLDEN, M. J. & MEADOWS, P. S.

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(*Squalus acanthias* L.)

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The Fecundity of the Spurdog (*Squalus acanthias* L.)

By

M. J. Holden
Fisheries Laboratory, Lowestoft

and

P. S. Meadows*
Marine Laboratory, Aberdeen

THE SPURDOG has become of increasing economic importance in recent years, the catch of dogfish by English, Norwegian and Scottish fishing vessels from the statistical regions IVA and VIA having risen from 3,870 metric tons in 1946 to 34,725 metric tons in 1960 (ICES, 1950, 1962). While these figures include all species of dogfish and sharks, the catch consists almost entirely of spurdogs. There is probably one stock of spurdogs in this area, as shown by AASEN's (1961) tagging experiments. The pregnancy cycle was first described by FORD (1921) and has been fully documented for the Newfoundland stock by TEMPLEMAN (1944). The cycle lasts two years. Ovulation occurs in December and January, and at the end of one year the embryos are about 10 cm long. Birth occurs the following November to January, the embryos averaging 27·5 cm in length (HOLDEN and MEADOWS, 1962). A further series of eggs matures within the ovaries while the embryos develop, and these pass down into the uteri almost immediately after parturition. These developing eggs can be distinguished in the ovary about eighteen months before ovulation because they are large and yellow. Non-developing eggs are small and white. FORD (1921) noted that there appeared to be a positive correlation between the length of the mother and the number of embryos carried. TEMPLEMAN (1944) showed that there was a definite correlation, the number of embryos increasing from an average of 3·24 in fish of 74–79 cm to 5·34 in fish of 94–99 cm. Such small numbers of progeny suggest that the spurdog might be extremely vulnerable to fishing, in that the stock could be diminished so rapidly that sufficient young would not be born to maintain it.

Methods

The number of eggs and embryos

Monthly samples of fish were taken from commercial landings at Aberdeen and Grimsby by vessels fishing off the coast of Scotland. The fish were measured to the nearest centimetre (total length), and the number of embryos and the

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*) Present address: Department of Zoology, The University, Glasgow W. 2.

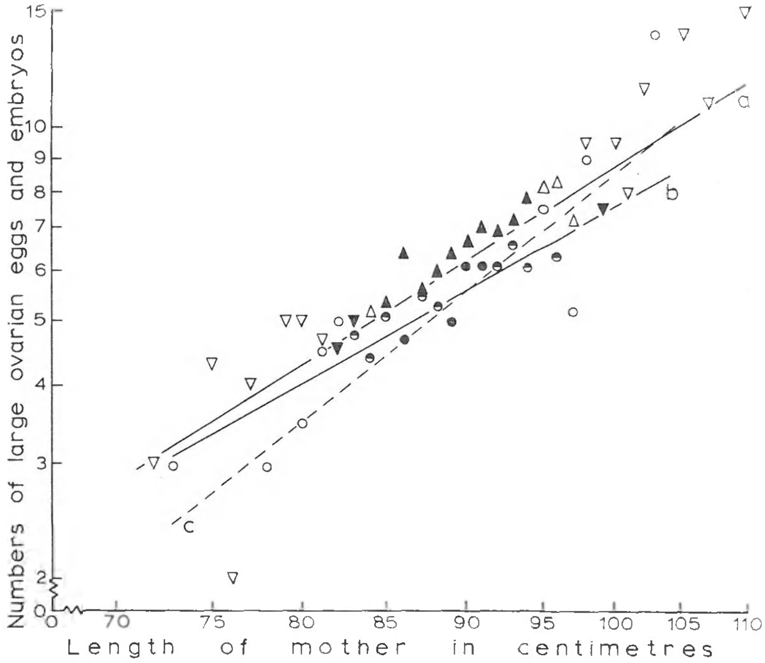

Figure 1. Relation between length of mother spurdog and the numbers of large ovarian eggs and embryos: points represent averages. Regression "a": number of large ovarian eggs $\log y = \bar{6}{\cdot}64 + 3{\cdot}15 \log x$; ▽ represents 1 to 5 observations, ▼ 6 to 10 observations, △ 11 to 20 observations, ▲ 21 + observations. Regression "b": number of embryos $\log y = \bar{5}{\cdot}22 + 2{\cdot}83 \log x$: ○ represents 1 to 5 observations, ◓ 6 to 10 observations, ● 11 to 20 observations. Regression "c": number of embryos derived from regression "a"; $\log y = \bar{7}{\cdot}06 + 3{\cdot}94 \log x$.

number of large yellow ovarian eggs were counted. The embryos were sexed and any abnormalities in egg or embryo development noted, e. g. addled (dead) eggs, aborted embryos. It was also recorded whether any embryos appeared to have been shed from the uteri. Where the uterine wall adhered closely to the embryos it was considered that no shedding had occurred.

Three hundred and eighty-two mature fish were examined, but of these it was considered that only 149 had not shed any embryos. No distinction has been made between the first and second year stages of the eggs or embryos. The regressions of numbers of eggs and numbers of embryos on length of mother have been calculated, transforming the data into logarithmic units to obtain a straight line relationship (Fig. 1: regressions "a" and "b"). The two regressions should converge because the growth rate decreases with size (Fig. 2), the distance between them along the "x" axis theoretically representing two years' growth, e. g. on average a female fish of 78 cm will carry four ovarian eggs and be nine years old. Two years later it will be 82·5 cm long (from Fig. 2) and will then carry four embryos, two years being the period that separates equivalent egg and embryo stages. Using this method a second regression of numbers of embryos against length of mother has been calculated (Fig. 1: regression "c"). This differs significantly from regression "b" ($P < 0{\cdot}02 > 0{\cdot}05$), suggesting that the subjective judgement whether embryos had been shed was not reliable.

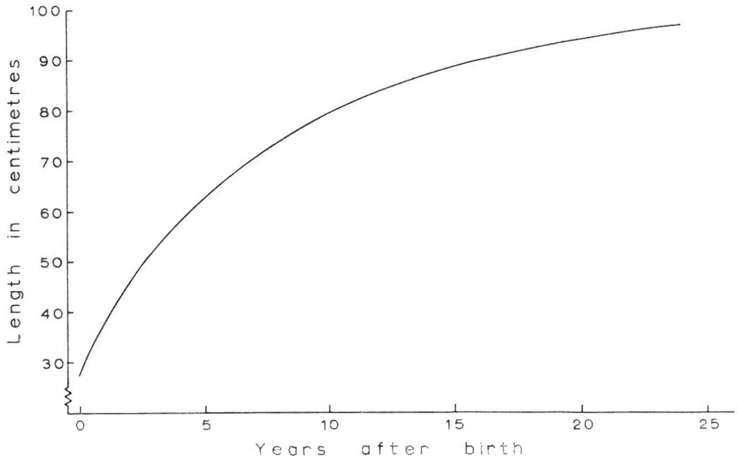

Figure 2. Calculated growth curve of female spurdogs (from HOLDEN and MEADOWS, 1962).

Abnormalities

Addled ovarian eggs were the commonest abnormality. Of 1,670 eggs examined, eighteen were addled. Of these, five were found in one maturing fish. Usually there was one, or, at the most, two addled eggs in any one female. In February 1961 one fish, 89 cm long, was observed with an egg capsule in each uterus, each containing two eggs, and two large addled eggs, one in each ovary, that had failed to be shed from the ovary at ovulation. In August 1960 a 94 cm fish was examined that had one live embryo in each of the uteri, measuring 22 cm and 23 cm, plus a dead embryo 9 cm long in the left uterus. The yolk sac of this embryo was broken.

Normally all mature female fish are either in the first or second year of the ovarian and uterine cycles, but in February 1961 one female was examined that had large embryos, 21–22 cm long, with the yolk sac absorbed, and small ovarian eggs 6–10 ml in volume. In the rest of the fish in the sample, the largest embryo found together with ovarian eggs of this volume was 17 cm, and this had a 20 ml yolk sac. All embryos are usually born by early January, so that not only were the ovarian and uterine cycles out of phase in this individual but the uterine cycle was out of phase with that in the rest of the sample. These abnormalities have been ignored in calculating the fecundity, and in particular the number of ovarian eggs noted is the total number, including addled eggs, because the error introduced by this is only of the order of 1 %.

Maturity

Seven hundred and seven female fish measuring between 70 cm and 110 cm were examined for maturity. They were classed into two categories: –

Immature: uteri threadlike; or, if thickened, white, firm and not vascularized; embryos absent.

Mature: uterine walls flaccid and highly vascularized; usually embryos present; developing eggs present in ovaries except immediately following ovulation.

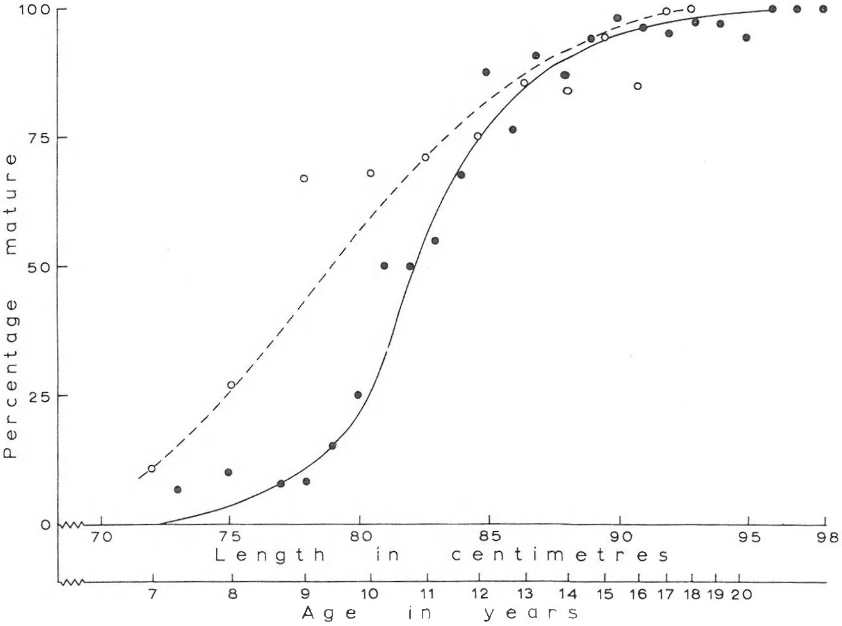

Figure 3. The proportion of female spurdogs that are mature at different lengths (age inserted from Fig. 2). ○ = maturity/age; ● = maturity/length.

The percentage maturity/length relationship is shown in Figure 3; age has been taken from Figure 2. One hundred and ninety-four female fish of known maturity were aged and the results also plotted in Figure 3. There is a difference of one year between the 50 % maturity points of the two curves. This is probably due both to the smallness of the sample and the difficulty in ageing fish to an accuracy of one year.

Discussion

It is evident that the spurdog has a low reproductive potential and that, like whales, there must exist a serious possibility that fishing could reduce the mature stock below the level at which it would replace itself. AASEN (1962) estimates from tag returns that the total annual mortality rate for this stock is 25 %, i.e. $z = 0{\cdot}287$. Using this figure and assuming an instantaneous natural mortality rate (M) of 0·1 (a reasonable assumption on the basis of BEVERTON and HOLT's (1959) theory linking the natural mortality rate with the von Bertalanffy growth constant K, which is 0·11 for female spurdogs (HOLDEN and MEADOWS, 1962)) the rate of decrease of a nominal stock of one thousand female fish has been calculated (Table 1). From market data collected at Grimsby recruitment to the fishery is complete at age five years, and it has been assumed for the purpose of calculation that no fishing occurs until this age. The numbers in each age-group have then been multiplied by the formula: –

$$\frac{\text{Number of young for fish of age-group} \times \text{proportion that are mature for age-group} \times \text{sex ratio}}{2}$$

Table 1

Calculation of number of female embryos produced by a nominal stock of 1000 female fish using regression "c" (Fig. 1) and its upper 95% confidence limit

Initial stock = 1000 female fish. Natural mortality rate (M) = 0·1. Total mortality rate (z) = 0·287. Assuming no fishing until five years (see text)

$$\text{stock at 5 yr} = 1000e^{-0{\cdot}5} = 606{\cdot}5$$
$$\text{stock at 8 yr} = 606{\cdot}5e^{-0{\cdot}861} = 256{\cdot}4$$

Age in years	Length, cm	Number of fish	Number of female embryos (regression "c")	Number of female embryos (upper 95% confidence limit)
8	73·7	256·4	3·4	5·4
9	76·6	192·3	10·2	16·1
10	79·3	144·2	21·3	33·7
11	81·6	108·2	43·1	68·4
12	83·7	81·1	59·4	94·1
13	85·6	60·9	57·0	90·2
14	87·3	45·6	51·5	81·6
15	88·8	34·2	43·8	69·3
16	90·1	25·7	35·1	55·6
17	91·3	19·3	28·2	44·6
18	92·4	14·4	22·3	35·4
19	93·3	10·8	17·7	28·1
20	94·2	8·1	13·9	22·0
21	95·0	6·1	10·7	16·9
22	95·6	4·6	8·3	13·1
23	96·3	3·4	6·5	10·3
24	96·8	2·6	4·9	7·7
25	97·3	1·9	3·7	5·9
Total number of female embryos			441·0	698·4

to give the number of female young that would be produced. The sex ratio is 0·5. The factor "2" allows for the pregnancy cycle taking two years. The calculation has been done using regression "c" (Fig. 1) and its upper 95% confidence limit, the equation for which is:—

$$\log y = \bar{7}{\cdot}26 + 3{\cdot}94 \log x$$

where y = number of young,
x = length of mother.

The results are given in Table 1. In neither instance does the number of young produced equal the initial stock which is the requirement if the stock is to maintain itself. Therefore under present conditions it is very improbable that the stock is replacing itself, assuming that the value taken for the natural mortality rate is correct. This assumption only affects the first five years of the calculation and if the same series of calculations is made using $M = 0{\cdot}1$, and with no fishing, the number of young that would be produced exceeds one thousand, and since the stock must have been in long-term balance before fishing started, a much higher value of M, approximately 0·2, would have been required to keep the stock in balance with the present fecundity and growth rate, i.e. the assumed value is therefore reasonable and possibly low.

Assuming that the stock is not replacing itself, three possible events may occur to restore the balance:—

1. The natural mortality rate will decrease, e.g. the predation by other species may decrease or the spread of disease be limited by the reduced numbers. Too

little is known about fluctuations in natural mortality rates to permit assertions to be made on this point.

2. The fecundity may increase, e.g. a larger number of young would be produced at any given age if the decrease in the size of the stock resulted in a more abundant food supply which in turn led to an increased growth rate and earlier maturation. The number of young carried for any given size of female is unlikely to increase because the size of the body cavity must limit to some extent the number of embryos. The spurdog is omnivorous (personal observations) and it is not evident that shortage of food is a factor limiting the rate of growth. In a similar case, that of the North Sea plaice, which decreased in abundance after the end of the 1939–1945 war, there was no observable increase in the growth rate. However, the high value of M (0·2) calculated earlier as necessary to keep the stock in balance if fishing ceased, as against a theoretical expectation of 0·1, may indicate that there has already been some increase in fecundity but that it has not been able fully to compensate for the effects of fishing. Alternatively, the natural mortality rate may not remain constant. There is some evidence from BONHAM's (1954) work on the food of dogfish that the spawning females may prey on the newly born, so that when stock density is high there is heavy predation of the young resulting in a big reduction in the number of recruits. After this initial high mortality, a level of natural mortality of 0·1 could then effectively maintain the stock balance. Even if the fecundity were to increase a rapid and large alteration would be required to compensate for the present total mortality and it appears unlikely that a large enough increase could occur so quickly.

3. Neither the natural mortality rate nor the fecundity will alter appreciably but the fishery will decline until a new balance is struck between fishing rate and recruitment. This appears the most likely sequence of events in which case the immediate prognosis for the fishery is poor, and AASEN's (1962) contention that the present annual mortality rate "does not give any ground for any fear of overfishing" is not justified.

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Summary

1. The fecundity of the north-west Scotland stock of spurdogfish is described. The numbers of large ovarian eggs and embryos increase with the size of the mother fish. Regressions of numbers against length are calculated.

2. Percentage maturity of female fish in relation to length and age is calculated.

3. Using an estimate of the natural mortality and an observed total mortality rate the reproductive potential of the stock is calculated. It is concluded that the stock is not replacing itself and that a decline in this fishery is to be expected.

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