International Council for
the Exploration of the Sea

C.M. 1985/H:55/Sess.Q
Pelagic Fish Committee

PREDATION ON THE EGGS OF NORWEGIAN SPRING-SPAWNING HERRING AT A SPAWNING GROUND OUTSIDE THE WESTCOAST OF NORWAY IN 1981.

by

Reidar Toresen
Institute of Marine Research
P.O. Box 1870 N-5011 Bergen, Norway

Abstract

Predation on the eggs of demersal spawners has been reported several times, and findings of haddock feeding on capelin or herring eggs is a well known phenomenon. A spawning ground where spawning has been detected through several years was selected as the study-area and investigations on the predation were carried out in three steps; a) stomach sampling, b) controlled experiments to find the rate of gastric emptying of herring eggs and c) bioacoustic surveys to study the distribution and abundance of predators. Haddock was found to be the main predator on eggs in the area. The total amount of fertilized herring eggs being eaten in a period of 30 days was estimated to be about 10 000 metric tonnes. This is the spawning product of about 20 000 tonnes of herring.

Introduction

The main spawning grounds of the Norwegian spring-spawning herring are situated along the west coast of Norway,-mainly at the Møre-coast north of Bergen, DRAGESUND, HAMRE and ULLTANG (1980). The spawning takes place at depths of 70-180 meters close to bottom where the eggs are dispersed on different kinds of substratum such as rock, gravel or sand. The spawning lasts for about 4-6 weeks, with a midpoint in the first few weeks of March. The incubation time varies between 18-24 days depending on the actual temperature at the sites, BLAXTER and HEMPEL (1963).

The eggs are preyed upon during the time before hatching. Findings of haddock having preyed on eggs of herring is a well known phenomenon first described by BOWMAN (1922).Predation on eggs of other demersal spawners like capelin has been the subject of research done by TEMPLEMAN (1965) on the Grand Banks off Newfoundland. Haddock has also been found to feed on the eggs of capelin in the Barents Sea, SÆTRE

and GJØSÆTER (1975). Off the westcoast of Norway investigations done by DRAGESUND and NAKKEN (1973) showed both haddock and saithe preying on the eggs of herring. However it has been difficult to quantify this kind of predation. In 1978 JOHANNESSEN carried out studies of the preying on herring eggs in the Lindåspollene outside Bergen JOHANNESSEN (1980). Here, young cod was found to be the main predator feeding heavily on the eggs of the local herring stock.

In the period after the severe reduction of the abundance of the Norwegian spring-spawning stock of herring in the late sixties the recruitment to this stock has been at a very low level. The predation on the eggs could be one of the factors prohibiting an increase in the recruitment to this stock and pilot studies were carried out in spring 1980 followed by main studies in 1981.

One of the most important spawning sites of herring along the Norwegian coast, the bank of Buagrunnen, was chosen as study area (Fig 1) and the aim of the investigations was to estimate the total amount of herring eggs being eaten at this locality. This was done by

- investigating the stomach content of cod, haddock and saithe to find the main predator and to quantify how much the individuals of these species can take of herring eggs
- controlled experiments measuring the rate of gastric emptying of herring eggs from the stomachs of the predators
- estimating the abundance of the stock of predators in the area by the use of acoustic methods

Material and methods

Stomach sampling

Stomachs from each of the three potential predators, cod,haddock and saithe were sampled in 5 cm length groups of the fish. The stomachs and their contents were taken from the fish and conserved on formalin for further studies in a laboratory. Here the weight of the different kinds of content was taken. If there were herring eggs in the stomach they were counted and the ages of the eggs (days after fertilisation) were decided.

Rate of gastric emptying

The rate of gastric emptying may be studied from samples in the field if the species under study have a very pronounced cycle of food intake. One could then measure the length of the cycle and get a measure of gastric emptying by quantyfying the average amount of stomach content through the cycle JONES (1974). Haddock, which was found to be the main predator on herring eggs, does not have a very pronounced cycle of food intake making it difficult to measure the rate of gastric evaculations in the natural environment. It was therefore decided to investigate this rate through a controlled experiment in a tank.

There are about as many models of gastric emptying on different food items as there are fish species and scientists, and a lot of investigations have been carried out to shed light on these problems, HUNT (1960), WINDELL (1966), TYLER (1970), JONES (1974), EL-SHAMY (1976), DOBLE & EGGERS (1978), JONES (1976), JOBLING & DAVIES (1979) and JOBLING (1980). In these studies the following points are considered to be the most significant in deciding the rate of gastric emptying; the temperature, the size of the predator, the size of the meal and the kind of food. However it is difficult to lay down a mathematical model that goes for several species and several food items, JOBLING (1981).

In this work the following relationship described by JONES (1974) was chosen;

$$r = Q * \left(\frac{L}{l}\right)^{k_1} * \left(\frac{W}{w}\right)^{k_2} \qquad (1)$$

where r = rate of gastric emptying

Q = quotient of gastric emptying, dependent on temperature, kind of food and way of feeding (single or multiple feeding)

L = length of the fish (cm)

l = mean length of the fishes in the experiment

W = size of meal (wetweight/kg)

w = mean weight of food given to the fishes in the experiment (wetweight/kg)

k_1 and k_2 are constants dependent on kind of food, the temperature and the way of feeding.

Altogether 49 haddock were utilized in the experiment and they were fed once with fertilized herring eggs. The eggs were put into their stomachs through a tube and the amount of food given was in direct relation to the length of the fish. Fish in the length group 42-49 cm were given 10 g, in the length group 50-59 cm they were given 20 g and fish larger than 60 cm were given 30 g of eggs. In this way, no fish received more than 1.6% of its own weight in food amount. This limit was set to reduce the effect of regurgitation. Within each of the three groups the amount of food in relation to the body weight varied between 9.0 and 16.0 g and the average food amount in the groups was 12.0 g or about 1.2% of the bodyweight. Every 12 hour after the feeding 5 individuals were picked out and the length of the fish and the amount of eggs left in the stomach was recorded. Table 1 shows the number of fish per length group, the amount of food given, the theoretical weight of each length group and the food amount in

relation to the bodyweight for each length group of fish used in the experiment.

Acoustic abundance estimation of predators at the spawning ground.

Acoustic abundance estimation of demersal fish started in the Barent Sea in 1970 HYLEN et al. (1972).In the seventies the methods have been developed and acoustic abundance estimation of bottom dwelling fish has become routine, DALEN, HYLEN and SMEDSTAD (1977), DALEN and SMEDSTAD (1979a). The methods which DALEN and SMEDSTAD (1979b) have described are also used for estimation of demersal fish at the spawning grounds in these investigations.

Two acoustic surveys were conducted in the area, one in the period 16-27 of March and one in the period 6-15 of April.

Pelagical and demersal trawl hauls were carried out to identify registrations and to get biological samples giving data for abundance estimation. The echo recording papers were scrutinized daily and the integrator readings (mm/nm) were divided into two categories of fish (cod/haddock and saithe/other demersal species) determined by the registrations and what was found when trawling in accordance with those registrations.

The average integrator values (M) for each 5 nautical miles where plotted on maps and the average M for each of the two categories of fish were calculated within the squares shown in Fig. 1. This average M was then further used to calculate the abundance of fish.

The following functions were used to convert the M values into fish densities;

$$C_{cod} = 5.25 * 10^{6} * L^{-2\ 18}$$

$$C_{haddock} = 1.72 * 10^{6} * L^{-1\ 69}$$

$$C_{saithe} = 3.64 * 10^{6} * L^{-2\ 09}$$

where L is the length of the fish. These functions are products of the target strength functions and the instrument constant of the research vessel F/F "G.O. Sars".

Results and discussions

Stomach contents

Table 2 shows the number of stomachs sampled for each of the three species cod, haddock and saithe in 1980 and in 1981. The table also shows the numbers and the proportion of the stomachs that contained herring eggs for each of the three species. Haddock did not have any competition from cod or saithe in the predation of herring eggs. Only a few cod and saithe stomachs contained eggs whilst eggs were found in about 40% of the haddock stomachs.

Haddock

Results from the trawl stations where predators of herring eggs were found in 1981 are shown in Table 3. Stations where no predators were found are not included because the results indicate that no spawning had taken place at these localities. At trawl stations with predators 47.8% of the haddock (haddock > 30 cm) had eggs in their stomach. At two of the stations 70% contained herring eggs. Of the stomachs containing eggs 24% had other particles of nutrition as well, and about 26% were empty.

Cod and saithe

The content of the stomachs of cod and saithe indicate that these species tend to search for food in the more open water masses. Herring and crill was found to be the most dominant kinds of food particles for these species. The samples were taken at the same trawl stations as those having haddock as egg predator.

Predation of herring eggs related to the size of the predator.

The proportion of haddock stomachs which contained herring eggs, other food particles, or that were found to be empty is shown in Figure 2 in 5 cm groups. Haddock in the size interval from 30 to 65 cm preyed on herring eggs. No predators were detected in the groups of fish shorter than 30 cm. The greatest proportion of predators was found in the length groups 35 - 64 cm.

Table 4 shows the average number of eggs found in the stomachs of haddock in the different length groups. The table also shows the standard deviation of the number of eggs and the maximum and minimum numbers of eggs found within each length group. The standard deviation of the number of eggs increases with the increasing length of the fish i.e. larger fish have greater variation of stomach filling than smaller fish.

Rate of gastric emptying

For each of the fish picked out during the experiment the following parameters were put down;

L = length

F = amount of food given/kg bodyweight

x = amount of food left in the stomach/kg bodyweight

h = number of hours between feeding and sampling

Figure 3 shows how the amount of food decreases as the time increases after feeding. The relation which expresses the proportion of food given;

$$PE = \frac{1}{5} \sum_{i=1}^{5} \frac{x}{F}$$

is plotted against the time after feeding. The slope of the line is -0.14 i.e. g/h. This is the rate of gastric emptying of herring eggs from the stomachs of haddock with average length of 51 cm and an average amount of food of 11.87 g/kg bodyweight given in one meal.

JONES (1974) gives a detailed description of how the data may be processed to make them fit into the function (equation 1) giving the length dependence and the dependence of amount of food to the gastric emptying. The final result from this experiment is;

$$r = -0.14 \left(\frac{L}{51}\right)^{1\,02} * \left(\frac{W}{12}\right)^{1\,44} \quad g/h \qquad (2)$$

which expresses the rate of gastric emptying of herring eggs from the stomachs of haddock at a temperature of 7^0 C. The length dependence of this relation shows no power, i.e. the rate of gastric emptying is independent of the length of the fish. It is however, dependent on the amount of food in the way that the rate of gastric emptying increases with increasing food amount.

Estimation of the abundance of haddock at the spawning ground

Two separate estimates of the abundance of haddock in the area were done. The results are shown in Table 5. The great difference in numbers of haddock between the two estimates is due to the fact that large amounts of small haddock were registered during the last survey. The number of haddock preying on herring eggs however, is fairly constant in the period.

Estimation of the predation of herring eggs at the spawning ground

Before an estimation of the total predation of eggs can be done, a few more questions need to be answered. How great a proportion of the estimated stock of haddock prey on eggs? And for how long does the predation in the area last?

One cannot assume that all the haddock in the area eat eggs. Some haddock prefer other kinds of food, and spawning does not take place

over the whole area. To decide the proportion of haddock preying on herring eggs the proportion of haddock having eggs in their stomachs in the trawl catches is used. Table 3 shows the numbers of haddock in the catches and the proportion of these having herring eggs in their stomachs. Tabel 6 shows the total numbers of haddock that have eaten eggs.

The time of exposure to predation may be seen from studying the age composition of the eggs in the stomachs. The incubation time for herring eggs at temperatures of 5-6^0 C is about 21 days, BLAXTER and HEMPEL (1963). By finding the age of the oldest eggs from the first catches of egg predators it is possible to get an indication of the starting time of spawning. In the same way, by finding the age of the youngest eggs from the latest catches of predators, it is possible to say for how long the eggs must have been exposed to predation. In 1981 there were eggs on the bottom in the period from 7. March to 29. April. However the concentration of eggs on the bottom has surely not been on the same level in the full period. The intensity of the spawning differs and at the end of the period a lot of eggs have hatched. However, the age composition of the eggs in the different catches gives a good indication of the intensity of spawning throughout the period. Table 7 shows the mean age of the eggs at different times in 1981. The time of spawning for the eggs is also given. In 1981 the highest intensity of spawning took place from the 14. to the 26. of March. With an incubation time of 21 days, there must have been a fairly high concentration of eggs on the seafloor in the period 14. March - 15. April, i.e. about 30 days.

The following equation expresses the total predation of eggs

$$P = t \sum_{i=1}^{n} NP_i * r(g/d)_i$$

where P = the total predation of herring eggs

t = the time of exposure to predation

NP_i = number of predators in length group i

$r(g/d)$ = rate of gastric emptying in length group i

To find the rate of gastric emptying in each length group, the general expression (equation 2) is used and the mean weight of herring eggs and the mean length in each length group is put into the formula.

Table 8 shows the mean weight of herring eggs in each length group and the rate of gastric emptying per hour and per day for the same groups.

Table 9 shows the mean number of egg predators per length group and the amount of herring eggs eaten by these predators per day and during a period of 30 days.

The total amount of herring eggs eaten in the period is $9.8 * 10^9$ g or about 10 000 metric tonns. The mean weight of fertilized herring eggs is 0.004 g and the fecundity of herring in the length group 35-39 cm is about $75.0 * 10^3$ eggs PARRISH and SAVILLE (1965). The weight of these eggs in fertilized condition is about 300 g. The predation of 10 000 tonnes of herring eggs is the spawning product of $32.7 * 10^6$ females. The mean weight of herring at this length is about 330 g giving an amount of 10 800 tonnes of females or a total of about 20 000 tonnes of herring.

The most uncertain point of this estimate is the rate of gastric emptying which is based on a controlled experiment with a single feeding of herring eggs. Under natural conditions the haddock probably fill their stomachs at least twice a day and the rate of gastric emptying will be greater. The estimate presented above therefore is most certainly too low.

REFERENCES

BLAXTER, J.H.S. and HEMPEL, G. 1963. The influence of egg size on herring larvae (Clupea harengus L.). J. Cons. perm. int. Explor. Mer, 28: 211-240.

BOWMAN, A. 1922. The occurence of "spawny" haddock and the locus and extent of herring spawning grounds. Fisheries, Scotland, Sci. Invest. 1922, IV.

DALEN, J. and SMEDSTAD, O.M. 1979a. Bunnfiskundersøkelser i Barentshavet vinteren 1978. Fisken Hav., 1979 (2): 1-13 (In norwegian).

DALEN, J. and SMEDSTAD, O.M. 1979b. Acoustic method for estimating absolute abundance of young cod and haddock in the Barent Sea. Coun. Meet. int. Coun. Explor. Sea, 1979 (G:51): 1-24 (Mimeo.)

DALEN, J., HYLEN, A. and SMEDSTAD, O.M. 1977. Akustisk mengdemåling av torsk og hyse i Barentshavet i februar 1976. Fisken Hav., 1977 (2): 3-15 (In norwegian).

DOBLE, B.D. and EGGERS, D.M. 1978. Daily feeding chronology, rate of gastric evaculation, daily ration and prey selection in Lake Washington juvenile sockeye salmon (Onchorhynchus nerka). Trans. Am. Fish. Soc. 107, 36-45.

DRAGESUND, O., HAMRE, J. and ULLTANG, Ø. 1980. Biology and population dynamics of the Norwegian spring-spawning herring. Rapp. et. Proc. Verb, Vol 177, Int. Cons. Explor. Mer. Copenhagen.

DRAGESUND, O. and NAKKEN, O. 1973. Relationship of parent stock size and year class strength in Norwegian spring-spawning herring. Rapp. P.-v. Reun. Cons. int. Explor. Mer., 164: 15-30.

EL-SHAMY, F.M. 1976. Analysis of gastric emptying in blue-gill (Lepomis macrochirus). J. Fish. Res. Bd. Can. 33, 1630-1633.

HUNT, B.P. 1960. Digestion rate and food consumption of Florida gar, wormouth and largemoth bass. Trans. Am. Fish. Soc. 89, 206-211.

HYLEN, A. JAKOBSEN, T., LAHN-JOHANNESSEN, J., SMEDSTAD, O.M. and SÆTRE, R. 1972. Bunnfiskundersøkelser ved Bjørnøya, Spitsbergen og i Barentshavet med F/F "G.O. Sars" 3-20 november 1970. Fisken Hav., 1977 (2): 3-15 (In norwegian).

JOBLING, M. 1980. Gastric evaculation in plaice, Pleuronectes platessa L.: effects of temperature and fish size. J. Fish. Biol. 17, 547-551.

JOBLING, M. 1981. Mathematical models of gastric emptying and the estimation of daily rates of food consumption for fish. J. Fish. Biol. 19, 245-257.

JOBLING, M. and DAVIES, P.S. 1979. Gastric evaculation in plaice, Pleuronectes platessa L.: effects of temperature and meal size. J. Fish. Biol. 14, 539-546.

JOHANNESSEN, A. 1980. Predation on herring (Clupea harengus L.) eggs and young larvae. Coun. Meet. int. Coun. Explor. Sea, 1980 (H:33): 1-12 (Mimeo.)

JONES, R. 1974. The rate of elimination of food from the stomacks of haddock, cod and whiting. J. Cons. int. Explor. Mer, 38(1): 18-27.

JONES, R. 1976. Estimates of the food consumtion of haddock (Melanogrammus aeglefinus) and cod (Gadus morhua). J. Cons. int. Explor. Mer, 38(1): 18-27.

PARRISH, B.B. and SAVILLE, A. 1965. The biology of the Northeast Atlantic herring populations. Oceanogr. mar. Biol., 3: 323-373.

SÆTRE, R. and GJØSÆTER, J. 1975. Ecological investigations on the spawning grounds of the Barents Sea capelin. FiskDir. Skr. Ser. HavUnders., 16: 203-227.

TEMPLEMAN, W. 1965. Some instances of cod and haddock behaviour and concentrations in the Newfoundland and Labrador Seas in relation to food. Int. Commn. NW Atlant. Fish. Spec. Publ. No. 6: 449-461.

TYLER, A.V. 1970. Rates of Gastric Emptying in Young Cod. J. Fish. Res. Bd. Can.: 27: 1177-1189.

WINDELL, J.T. 1966. Rates of digestion in bluegill sun-fish. Invest. Indiana Lakes Streams.: 7: 185-214.

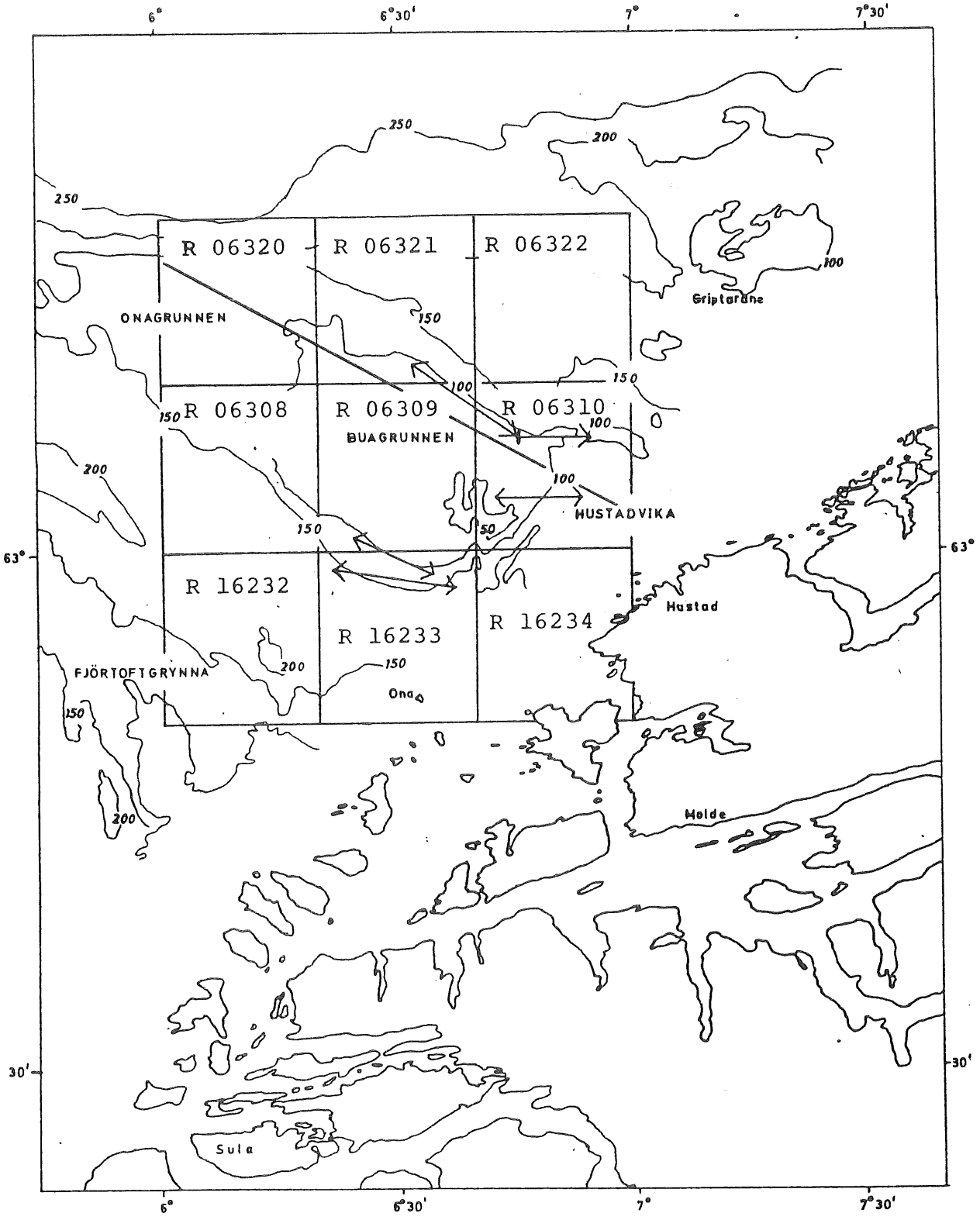

Figure 1. Map covering parts of the Møre coast, western Norway. The squared parts are the areas investigated to find herring egg predators.

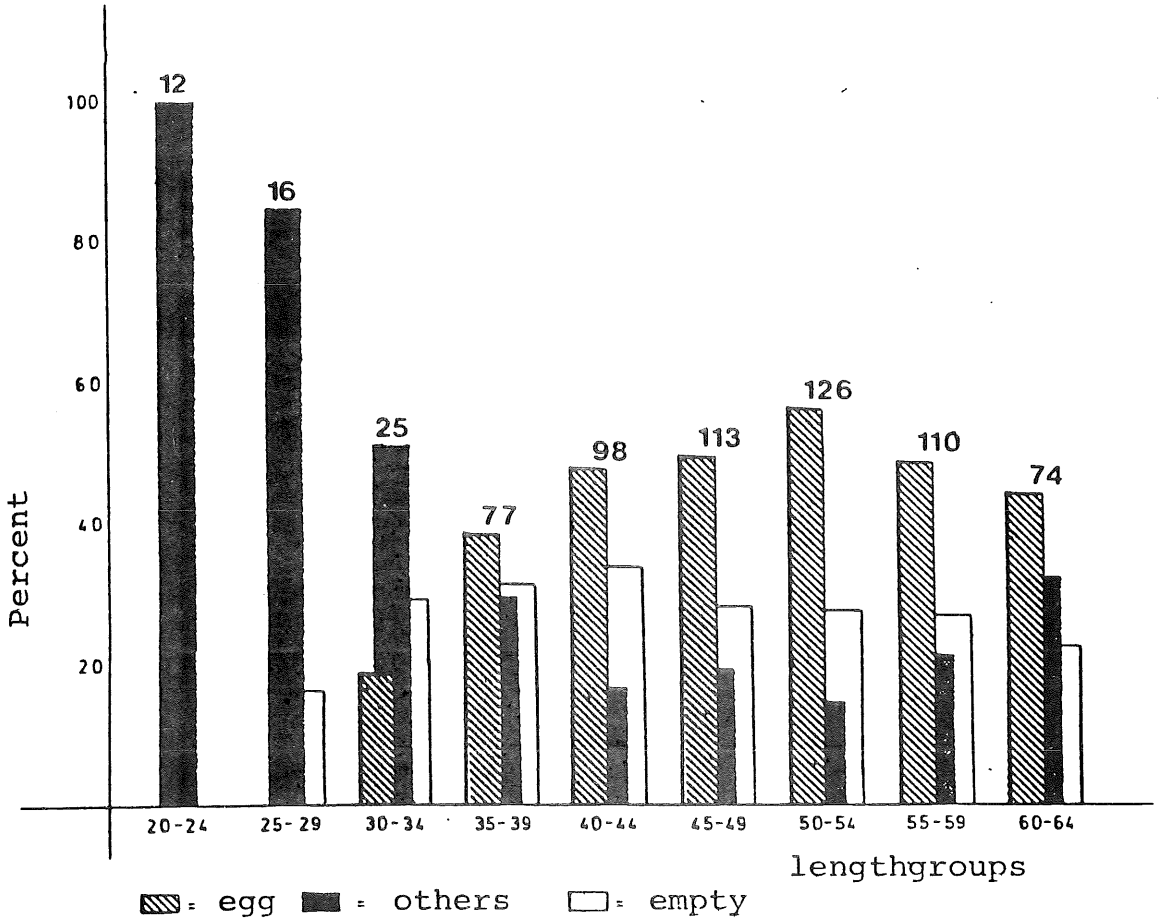

Figure 2. Proportions of stomachs from haddock containing either eggs, other kinds of food particles or that were empty. Number of stomachs on tops.

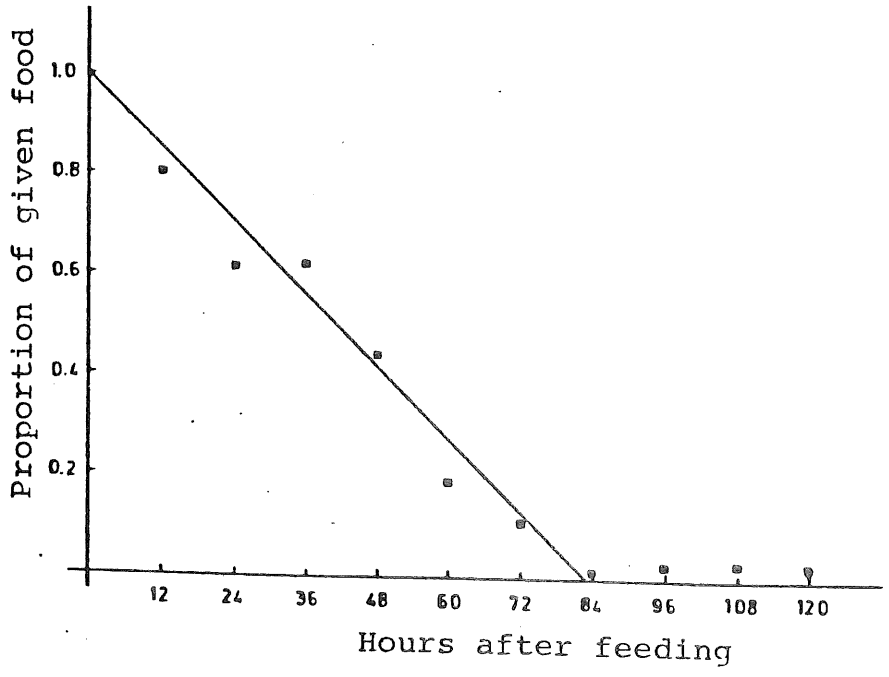

Figure 3. The mean rate of gastric emptying of the fish in the experiment.

Table 1. Number of fish per length group, amount of food in the groups, theoretical weights and the amount of food given in relation to the weight.

Length	n	Food	Weight	Food/Weight (g/kg)
42	4	10	740.9	13.49
44	2	10	851.8	11.73
45	3	10	911.3	10.95
46	4	10	973.4	10.27
47	5	10	1038.2	9.63
48	5	10	1103.9	9.04
49	1	10	1176.5	8.49
50	2	20	1250.0	16.00
51	2	20	1326.5	15.07
52	1	20	1406.0	14.22
53	2	20	1488.7	13.43
54	5	20	1574.6	12.70
55	1	20	1663.7	12.02
56	1	20	1756.2	11.38
57	2	20	1851.9	10.80
58	2	20	1951.1	10.25
59	1	20	2053.8	9.73
60	3	30	2160.0	13.88
61	1	30	2269.8	13.21
62	2	30	2383.3	12.58

Table 2. Number of stomachs sampled for each of the three species cod, haddock and saithe in 1980 and 1981. The numbers and the proportion of the stomachs containing eggs of herring are also given.

Specie	1980			1981		
	n	with eggs	% eggs	n	with eggs	% eggs
Cod	269	0	0	488	1	0
Haddock	501	205	40.9	623	293	47.0
Saithe	123	3	1.5	169	2	1.2

Table 3. Data from trawl stations with catches of haddock showing numbers of stomachs sampled, proportion with herring eggs and proportion with herring eggs also containing other particles in stomach.

Date	number of samples	% with egg	% egg + sand	% egg + crill	% other content
16/3	170	62	0	12	18
18/3	104	68	20	3	14
22/3	22	9	0	100	63
25/3	28	71	10	35	28
9/4	48	19	0	33	48
10/4	30	70	0	14	13
11/4	11	18	0	0	18
11/4	99	19	0	29	30
12/4	101	44	5	23	32

Table 4. Mean number of herring eggs in the stomachs of haddock divided by length groups. The standard deviations and the maximum and minimum numbers are also given.

Length	Mean Number	Standard Deviation	Max Number	Min Number
30-34	2411	2070	5310	640
35-39	4123	3201	12630	70
40-44	7007	5815	23655	136
45-49	13625	8234	29700	390
50-54	21009	12778	67050	335
55-59	24579	18041	69821	1940
60-64	35878	21337	75784	2309

Table 5. Abundance estimates of haddock at Buagrunnen, March-April 1981.

Date	N * 10^6	Tonnes * 10^3
16-27/3	16.9	21.7
6-14/4	39.4	20.3

Table 6. The total number of haddock (N * 10^{-6}) preying on herring eggs in length intervals of 5 cm.

Length	16 - 27/3	6 - 14/4	Mean
30-34	0.15	0.19	0.17
35-39	0.69	0.88	0.79
40-44	1.31	1.62	1.47
45-49	1.85	1.43	1.64
50-54	2.08	1.43	1.76
55-59	2.11	0.71	1.41
60-64	1.09	0.08	0.59

Table 7. Mean age of the eggs at time of catching. Mean date of spawning is also given.

Date	Mean age	Mean date of sp.
16/3	2	14/3
17/3	3	14/3
18/3	2	16/3
22/3	6	16/3
25/3	8	17/3
9/4	12	27/3
10/4	18	23/3
11/4	16	26/3
12/4	17	26/3

Table 8. Mean weight of herring eggs per length group and the rate of gastric emptying per hour and per day of this amount.

Length	Egg (g)	rate (g/h)	rate (g/d)
30-34	10.2	0.07	1.68
35-39	17.1	0.68	4.04
40-44	27.6	0.85	9.23
45-49	52.2	1.08	25.92
50-54	80.6	2.23	53.52
55-59	92.2	2.97	72.28
60-64	130.0	5.25	126.00

Table 9. Mean number of egg predators and how much they eat in grams per day and per 30 days.

Length	Number of Predators * 10^{-6}	g/d * 10^{-6}	g/30d * 10^{-9}
30-34	0.17	0.29	0.009
35-39	0.78	3.15	0.095
40-44	1.46	13.48	0.404
45-49	1.64	42.51	1.275
50-54	1.76	94.20	2.826
55-59	1.41	100.50	3.015
60-64	0.58	73.80	2.192
Total	7.80	327.21	9.820