CHANGES IN THE CHEMICAL COMPOSITION OF THE HERRING DURING THE REPRODUCTIVE PERIOD

By T. H. MILROY, *Professor of Physiology, Queen's College, Belfast.*

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The chemical changes which occur in the salmon during the various periods of its life history have been worked out with great care and thoroughness by Miescher,¹ Noël Paton² and others, and the results which have been obtained have greatly increased our knowledge of the relationship between the reproductive organs and the muscles of this fish.

It is natural to suppose that a somewhat similar cycle of changes might occur in the herring, and as this fish constitutes such an important article of diet, it was deemed advisable to study the changes in its composition at various seasons of the year.

At the request of the Scottish Fishery Board I examined fish obtained at various seasons and in different stages of reproductive activity. In the first place I examined fish caught on the West Coast of Scotland (Loch Fyne District) for a period of one year, starting with fish with immature ovaries or testes, and ending with spent fish.

The fish caught in May showed very immature genitalia, and, as summer and autumn proceeded, the ovaries showed a continuous increase until December, when full maturation was attained.

In January and February the fish were either spawning or spent.

During March and April the fish were spent, but began to show commencing growth of ova in the old ovarian capsules.

A similar investigation was subsequently carried out in the case of East Coast fish, and the results of this examination will be given in a subsequent paper.

The fish in all cases were sent in a double-walled carrier, an ice-salt mixture filling the space between the walls.

1. *Die Histochemischen u. Physiologischen Arbeiten*, by Miescher, 1897.

2. 'The Life History of the Salmon,' *Scottish Fishery Board Reports*, 1898.

The fish were measured and weighed, and the genitalia then removed and also weighed.

The ova were examined microscopically, and their diameter measured with the ocular micrometer.

The length was measured from end of snout to end of tail fin, while the girth was taken in front of the dorsal fin around the thickest part of the fish.

The fish were then skinned, and the muscles passed through a mincing machine. It was found impossible to do more than analyse the muscles and the ovaries. Some analyses were made of different muscles, but the variations in composition were so slight that the plan was abandoned and specimens taken of the general musculature instead.

METHODS OF ANALYSES

It was impossible to adopt many precautions which might have been desirable, owing to the necessity for carrying out a large number of analyses rapidly.

The water content of the muscles and ovaries was arrived at by drying the minced substance in vacuo over sulphuric acid.

The total nitrogen was estimated by Kjeldahl's method, and the P_2O_5 by incineration with pure NaOH and KNO_3 , and subsequent treatment by the ammonium molybdate method.

The protein percentage in most cases was simply arrived at by converting the total nitrogen into terms of protein, but in the case of the East Coast fish previously mentioned the coagulable protein was estimated by the anhydrous sodium sulphate method.

The fat was estimated in the powdered dry material after thorough admixture with pure silver sand, the powder being in the first place extracted with hot alcohol, and then with ether by Soxhlet's method.

It was thought advisable not only to give the percentage amounts of protein, fat, and P_2O_5 , but also the absolute amounts in the collective muscles and genitalia respectively of the same fish.

Tables are also given showing the ratios between the weight of the fish and the reproductive organs at different periods, and also those existing between the more important constituents of the muscles and genitalia.

Analyses of herrings¹ have been made by different investigators, but so far as my knowledge goes no systematic examination of the fish has been made at the different periods of its reproductive life.

Atwater gives the maximal, minimal, and average amounts in the herrings examined by him, but makes no statement as to the condition of the genitalia.

His numbers are the following :—

	Water	Water-free substance	Protein <i>i.e.</i> , $N \times 6.25$	Fats	Ash
Maxima	76.11	30.97	19.12	11.01	1.9
Minima	69.03	23.89	15.31	4.89	1.5
Average	72.19	27.90	17.75	8.02	1.69

RESULTS OF ANALYSES OF WEST COAST HERRINGS

Those fish which were sent for examination during May were smaller than those received at later periods.

The following table gives the necessary information with regard to their condition :—

TABLE I.—LOCH FYNE HERRING, MAY 10TH, 1906

Length cm.	Girth cm.	Weight cm.	Condition
25	11½	113	Very immature, previously spent herrings.
23½	11	101	
22½	12	104	There were large numbers of very small ova present, varying in size from 0.07 to 0.15 mm. in diameter
23½	11	102	
23	10½	93	
23	10	90	
23	10½	88	
21½	10½	80	
22½	10½	85	
22	10	80	
21½	10	74	
22	10	75	
Average 22.9 cm.	10.7 cm.	90.4 gm.	

Weight of genitals (fresh) of 12 herrings, 2.5 grammes. The water percentage of these genitals was 71.52.

1. Payen, *Substances Alimentaires*, p. 488; König, *Nahrungsmittel*, Bd. I, pp. 201-7; and Atwater, *U.S. Commissioner's Report on Fish and Fisheries*, 1888, pt. XVI, 1892.

Analyses of the muscles of these herring :—

Female—

(a) Amounts stated in percentages of fresh material.

Water	Protein	Fat	P ₂ O ₅
72.69	18.98	7.25	0.68

(b) Grammes in the total muscles of the average fish of this series.

Protein	Fat	P ₂ O ₅
11.38	4.35	0.40

These herrings had probably spawned some time between February and April on the Ayrshire coast (Ballantrae spawning beds), and had then passed up Loch Fyne. They were caught near the opening of that Loch. Judging from the amount of fat present, they had, however, probably resumed feeding for more than a month, but the collapsed condition of the large ovarian capsules showed that within a comparatively recent time the fish had discharged their ova.

The high water percentage of the muscles is also characteristic of fish that have been recently spawning.

On the following day some herrings were caught in the same neighbourhood, and these showed even more marked signs of recent spawning. (Table II.)

They were on the average smaller fish, with one exception. This one (No. 10) was examined with the rest because it was evidently in the same condition as the others, which were on the average thinner and lighter than those of the previous set.

As will be seen from the table, the water percentage is higher and the fat lower than in the previous set, while the phosphorus percentage is higher than in any other muscles which were examined.

TABLE II.—MAY

	Length cm.	Girth cm.	Weight gm.	Condition
1	20	8.5	58	The ova were very immature. The weight of the 10 pairs of genitals was 2.4 gm. in the fresh condition.
2	20.5	9	60	
3	20.5	9.5	67	
4	20.5	9.5	67	
5	20.5	9	64	
6	21.4	9	72	
7	21.5	10	75	
8	22.5	9	75	
9	21	9.5	70	
10	25	11	116	
Average	21.3 cm.	9.4 cm.	72.4 gm.	

Muscle.

(a) Amounts stated in percentages of fresh material.

Water	Protein	Fat	P ₂ O ₅
73.01	17.55	5.85	0.82

(b) Grammes in the total muscles of the average fish in the series.

Protein	Fat	P ₂ O ₅
8.47	2.82	0.39

Fish caught during June and July were practically in the same condition, there being only slight growth of the genitalia; the weight of the fish gradually increased, but the percentage composition of the muscles altered very slightly.

It is scarcely necessary to give the numerous analyses of June fish which were made, because they were practically identical with those mentioned under the first set of the May fish.

An example is here given of fish caught at the end of July. The ovaries were, although still immature, sufficiently large to allow of their analysis.

July.—The water percentage of the muscles is still high, although slightly below that occurring in the May fish.

The protein percentage is practically the same, and the fat slightly higher than in the average May fish.

The ovaries were larger, with the ova in a slightly more mature

condition, averaging about 0.2 mm. in diameter. Analyses were therefore made of the genitalia.

TABLE III.—JULY

Length cm.	Girth cm.	Weight gm.	Weight of Genitals gm.
24	12	116	0.35
22	11.5	96	0.46
23.5	12	99	0.20
23	13	120	0.67
23	11.5	91	0.20
22.5	12	105	0.74
23	12	107	0.33
24	12.5	124	1.18
21.5	11	82	0.49
22.5	12	105	0.43
22.5	11.5	102	0.39
22	11	92	0.22
23	12	97	0.15
24	13	127	0.50
22.5	12	100	0.44
25	13	137	0.53
24	12.5	119	0.81
22	11	88	0.20
22	11	92	0.20
23	13	120	0.65
Average	22.9	11.9	100.9
			0.45

Analyses of the Muscle (fresh) :—

(a) Percentages.

Water	Protein	Fat	P ₂ O ₅
71.60	18.18	7.32	0.45

(b) Grammes in the total muscles of the average fish.

Protein	Fat	P ₂ O ₅
12.18	4.90	0.30

Analyses of the genitalis (fresh) :—

(a) Percentages.

Water	Protein	Fat	P ₂ O ₅
72.5	13.52	8.92	0.77

(b) Grammes in the amount of genitalis present in the average fish of series.

Protein	Fat	P ₂ O ₅
0.05	0.03	0.003

September.—By the middle of September the ovaries were almost 1 gramme in weight, and the ova measured about 0.2 to 0.45 mm. in diameter.

It will be sufficient simply to state the percentage composition of the muscle flesh at this period.

Water	Protein	Fat	P ₂ O ₅
63.68	19.28	11.81	0.64

In all the fish examined about this time the water percentage was at its lowest, and there was also a distinct increase in the amount of fat and protein.

The ovaries at this period had the following percentage composition :—

Water	Protein	Fat	P ₂ O ₅
66.02	18.91	7.34	1.23

The total amounts present in the ovaries of the average fish of this series were, of course, very small, namely :—

Protein	Fat	P ₂ O ₅
0.17	0.07	0.011

The relatively high fat percentage of the ovaries indicates that the degenerated ovarian tissue of the spent fish has not yet been entirely used up.

October.—During this month fish were obtained in different stages of maturity, some with ovaries weighing from 2 to 3 grammes, others weighing about 9 grammes ; while the ova varied from 0.3 to 0.6 mm. in diameter.

By far the larger number of the fish caught at this period were heavier than those obtained at an earlier season, but the changes in composition were of the same kind in all.

As will be seen from Table IV, the most marked alteration in the muscles is the great increase in the fat, the highest percentage being observed in fish caught at this season.

It will be observed from a study of the later series that as the ovaries begin to increase rapidly in size the fish begins to use up the store of fat which has been accumulating in the muscles during the earlier months.

Two series of fish are given in the following table, one (Series A) including those caught during the earlier part of the month, the other (Series B) towards the close of October. (Table IV.)

Under Series B the results of the examination of male fish caught at this season are also given. As will be seen, they correspond very closely to the females.

TABLE IV.—SERIES A (OCTOBER 7TH)

Length cm.	Girth cm.	Weight gm.	Condition
28	15	206	The ovaries from these seven herrings weighed collectively 17 gm., and the average size of ova was 0.28 mm.
27	13.5	150	
25	13	147	
24.5	12.5	130	
23.5	12	115	
23.5	12.5	122	
26	13	148	
Average 25 cm.	13 cm.	144.5 gm.	

SERIES B (OCTOBER 20TH)

Length cm.	Girth cm.	Weight gm.	Condition
29.5	16	257	The ovaries from these eight herrings weighed collectively 74 gm., and the average size of the ova was 0.59 mm.
28.5	15.5	220	
27.5	13.2	167	
24.5	12.5	129	
24	12.2	119	
25	14.5	220	
29.5	15.5	229	
28	14	197	
Average 27 cm.	14 cm.	192 gm.	

Series A.

Muscles.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
69.97	12.78	14.25	0.53

(b) In total muscles of average fish.

Protein	Fat	P ₂ O ₅
12.39	13.82	0.51

Ovaries.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
78.21	17.26	2.53	0.71

(b) In ovaries of average fish.

Protein	Fat	P ₂ O ₅
0.41	0.33	0.01

Series B.

Muscles.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
70.46	14.84	12.70	0.57

(b) Per average fish.

Protein	Fat	P ₂ O ₅
18.99	16.25	0.73

Ovaries.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
68.02	22.45	4.80	0.93

(b) Per average fish.

Protein	Fat	P ₂ O ₅
2.08	0.44	0.05

*Males—**Muscle.*

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
68.91	16.18	12.63	0.50

(b) Per average fish.

Protein	Fat	P ₂ O ₅
17.91	13.98	0.55

Testes.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
72.13	22.62	2.25	0.86

(b) Per average fish.

Protein	Fat	P ₂ O ₅
5.42	0.54	0.20

November.—During November there was a rapid increase in the size of the ovaries, the ova measuring about 0.8 mm. in diameter on the average. The water percentage of the muscles was lower than in the preceding month, and the fat showed the first indication of being used up by the fish from the distinct decrease in its amount, while the protein showed a rise.

It is probably about this period that the winter spawning fish begin to take a smaller quantity of food, and, therefore, they fall back upon their fat store as a source of the necessary energy.

The muscles of the male fish are practically of the same composition as those of the female. (Table V.)

TABLE V.—NOVEMBER FISH

I. Females

Length cm.	Girth cm.	Weight gm.	Weight of ovaries gm.
30	16.5	275	35.7
31	16	270	38.2
33	17.5	326	51.6
31	16	255	31.8
30	16	261	25.6
31	16	260	18.9
32	16.5	297	31.6
32	17	290	35.2
32	16.5	275	31.4
30	16.5	276	28.8
32	16.5	304	32
29	15	210	20.1
30	15	204	15.4
29	14	192	15.8
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Average	30.8 cm.	16 cm.	264 gm.
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			29.5 gm.

The ova were from 0.8 to 1 mm. in diameter.

II. Males

Length cm.	Girth cm.	Weight gm.	Weight of Testes gm.
31	17	279	44.5
31	17	316	52
31	16	277	40.6
29	14	215	31.4
30	16	257	40.9
33	16	296	37.3
32	16	287	40.1
30	17	290	41.1
31	17	303	46.6
31	16	252	35.6
31	15.5	230	26.8
29	14.5	195	24.4
30	16	255	44.6
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Average	30.7 cm.	16 cm.	265.5 gm.
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			38.9 gm.

*Females—**Muscle.**(a) In percentages.*

Water	Protein	Fat	P ₂ O ₅
66.34	19.87	10.85	0.59

(b) In total muscles of average fish.

Protein	Fat	P ₂ O ₅
34.97	19.09	1.03

Ovaries.

(a) In percentages of fresh material.

Water	Protein	Fat	P ₂ O ₅
68.04	25.04	2.85	0.91

(b) Per average fish.

Protein	Fat	P ₂ O ₅
7.38	0.84	0.26

*Males—**Muscle.*

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
68.22	17.94	10.84	0.46

(b) Per average fish.

Protein	Fat	P ₂ O ₅
31.77	19.18	0.81

December.—The fish caught during this month were either ready for spawning or had commenced to spawn.

An example will first be given of fish which although probably about to spawn still show a moderately high percentage of fat, and a low percentage of water in the muscles. They were, in fact, in very good condition. The genitalia were, as will be seen from the table, of the maximum weight, and the ova were mature.

TABLE VI.—EARLY DECEMBER FISH

Females

Length cm.	Girth cm.	Weight gm.	Weight of ovaries. gm.
31	17.5	326	63
30.5	15	268	43
30.5	16.5	272	30
31	16.5	330	48
30.5	16	285	47
31	17.5	318	51
Average	30.7 cm.	16.5 cm.	299.8 gm.

Males

Length cm.	Girth cm.	Weight gm.	Weight of testes gm.
31	17	298	61
31	17	320	55
Average	31 cm.	17 cm.	309 gm.

*Analyses :—**Females—**Muscle.**(a) In percentages.*

Water	Protein	Fat	P ₂ O ₅
67·36	20·56	8·18	0·68

(b) Per average fish.

Protein	Fat	P ₂ O ₅
41·12	16·36	1·37

*Ovaries.**(a) In percentages.*

Water	Protein	Fat	P ₂ O ₅
67·33	25·72	2·89	1·03

(b) Per average fish.

Protein	Fat	P ₂ O ₅
12·68	1·35	0·48

*Males—**Muscle.**(a) In percentages.*

Water	Protein	Fat	P ₂ O ₅
68·31	21·45	9·24	0·73

(b) Per average fish.

Protein	Fat	P ₂ O ₅
44·18	19·03	1·51

*Testes.**(a) In percentages.*

Water	Protein	Fat	P O ₅
72·10	22·05	3·73	2·10

(b) Per average fish.

Protein	Fat	P ₂ O ₅
12·78	2·16	1·21

The following table (VII) gives the results of the examination of herrings obtained farther North. They had commenced spawning ; in fact, had discharged probably about the half of their store of ova. The ova present were, of course, fully ripe. The fish were smaller and in much poorer condition than those of the previous series.

As they are not from the same neighbourhood they are not strictly comparable with the preceding series, but it was impossible to obtain herrings from Loch Fyne during late December and January.

These, however, belong to the same class of herrings as those which are given in the subsequent January and February series.

Two herrings (females) were taken for analysis from a batch containing fish of approximately the same size. Their measurements were :—

TABLE VII.—LATE DECEMBER FISH

Length cm.	Girth cm.	Weight gm.	Weight of ovaries gm.
29	14.5	195	26
29	14.5	194	35
Average 29 cm.	14.5 cm.	194.5 gm.	30.5 gm.

Size of ova, 0.8 to 1.2 mm.

Analyses :—

Muscle.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
72.50	23.01	2.75	0.77

(b) Per average fish (total in muscles).

Protein	Fat	P ₂ O ₅
28.76	3.4	0.96

Ovaries.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
65.73	27.76	3.34	1.19

(b) Per average fish.

Protein	Fat	P ₂ O ₅
8.46	1.02	0.34

The most striking changes in the muscles of these herrings are the marked fall in the fat percentage and the rise in the water percentage.

This marked decrease in the fat was always found to take place either just at the onset of spawning or after spawning had been in progress for some time.

In the case of the fish from the East Coast of Scotland spawning in early autumn, the fat percentage did not sink so low, and had often reached its minimum in the so-called 'full' fish—that is, the herring with mature ovaries.

This will be seen from a study of the analyses of these fish which will be given in a later paper.

The fat percentage of the ovaries has risen slightly above that of the mature fish prior to spawning, this being characteristic of the spawning process.

January (Table VIII).—Some of the late December fish showed the same characters as those taken in January.

They could not be obtained at this time in Loch Fyne, but some were analysed which came from farther North. They were in nearly all cases slightly smaller fish. Two series are given, one with spawning proceeding rapidly, the other in the spent condition. The male fish were not examined.

TABLE VIII.—JANUARY. SERIES A (spawning)

Length	Girth	Weight	Weight of ovaries
cm.	cm.	gm.	gm.
27·5	13·5	165	18
26·5	14	157	14·8
26	13·5	141	25
26	12	127	11·5
26·5	13	168	20·3
26	14	160	18·3
26	13	150	19·4
25	12	115	10·5
26	13·5	150	18·8
Average	26 cm.	148 gm.	17·4 gm.

Series A.

Muscles.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
74·12	18·91	2·02	0·66

(b) Per average fish.

Protein	Fat	P ₂ O ₅
18·15	1·93	0·61

Ovaries.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
70·00	24·75	3·72	0·93

(b) Per average fish.

Protein	Fat	P ₂ O ₅
4·23	0·63	0·16

These fish were in much the same condition as those of the preceding series, but they had a higher water and a lower protein and fat percentage.

Among the fish obtained at this time there were two which were completely spent, the ovaries being collapsed, and only a few remaining ova seen in the collapsed tissue.

TABLE IX.—SERIES B (spent)

Length cm.	Girth cm.	Weight gm.
23	12	153
28	12	140
Average 25.5 cm.	12 cm.	146.5 gm.

Series B.

Muscles.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
75.30	19.69	1.55	0.77

(b) Per average fish.

Protein	Fat	P ₂ O ₅
18.53	1.51	0.75

The water percentage has risen, and the fat fallen to a very low level.

February (Table X).—Practically all the fish sent during this month were found to be spent, and in even poorer condition than those obtained in January. As they were obtained from the same place as the January fish, the two series are readily comparable.

TABLE X.—FEBRUARY

Length cm.	Girth cm.	Weight gm.
26	11	115
28	12	143
28	12	155
29	13	156
29	12	150
28	12	136
Average 28 cm.	12 cm.	142.5 gm.

I.—*Muscles*.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
78.97	18.05	0.68	0.73

(b) Per average fish.

Protein	Fat	P ₂ O ₅
16.60	0.62	0.66

II.—*Ovaries* (spent). The average weight of the ovaries per fish was 1 gm.

(a) In percentages.

Water	Protein	Fat	P ₂ O ₅
82.07	3.78	11.83	0.91

(b) Per average fish.

Protein	Fat	P ₂ O ₅
0.29	0.09	0.016

From these analyses it is seen that the fish had used up practically all their store of body fat. The muscles contained a very high percentage of water, and were in the poorest condition.

The spent ovaries showed the characteristic high percentage of fat seen in that condition, in this case an extremely large amount being present.

It was impossible to obtain West Coast herrings in March, but I examined fish caught in April, and they were practically in the same condition as those taken in May, and of which analyses have been given.

Before studying the changes in the chemical composition of the muscles and ovaries, as shown in the preceding tables of analyses, it is important to note certain points of general interest with regard to the growth of the ovaries.

If one arranges the weights of the fish and ovaries in such a table as the following, one gets a clearer idea of the various periods in the life history of the herring. (Table XI).

TABLE XI.—RATIOS OF WEIGHT OF FISH TO WEIGHT OF OVARIES AT DIFFERENT SEASONS

Period	Weight of fish	Weight of ovaries	Condition
May ...	434.6	: 1	Immature
May ...	301.6	: 1	"
July ...	224.2	: 1	"
September ...	84.2	: 1	" (Ova 0.15 to 0.45 mm.)
October A ...	60.2	: 1	" (Ova 0.28 mm.)
October B ...	20.8	: 1	" (Ova 0.59 mm.)
November ...	8.9	: 1	Almost mature (ova 0.8 to 1 mm.)
December ...	6.3	: 1	Mature (ova 0.9 to 1.2 mm.)
December ...	6.3	: 1	Spawning " "
January $\frac{1}{4}$...	8.5	: 1	" " "
January $\frac{1}{3}$...	—	—	Spent
February ...	—	—	"

It is interesting to note that the main growth of the ovaries takes place after the most active feeding period is over.

These fish, which spawn in January and February, have their principal feeding time between April and September.

From April to June they feed mainly on copepods, from June to September on schizopods.¹ Food is, however, taken also during October, November, and December, but in smaller amount.

The spawning, according to Brook and Calderwood, takes place six to eight months after the period of richest feeding.

There is no doubt that with the increase in the development of the genitals the desire for food diminishes until spawning time arrives, when no food is taken.

The most interesting period to study carefully is that included under the October, November, and December series.

If one select from each of these tables the fish that are evidently comparable as regards length and girth, namely, in the October Series B the two fish 29.5 cm. in length, in the November series the three fish 30 cm. in length and 16 to 16.5 cm. in girth, and the three 30.5 cm. fish in the December series, one notices that there is certainly no loss in the weight of the fish, but rather a gain as the season advances. That is to say, during the period when the greatest increase in the development of the ovaries takes place, there is no evidence of this growth of the reproductive organs occurring entirely

1. Brook and Calderwood, 'Report on the Food of the Herring,' *Fourth Annual Report, Scottish Fishery Board*, 1886, *Appendix F*, No. VI. pp. 102-128.

at the expense of the other tissues, seeing that there must be in addition some combustion of food material stored in the tissues to cover the energy requirements. There can be no doubt that during this period the fish is beginning to use up its store of fat instead of increasing it as was the case only a short time before.

That there is a distinct loss in the total fat of the muscles of the December fish compared with the October ones is shown by again comparing the amounts of this constituent present in fish of similar size caught during these months. Taking again the same fish from the October, November, and December series as was done for the comparison of weights, one finds that the total fat content of the muscles in the October fish is 20.56 grammes, in similar November fish 19.57 grammes, and in December fish 14.99 grammes. There can be no doubt that this loss of fat cannot be accounted for by a transference to the growing genitalia. The probability is that it is being used to furnish the necessary energy required for the work which the fish is performing.

THE NATURE OF THE CHEMICAL CHANGES IN THE MUSCLES OF THE HERRING

The Water Content of the Muscles.—The percentage of water in the muscles rises when spawning commences, and reaches its maximum in the spent fish.

There are, however, exceptions to this rule, as, for example, in the case of the late December fish. The lowest water percentage is, as a rule, to be found when rapid growth of the ovaries is taking place.

Protein.—The changes in the amount of protein are difficult to follow. This may be due in part to the fact that it really was the total nitrogen which was estimated in the case of the analyses given in the preceding tables, or it may be due to the variations in the water content. In the first place, the lowest protein percentage is found at the time when the fat is at its highest level.

There seems to be a gradual transformation of protein, or possibly glycogen, into fat when the stage of active feeding passes into that

of reproductive activity. The average protein percentage between May and September is approximately nineteen, while in October it is fourteen. During the period of rapid growth of the ovaries, and before full maturity, the protein percentage again rises, being due probably to the loss of water from the muscles during this time.

Fat.—Reference has already been made to the variations in the amount of this constituent, but it is necessary to refer to them in more detail.

It is the one constituent which shows regular alterations in its amount during the various stages of reproductive activity, although it is quite possible that glycogen may show similar changes.

It has, however, not been possible up to the present to carry out a satisfactory series of glycogen determinations at the various periods of reproductive activity. This may be said, however, that the amount of glycogen in the spent fish was extremely small in the analyses which I have made.

During the months of May, June, July, August, September, and the early part of October there is a gradual increase in the percentage amount of fat in the muscles.

This increase is most marked from August up to the beginning of October.

It is most likely that during the summer months, when the young ova are just beginning to appear, the food material is mainly stored in protein form in the muscles, while in late autumn the main storage form is fat. In November and early December, when the ovaries are increasing most rapidly in size, the fish falls back upon its store of muscle fat to supply the necessary amount of energising material. By the time that active spawning has commenced the fat shows a great decrease, and in the spent fish of February it reaches its minimum.

The reason why there is not a more rapid fall in fat during October and November is that the fish during this time is still feeding, although, probably, not to the same extent as at the earlier periods. During the process of spawning the feeding ceases altogether.

There can be no doubt that the fish feeds voraciously during

the summer months, hence the frequent occurrence of distended stomach and intestines in fish with immature ovaries. This may lead to the abnormal condition called by fishermen on the West Coast of Scotland 'gut-poke.' Such fish rapidly undergo decomposition owing to the deficient absorption of the intestinal contents. This condition is never found in fish with mature ovaries.

It is interesting to notice the ratios of protein to fat in the muscles at the various seasons. The following table gives these ratios. (Table XII.)

TABLE XII.—PROTEIN : FAT IN THE MUSCLES

Period	Protein	Fat	Condition
May ...	2.61	: 1	Immature
May ...	3.00	: 1	"
July ...	2.48	: 1	"
September ...	1.63	: 1	" (Ova 0.15 to 0.45 mm.)
October A ...	0.89	: 1	" (Ova 0.28 mm.)
October B ...	1.16	: 1	" (Ova 0.59 mm.)
November ...	1.83	: 1	Almost mature (ova 0.8 to 1 mm.)
December ...	2.51	: 1	Mature (ova 0.9 to 1 mm.)
December ...	8.36	: 1	Spawning
January ...	9.36	: 1	"
January ...	12.70	: 1	"
February ...	26.54	: 1	Spent

Phosphorus.—The variations in the amount of phosphorus are somewhat irregular and difficult to account for.

In October and November fish with rapidly increasing ovaries the average percentage is approximately 0.56 P_2O_5 , while during the preceding months from May to September it may be taken as 0.68.

The peculiarly low percentage present in the July fish is difficult to account for. When the ovaries have reached maturity, and also after spawning, the P_2O_5 percentage in the muscles again rises.

CHEMICAL CHANGES IN THE OVARIES

The ovaries of the fish examined showed an increase in size from July to December, but as there were great variations in the size of the fish caught at the various seasons, it is more important to study the amount of the various ovarian constituents per 100 grammes of muscle rather than per average fish.

The following table gives this information :—

TABLE XIII.—OVARIAN CONSTITUENTS PER 100 GRAMMES MUSCLE

Period		Protein	Fat	P ₂ O ₅
July	...	0·074	0·044	0·0044
September	...	0·318	0·131	0·0206
October A	...	0·425	0·342	0·0103
October B	...	1·625	0·343	0·0625
November	...	4·193	0·477	0·1477
December	...	6·040	0·675	0·2400
December	...	6·523	0·799	0·2621
January	...	4·286	0·638	0·1621

There is thus a gradual increase of these constituents until spawning occurs. When we compare these figures with the percentage composition of the muscles at the same seasons, one notices that during the time when the protein of the ovaries is showing a distinct increase—for example, from November to December—there is no corresponding decrease in the muscle protein. It is true that between September and October there is a fall in the muscle protein percentage, but it is more readily accounted for by the local increase in fat than by a withdrawal of protein to the genitals.

The herring is thus in a different position from the salmon, at least if one compares the salmon caught in the estuary of a river with those caught in the upper reaches.

The salmon during its sojourn in the river abstains entirely from food. If one, however, studies the composition of the early and late estuary salmon examined by Noël Paton, one notices that there are but slight variations in the protein percentage and in the total amount per standard fish, whether the ovaries be immature or mature.

The herring undoubtedly does feed practically until spawning occurs, although probably much less food is taken in the later months.¹

1. Scott, 'The Food of the Herring,' *Scottish Fishery Board Reports*, Part III, p. 260, 1907.

There can, therefore, be no doubt that the herring is not entirely dependent upon its muscle proteins for the growth of the ovaries.

The appearance of fat in large amount in the ovaries of spent fish is similar to that noted by Miescher in spent salmon. This formation of fat was regarded by Miescher as of great nutritive value to these fish.

Male Herrings.—Somewhat similar changes take place in the muscles of the male fish, the highest fat percentage being found just before rapid growth of the testes takes place.

During the later period the fat percentage falls just as in the female.

Composite tables are subjoined, which enable readily a comparison being made between fish caught at various seasons.

Before giving these tables one may shortly summarise the results of the investigation into the life-history of the herring by dividing up the year into the following three periods :—

1. *The Restitution or the Feeding Period.*—This continues for three to four months after spawning, and constitutes the principal feeding time. The spent, thin fish recovers, and accumulates during this time a large store of fat.

2. *The Ripening or Maturation Period.*—This continues for six to seven months. The herring still takes food, but gradually with less desire, and the sexual organs increase as the store of muscle fat diminishes.

3. *The Spawning Period.*—This continues probably for about two months, and during this time feeding stops. Hence there results a very great fall in the fat, accompanied by an increase in the water content of the muscles.

Heincke (*Naturgeschichte des Herings*, p. 48) has shown that the herring after spawning seeks a place where it can get ample food to recuperate. For example, the herrings of Schley, after leaving the spawning beds in June, take three to four months to feed up in Kiel Bay. In September and October they are fattest, and then begins

anew the development of the reproductive organs, which up to this time was checked. This takes up the whole autumn and winter, the fish still taking food, but not using it for the building up of fat, but for the development of the genitalia. With the increase in the development of the genitals the desire for food diminishes until spawning time arrives, when no food is taken.

Hence Heincke, although basing his statements on the life-history of the herring simply on general observations, comes to conclusions which are practically identical with those arrived at by me from a study of the chemical composition of the herring at various seasons,

COMPOSITION OF MUSCLES AND OVARIES IN HERRINGS (AVERAGE FISH OF EACH SERIES)

DATE	PER FISH						MUSCLE.						OVARIES.					
	Lgth.	Girth	Wght.	Wt. of Ovars.	Size of Ovs.	Water	PER CENT. IN FRESH MUSCLE				PER AVERAGE FISH			PERCENTAGES			PER FISH	
							Pro-tein	Fat	P ₂ O ₅	Pro-tein	Fat	P ₂ O ₅	Pro-tein	Fat	P ₂ O ₅	Pro-tein	Fat	P ₂ O ₅
May ...	22.9	10.7	90.4	gm. 0.208	mm. v. immat.	72.69	18.98	7.25	0.68	11.38	4.35	0.40	—	—	—	—	—	—
May ...	21.3	9.4	72.4	0.24	"	73.01	17.55	5.85	0.82	8.47	2.82	0.39	—	—	—	—	—	—
July ...	22.9	11.9	100.9	0.45	"	71.60	18.18	7.32	0.45	12.18	4.90	0.30	72.5	13.52	8.92	0.05	0.03	0.003
September ...	20	—	80	0.95	0.15-0.45	63.68	19.28	11.81	0.64	10.41	6.37	0.34	66.02	18.91	7.34	0.17	0.07	0.011
October, Series A ...	25	13	144.5	2.4	0.2-0.3	69.97	12.78	14.25	0.53	12.39	13.82	0.51	78.21	17.26	2.53	0.41	0.33	0.01
" " B ...	27	14	192	9.2	0.4-0.5	70.46	14.84	12.70	0.57	18.99	16.25	0.73	68.02	22.45	4.80	2.08	0.44	0.05
November ...	30.8	16	264	29.5	0.8-1	66.34	19.87	10.85	0.59	34.97	19.09	1.03	68.04	25.04	2.85	7.38	0.84	0.26
December, Series A	30.7	16.5	299.8	47	0.9-1.2	67.36	20.56	8.18	0.68	41.12	16.36	1.37	67.33	25.72	2.89	12.08	1.35	0.48
" " B	29	14.5	194.5	30.5	0.8-1.2	72.5	23.01	2.75	0.77	28.76	3.43	0.96	65.73	27.76	3.34	8.46	1.02	0.34
January, Series A ...	26	13	148	17.4	0.8-1.4	74.12	18.91	2.02	0.66	18.15	1.93	0.61	70.00	24.75	3.72	4.23	0.63	0.16
" " B ...	25.5	12	146.5	—	Spent	75.30	19.69	1.55	0.77	18.53	1.51	0.75	—	—	—	—	—	—
February ...	28	12	142.5	1.26	Spent	78.97	18.05	0.68	0.73	16.60	0.62	0.66	82.07	3.78	11.85	0.29	0.09	0.016

MALES—AVERAGE COMPOSITION OF MUSCLES AND TESTES

DATE	Lgth.	Girth	Wght.	Weight of testes	MUSCLE.						TESTES.								
					PER CENT. IN FRESH MUSCLE			IN TOTAL MUSCLES OF AVERAGE FISH			IN PERCENTAGES			TOTAL IN TESTES PER AVERAGE FISH					
					Water	Pro- tein	Fat	P ₂ O ₅	Pro- tein	Fat	P ₂ O ₅	Water	Pro- tein	Fat	P ₂ O ₅	Pro- tein	Fat	P ₂ O ₅	
September ...	...	...	...	...	gm.	61.68	18.65	14.25	0.52	9.32	7.12	0.25	72.00	22.18	2.84	—	0.21	0.027	—
October ...	...	...	...	24	68.91	16.18	12.63	0.50	17.91	13.98	0.55	0.55	72.13	22.62	2.25	0.86	5.42	0.54	0.20
November ...	...	...	...	38.9	68.22	17.94	10.84	0.46	31.77	19.18	0.81	—	—	—	—	—	—	—	—
December ...	...	...	...	58	68.31	21.45	9.24	0.73	44.18	19.03	1.51	72.10	22.05	3.73	2.10	12.78	2.16	1.21	1.21