The Food of *Calanus finmarchicus* during 1923.

By

Sheina Marshall, B.Sc.

Marine Station, Millport.

With 1 Figure.

In view of the importance of *Calanus* as a food for fish, and especially for the Herring, its food and feeding habits have been kept under examination throughout the course of the year.

Calanus finmarchicus occurs in the Clyde sea area all the year round, and has its maximum in May and June, when it occurs in large quantities. It is scarcest during the late summer and early autumn, and is more abundant in January and February than in March and April.

The results are based on the examination of over 3000 *Calanus*, of which 52 per cent contained recognisable food. The number examined monthly varied, being usually greater in the months when they were abundant. The figures are shown in Table I.

Month.	No. of *Calanus* examined.	Guts empty.	Guts contain no recognizable remains.	Guts contain recognizable food.	Guts in Column five containing					
					Diatoms.	Dinoflagellates.	Silicoflagellates.	Coccolithophores.	Radiolarians.	Crustaceans.
		%	%	%	%	%	%	%	%	%
1923										
January.	179	38	43	19	38	0	6	0	54	27
February.	328	24	30	46	36	0	1	0	58	48
March.	135	27	15	58	57	1	3	0	43	39
April.	268	28	7	65	99	4	0	4	1	7
May.	256	27	7	66	96	7	0	1	1	9
June.	241	28	9	63	95	5	0	12	0	25
July.	141	21	13	66	80	43	1	17	0	28
August.	120	22	16	62	68	42	8	3	0	22
September.	130	21	10	69	91	21	30	0	0	13
October.	155	28	2	70	100	3	7	0	0	12
November.	257	31	19	50	91	5	6	0	17	16
December.	336	41	29	30	73	3	6	0	35	16
1924										
January.	188	31	36	33	67	2	10	0	33	13

Table I.—The last six columns show the percentage number of feeding Calanus (those in column five) whose guts contain specimens of the various groups.

The guts were, as a rule, examined fresh, for it was found much easier to identify the remains when fresh than when preserved. In cases where this could not be done the *Calanus* were preserved in weak formalin. It was found that after leaving them alive in the jar for several hours, all the guts were filled with copepod remains, and so the *Calanus* were all either preserved or examined within an hour or two of capture. Most of the food was in the form of fæcal pellets at the hind end

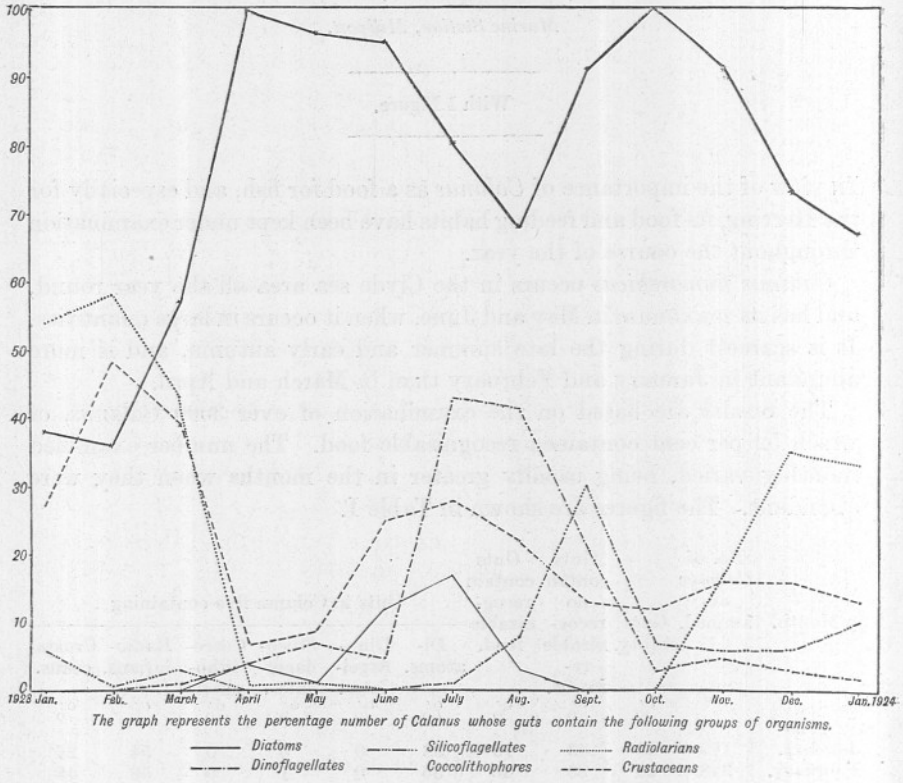

FIG. 1.

of the gut, and it is most probable that this had been taken in before capture.

The method adopted was to cut off the head of the *Calanus* about the level of the mouth, so as to free the front end of the gut, and then to draw out the latter with its contained food pellets, from the hinder end. The guts were then removed to a drop of clean sea water, the food pellets teased up, and examined with an oil-immersion.

A certain proportion of the guts, generally 20 to 30 per cent, was

always empty, and a certain proportion always contained small quantities of unrecognisable brownish or greenish debris. The latter proportion varied very much, from between 30 to 40 per cent in winter to 2 per cent during the autumnal diatom maximum in October. The surprisingly small proportion of *Calanus* feeding in winter was later found to be due to the habits of the copepod. In winter they cease almost entirely to feed during the day and feed instead at night. From November onwards few of the *Calanus* contain any recognisable food until an hour or two after dark, and they stop feeding again whenever it becomes light. Even bright moonlight seems to have a deterrent effect. As spring comes on and the diatoms increase in number the proportion feeding by day grows larger, and in summer, records from the day and night differ little, although the percentage feeding is always higher in summer than in winter, even at night. The reason for this change of habit is not apparent. There are, as a rule, larger numbers of copepods, and crustacea generally, present at the surface during the day than during the night, and this holds good for summer as well as winter. The surface is probably richer in their food than the lower layers, but this does not explain the difference between summer and winter, nor the fact that moonlight seems to act in the same way as daylight.

The food consists mainly of diatoms, which confirms the previous work on the subject (Dakin, 1901; Esterly, 1916; Lebour, 1922). When diatoms are scarce other organisms are eaten instead. During the winter minimum a species of Radiolarian, *Acanthonia mülleri*, is common in the plankton, and this forms an important part of the diet, along with the winter diatoms, *Coscinodiscus* and *Biddulphia*. The winter 1923–4 was not so good for Radiolarians as the previous winter, and the proportion eaten was smaller.

As spring comes on, diatoms bulk more and more largely, and during the spring maximum in April almost every gut contains numbers of *Skeletonema* with *Thalassiosira* a close second. These two diatoms changed places in May, and in this month and in June *Thalassiosira* was eaten oftener than *Skeletonema*, this change corresponding with conditions in the tow-nets. Various species of Naviculids were common in April, May and June, and *Fragilaria* in long bands was common in the guts in the end of May and in June.

In July diatoms were still the most important food, but the species eaten this month was *Rhizosolenia fragillima*, a small form very abundant in the tow-nets for about three weeks. In August *Rhizosolenia* was still important, but (again corresponding with changes in the plankton) the species this month was *R. shrubsolei*, and *Chætoceros* was eaten more freely than *Rhizosolenia*.

A group which is of importance during the summer months is the

Peridiniales. Gymnodinians are probably eaten much more than the records show, since they will disintegrate very rapidly. The exploded nematocysts of *Polykrikos* were found in one gut in September, and in July and August a small yellowish Peridinian was common. *Peridinium* itself was most abundant in August and September, the species most commonly eaten being *P. pellucidum*, although it was often impossible to identify the species. *P. depressum* was the species commonest in the tow-nets, and had its maximum at the end of July and beginning of August. Considering the abundance of *Ceratium* in August one would have expected it to be used as much as *Peridinium*, but such is not the case. I did not find it in any gut, nor has it been recorded by other workers. *C. tripos* is recorded from the gut of *Centropages typicus* (Lebour, 1922). *Dinophysis* and *Phalacroma* also occurred occasionally. *Prorocentrum* was found by Esterly to be common, but was rare here.

In the latter half of September and the beginning of October occurred the autumnal maximum of diatoms, consisting like the spring maximum of *Skeletonema* and *Thalassiosira* and the *Calanus* guts were again full of these diatoms. The numbers eaten decreased after this, although *Thalassiosira* remained of importance throughout the winter. *Coscinodiscus* and *Biddulphia* appeared in the guts in November, as did *Acanthonia*.

The Silicoflagellates are eaten in small quantities, most frequently during the *Distephanus* maximum in September. *Dictyocha* is rare, and was found only once or twice, but *Distephanus* is occasional throughout the winter, and *Ebria* throughout the summer.

Pontosphæra huxleyi was eaten during the summer (April to August), but although it occurred in 17 per cent of the guts in July it was never present in large numbers, and cannot be looked on as an important constituent of the food. The same may be said of the Silicoflagellates. Esterly, however, found some guts of *Calanus* packed with coccoliths, probably those of *Pontosphæra huxleyi*.

A certain proportion of the *Calanus* are always to be found eating Crustacea. These are not often recognisable, sometimes only bristles or hairs being present, but other copepods were occasionally identified. Most were eaten in winter, and at their summer maximum.

Remains of other organisms, such as molluscan larvæ, cœlenterate nematocysts (possibly ingested on other Crustaceans), Tintinnoids (*Tintinnopsis ventricosa* and *Tintinnus subulatus*), bits of algæ and so on are occasionally found, but are of little importance.

In addition to the recognisable fragments, usually the indigestible chitinous or siliceous tests, there is always a mass of greenish or brownish debris. Part of this must be due to the contents of the diatoms or other

food, but part is possibly due to soft-bodied organisms which leave no recognisable remains.

The food in any one gut is generally mixed. Some individual records are given below to illustrate this :—

January. (1) Masses of *Coscinodiscus*, some *Biddulphia sinensis*, many Radiolarian spines and bits of copepod.

(2) Five Acanthometrid centres and spines, and copepod remains.

April. (3) Much *Skeletonema*, some *Thalassiosira* and a bit of *Coscinodiscus*.

(4) Much *Skeletonema*, a *Navicula*, a bit of *Biddulphia* and several *Ditylium brightwelli*.

June. (5) Several Naviculids, a *Synedra*, a *Peridinium pellucidum* and several *Pontosphæra huxleyi*.

July. (6) About fifty cells of *Rhizosolenia fragillima*.

(7) Masses of *R. fragillima*, a little *Chætoceros*, several *Navicula* and bits of other diatoms, a *Tintinnus* case, a *Pontosphæra huxleyi*, numerous Gymnodinians and crustacean remains.

August. (8) Masses of *Chætoceros* and a *Distephanus*.

(9) Remains of at least nine *Peridinium* (mostly *P. depressum*) and two *Gymnodinium*.

September. (10) Bits of *Chætoceros*, *Skeletonema*, *Coscinodiscus*, *Rhizosolenia*, Naviculids, a *Tintinnus subulatus*, a *Peridinium*, and eight nematocysts of *Polykrikos*.

(11) A little *Skeletonema*, a good deal of *Thalassiosira*, a *Distephanus* and an *Ebria*.

November. (12) Enormous quantities of *Thalassiosira*, bits of *Coscinodiscus*, a large Naviculid and a *Dinophysis*.

December. (13) An *Acanthonia*, some *Coscinodiscus* and *Biddulphia*.

The last two records were from night tow-nettings.

Table I shows the number of copepods examined, and the number feeding. The other columns show the percentage of feeding *Calanus* whose guts contained specimens of the various groups of organisms. Fig. 1 expresses the same results graphically. It will be seen that the

highest point on each curve corresponds to the time when the group was at its maximum.

The contents of the gut of *Calanus* are thus seen to reflect fairly accurately the progressive changes in the microplankton. Diatoms are undoubtedly the most important constituent, at least of those recognisable. In view of Pütter's calculations, estimating that to satisfy its food requirements a *Calanus* would need to take in daily an amount corresponding to 15,800 *Coscinodiscus*, or 9,750,000 *Thalassiosira nana*, it has sometimes been supposed that the greater part of the energy was derived from naked flagellates, ciliates, etc., which were quickly absorbed, leaving no trace. My material was examined fresh, and although there were, especially in summer, a certain number of flagellates recognisable, yet the number was not so great as to suggest that they formed the most important part of the food supply. It is not known how long the process of digestion takes in copepods, but the numbers of diatoms counted in any one gut are very far below Pütter's figures. It is difficult to estimate the number exactly, but in the case of *Rhizosolenia fragillima* the number is often over sixty, and in the case of *Skeletonema* it is very much higher. The larger diatoms, *Coscinodiscus*, *Biddulphia* and larger species of *Rhizosolenia* are always broken, but the number is much lower.

No particular preference is shown for any one type of diatom. The small round forms, *Skeletonema*, *Thalassiosira* and small *Coscinodiscus*, are certainly by far the most abundant, but this is probably due to their abundance in the plankton. Organisms with long spines (e.g. *Chætoceros*, *Acanthonia*), such as might have been supposed to afford them some protection, are eaten quite freely. When an *Acanthonia* is found in the gut the spines are usually broken off short, and the solid central portion remains compact, with the broken bases sticking out round it.

A few observations were made on some of the other copepods, *Pseudocalanus elongatus*, *Temora longicornis*, *Acartia clausi*, *Centropages hamatus* and *Anomalocera patersoni*. Conditions here were much the same as in *Calanus*. Diatoms formed the chief part of the food in most cases, although *Temora*, *Centropages* and *Anomalocera*, as Lebour found at Plymouth, are crustacean feeders to a greater extent than the others. *Temora* appears to be the most voracious. Its gut is practically always full and it eats a large variety of organisms.

Undoubtedly the most important diatom in the Clyde sea area, as regards food, is *Skeletonema costatum*. In spring, and again in autumn, it occurred in enormous quantities, and every crustacean gut examined, from Mysids and Euphausids to copepods, contained it, often in large numbers. It was also eaten by planktonic larvæ, Polychætes, *Mitraria*, *Cyphonautes*, by Appendicularians (*Fritillaria furca* and *Oikopleura dioica*) and by Ciliates and Gymnodinians.

LITERATURE.

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