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Diatoms-An attempt to determine their fate.

By

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The work, reported below, was begun at the Atlantic Biological Station, St. Andrews, N. B., under the direction of Dr. A.G. Huntsman, during the summer of 1926, and was continued during the fall and winter months of 1926-27, in the Department of Zoology, at the University of Western Ontario.

There is no doubt but that diatoms are the most important pelagic plants. It has long been assumed that they are the basis of all higher life in the sea,—that the diatoms are eaten by the copepods and other small animals, which in turn are devoured by the jellyfish, true fish and some of the higher vertebrates. But more recently, the first part of the assumption has been questioned, and challenged. Previous workers have examined the stomach contents of these small animals, found the diatoms, and have drawn immediate conclusions as to their food. But later scientists have said that these animals may ingest everything that comes in their way—including the diatoms—but they may not receive any real food value from them. And since the diatoms have hard shells, they could surely not be digested. So the problem arises, if the diatoms are not eaten, what happens to them? Do they die and then become deposited or dissolved into the water, or how can they be accounted for? What is their fate?

It has been known for some time that the diatoms vary greatly in number throughout the year: they have their maxima and minima. If, then, the diatoms were eaten, it would seem logical that there should be some correlation between these maxima and minima, and those of the animals by which they were devoured. Since the copepods are by far the most common of the pelagic animals, an attempt was made to correlate their variations in number with those of the diatoms. This is shown by means of a graph. One line denotes the number of copepods taken, from August 1925 until June 1926, as determined by vertical hauls with 5 net, at Prince Station 6. The other line gives the number of diatoms taken with 18 net, at the same station, throughout the same period of time. The latter were only roughly counted by measuring with a ruler the height of the green material in the tow jar. It will be seen from the graph that the copepod maxima seems to follow the diatom maxima, in one case, at least. In June, as the copepod curve goes up, the diatom curve comes down, which is what is to be expected, if the diatoms are eaten by the copepods.

The vertical distribution of copepods and diatoms during the day and night was also worked out. 5 tows were taken at Prince Station 492, at depths of, 0,5,10,15,20 meters, at different times of day and night, on July 22, 1926, and the number of copepods were counted in each tow. Diatom tows 18 were taken at the same time, and the number of diatoms, counted. Water samples were also taken along with the tows to see if there were anything else in the water that the copepods might utilize as food. A definite amount of each water sample was centrifuged and all the organisms in it, counted. In any of the samples, the organisms consisted chiefly of diatoms, with a few unicellular algae or flagellates. (see table no. 2) The following table (no.1) shows the number of diatoms per cubic centimeter of water sample, the total number of diatoms in the tow, as measured by the counting cell, and the number of copepods in the tow, at each depth, during the different periods of the day.

In the two cases where the records are complete for the various depths, the maximum number of copepods seems to be just below the maximum number of diatoms,—taking the count of diatoms from the centrifuged samples, which would seem to be more reliable. This result agrees with that of Gran.

The method employed in centrifuging the water was as follows: an ordinary drift bottle was filled with sea water from the required depth. After shaking thoroughly, 15 ccs. of the liquid were centrifuged for 10 minutes. With a pipette 13 ccs. of the supernatant liquid were drawn off carefully, and the remaining 2 ccs. were examined. At different times, the water taken off was centrifuged for a second 5 minutes, and the lowest 2 ccs. examined, but nothing further was found. Examination was by means of low power on the microscope, with the aid of high power for the details of small particles. Five samples, each containing .04 ccs., were examined each time from the 2 ccs. portion.

The following table (no.2) gives the number and variety of organisms found in the centrifuged water.

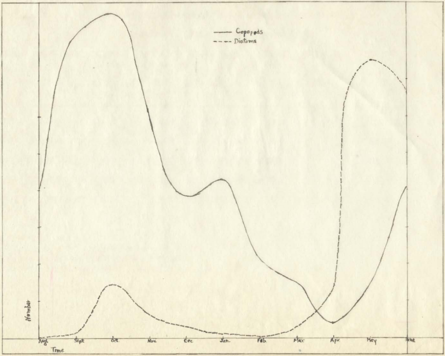
Copepods
Diatoms
Number
Aug.
Sept
Oct.
Nov.
Dec
Jan.
Feb.
Mar.
Apr.
May
June
Time

Table No. 1.

Distribution of copepods and diatoms during the day.

July 22, 1926. Prince Station 492.

	6.02 A.M.	6.55 A.M.	5.20 A.M.	12.28 P.M.	12.45 P.M.	11.41 A.M.	10.34 P.M.	10.02 P.M.	7.53 P.M.
D	C	D_1	D_2	C	D_1	D_2	C	D_1	D_2
0	530	5,870,000	0	2,680	9,200,000	90	26,620	13,690,000	265
5	14,430	26,400,000	680	14,450	17,380,000	555		34,690,000	595
10	57,400	375,600,000	550	52,210	144,500,000	375		31,670,000	345
15	46,690	269,170,000	670	20,970	213,900,000	295	67,600	92,320,000	118
20	49,720	231,600,000	405	8,200	130,320,000	180	181,720	104,440,000	160

D denotes Depth, in meters.
C " Copepods, total number in tow.
D_1 " Total number of Diatoms from the tow.
D_2 " Number of Diatoms per cc. of water sample.

No. 2.

Number of Diatoms per cc. of Sea Water as estimated from centrifuged water samples.

					5.20 – 5.54 A.M.		
Depth in meters –	0	2 1/2	5	10	15	20	28
Chaetoceros		45	135	110	530	275	260
Leptocylindricus		370	545	435	140	90	50
Coscinodiscus						25	
Pleurosigma				5		15	60
Fragillaria							20
Thalassiothrix							10
Rhizosolenia							5
Total NO. of Diatoms per cc. of sea water =		415	680	550	670	405	405
Other Organisms Present:							
Protozoa	5				5	20	5
Fungus filaments		10	mass	25	10		5
Algae	25	25		70	120	45	
Tintinnids	35	15	10	5	5	15	
Spores	mass	35	25	50		5	
Peridinians	20	20	15	15	5		
Distephanus				10	5		
Podon	5						
Crustacean larvae							5
Total =	90+	100	50	175	150	85	15

Table No. 2 (continued)

11.41 A.M. to 12.19 P.M.

Diatom   No. per cc. of sea water.

Depth in meters-	0	2 1/2	5	10	15	20	28
Chaetoceros	25	20	365	200	185	105	10
Leptocylindricus	35	155	175	150	65	10	
Coscinodiscus		15	10	10	40	45	35
Pleurosigma		5		5	5	5	
Paralia							80
Navicula						15	
Melosira	30						
Cocconeis			5	5			
Total No. of Diatoms =	90	195	555	370	295	180	125

Other Organisms Present:

Fungus filaments	5	5		mass			
Algae	10	30	80	20	15	10	5
Tintinnids		5	15				
Spores	5	mass		90			20
Peridinians	35	20	55	20			
Distephanus				5		5	5
Bivalve larvae				5			
Total =	55	60+	150	140+	15	15	30

Table No. 2 (continued)

7.53 to 8.38 P.M.

<u>Diatom</u>	<u>No. per cc. of sea water.</u>						
Depth in meters-	0	2 1/2	5	10	15	20	28
Chaetoceros		30		75		80	
Leptocylindricus	265	370	595	265	3	25	
Coscinodiscus				5	65	50	20
Pleurosigma					15		60
Paralia					30		10
Navicula						5	
Cocconeis					5		
Total No. of Diatoms =	265	410	595	345	118	160	90
<u>Other Organisms Present:</u>							
Protozoa					10	5	10
Fungus filaments, mass							mass
Algae	5	10	·	90	10	65	50
Tintinnids	35	15	15	5			
Spores	20			mass			85
Peridinians	15	35	10	10	5		10
Crustacean larvae					10		
Bivalve larvae		5		20			
Copepod larvae		5					
Total =	75+	70	25	125+	35	70	155+

Note-(+) sign denotes the presence of a mass of spores or fungus filaments, which could not be counted.

Copepods from each of the tows taken on July 22, at Prince Station 492, were examined to find the intestinal contents. Since nearly all the copepods in these tows were of the small, almost transparent type, by means of a binocular one could readily distinguish the pellets of food in the intestine. These pellets, with the adjoining intestine--and sometimes the entire intestine--were dissected out, put in a drop of distilled water, and examined with oil immersion.

In practically every pellet, there was a mass of greenish brown particles in which nothing could be identified.

The results were as follows:

Depth 5 meters 6.21-6.26 A.M.

Practically all the copepods were empty. In one examined, there was found a small amount of greenish brown material in the fore-gut.

Depth 10 meters. 6.21-6.26 A.M.

copepod	intestinal contents
(1)	3 Coscinodiscus.
(2)	Greenish brown mass, only.
(3)	2 Coscinodiscus. In another Coscinodiscus, both valves were present as seen in side view. Later, it was viewed from the top and appeared empty. It was surrounded by greenish brown particles which may have been the contents, thrust out by tapping.
(4)	1 Coscinodiscus, entire. 1 " , broken. 1 Peridinian.

Depth 15 meters, 6.02-6.07 A.M.

(1) In the anterior part of the mid-gut were found, 3 Coscinodiscus, entire.
Near the end of the mid-gut, there were 3 Coscinodiscus, entire.

(2) Mass of greenish brown particles, only.

(3) 1 Coscinodiscus.

(4) Mass of greenish brown particles, only.

(5) Mass of greenish brown particles, only.

(6) 1 piece of Coscinodiscus.
1 small round object—probably an algal spore.

Depth 20 meters, 6.02-6.07 A.M.

(1) Mass of greenish brown particles, only.

(2) Pellet in fore-gut contained:
1 Coscinodiscus, and several pieces.
1 Pleurosigma and several pieces.
Pellet in mid-gut contained:
several pieces of Coscinodiscus
several pieces of Pleurosigma.

(3) 3 Coscinodiscus, entire margins, one broken on top; few pieces of Coscinodiscus.
several pieces of Pleurosigma.

(4) Several Coscinodiscus, some with entire margins, some broken;
Mass of Pleurosigma pieces.

(5) In the anterior part of the mid-gut were:
1 Coscinodiscus, and a few small pieces.
3 nematocysts.
In the posterior part of the mid-gut were:
pieces of 1 Campylodiscus,
3 Coscinodiscus, entire margins.
1 Coscinodiscus, showing both valves.
several pieces of Coscinodiscus.

(6) 3 Coscinodiscus, and several pieces.

(7) Mass of greenish brown particles, only.

(8) In pellet at the anus: 1 Coscinodiscus.

(9) In the anterior part of the mid-gut, there was only a mass of greenish brown particles. In the posterior part, was a mass of pieces of Pleurosigma.

(10) Few small pieces of Coscinodiscus.

Surface, 12.45-12.50 P.M.

(1) Mass of greenish brown particles, only.

(2) Remains of a smaller Crustacean, possibly a Copepod.

Depth 5 meters, 12.45-12.50 P.M.

(1) 1 Coscinodiscus, and several pieces.

(2) 1 Melosira.
2 nematocysts;
2 small fragments of filaments resembling Oscillatoria.

(3) In pellet at the anus:
21 nematocysts, some exploded, and some closed.
1 fungus spore.
In pellet, in the anterior part of the mid-gut.
Masses of nematocysts
1 round green spore, with spine covered coat.

(4) 1 Coscinodiscus, and several pieces.

(5) Pieces of Coscinodiscus.

(6) 1 piece of Coscinodiscus.

(7) Few pieces of Coscinodiscus.

(8) 1 Coscinodiscus, and several pieces.

(9) 3 Coscinodiscus.
pieces of Dictyocha.
piece of Nitzschia.

(10) Mass of greenish brown particles, only.

Depth 10 meters. 12.45-12.50 P.M.

(1) Mass of greenish brown particles, only

(2) 7 Coscinodiscus, and several pieces.
1 Nitzschia.

(3) 3 Coscinodiscus.
1 piece of Navicula.

(4) 1 Coscinodiscus

(5) Small pieces of Pleurosigma.

(6) 5 Coscinodiscus.

(7) 2 Coscinodiscus, and several pieces.
1 Nitzschia, entire.
1 Navicula.
1 Ebria.
Pieces of Pleurosigma.
Pieces of Distephanus.
2 pieces of filament resembling Oscillatoria.

(8) 1 piece, resembling Leptocylindricus.

(9) 1 Coscinodiscus.

(10) 7 Coscinodiscus, and pieces.
1 Nitzschia.
Piece of Pleurosigma.

(11) 1 Coscinodiscus, and pieces.
1 piece of Nitzschia.

(12) 2 Coscinodiscus, and pieces.
1 piece of Pleurosigma.
1 long piece of a Crustacean Antenna, resembling that of a copepod.

Depth 15 meters. 12.28-12.33 P.M.

(1) 1 small piece of Pleurosigma.

(2) Several pieces of Coscinodiscus.

(3)	2 Coscinodiscus, and a few pieces. 1 piece of Campylodiscus.
(4)	7 Coscinodiscus, and several pieces.
(5)	13 Coscinodiscus, and several pieces Several large pieces of Pleurosigma.
(6) (6)	Mass of greenish brown particles, only.
(7)	2 Coscinodiscus, and a few pieces. 1 Triceratium. 6 nematocysts.
(8)	4 Coscinodiscus.
(9)	6 Coscinodiscus and pieces. 1 Triceratium. 6 nematocysts.
(10)	1 Coscinodiscus.

Depth 20 meters. 12.28-12.33 P.M.

(1)	Mass of greenish brown particles, only.
(2)	In the anterior part of the mid-gut: 3 Coscinodiscus. In the posterior part of the mid-gut: 3 Coscinodiscus, and pieces. A few pieces of Distephanus.
(3)	1 Navicula. 1 Nitzschia. 1 Campylodiscus. 1 piece of Coscinodiscus.
(4)	1 Coscinodiscus. Mass of Nitzschia, some broken.
(5)	2 Coscinodiscus, and several pieces.
(6)	1 Coscinodiscus, and several pieces.
(7)	10 Coscinodiscus.

(8)	In the anterior part of the mid-gut: 2 Coscinodiscus, and pieces. 1 piece of Nitzschia.
(9)	In the posterior part of the mid-gut: 1 Coscinodiscus, and a few pieces. pieces of Pleurosigma.
(9)	In pellet emerging from the anus: pieces of Coscinodiscus. pieces of Pleurosigma.
(10)	6 Coscinodiscus.
(11)	2 Coscinodiscus; 1 Nitzschia.

Surface. 10.54-10.59 P.M.

(1)	2 Coscinodiscus. 1 Nitzschia.
(2)	8 Coscinodiscus A few pieces of Dictyocha.
(3)	2 Coscinodiscus, and a few pieces. 1 Distephanus, complete, and a few pieces. 3 small discs of Coccosphaera.
(4)	4 Coscinodiscus, and several pieces.
(5)	4 Coscinodiscus, and several pieces. Several pieces of Pleurosigma. 1 Nitzschia.
(6)	Mass of greenish brown particles, only.
(7)	1 Peridinium.
(8)	3 Coscinodiscus, and several pieces. 1 Distephanus speculum, and pieces of another.
(9)	1 Peridinium.
(10)	1 Peridinium. A few small pieces of Pleurosigma.

Depth 15 meters. 10.34-10.39 P.M.

(1) 1 Distephanus.

(2) 1 Coscinodiscus.

(3) 3 Coscinodiscus.

(4) In the posterior part of the mid-gut:
1 Coscinodiscus.
In the anterior part of the mid-gut:
2 Coscinodiscus.

(5) Near the posterior end of the mid-gut:
1 Coscinodiscus, and 2 pieces.
1 valve of Navicula.
In the caecum, anterior to the fore-gut:
1 Coscinodiscus, entire and with contents.
1 Coscinodiscus, entire margin; part of the top was removed, and part of the contents was gone.

(6) Mass of greenish brown particles, only.

(7) 5 Coscinodiscus, some broken and some entire.

(8) Mass of greenish brown particles, only.

(9) 2 Coscinodiscus.
4 small round green objects, resembling unicellular algae.

(10) Mass of greenish brown particles, only.

Depth 20 meters. 10.34-10.39 P.M.

(1) Pieces of Coscinodiscus.

(2) Mass of Coscinodiscus, some entire, some broken.

(3) Mass of greenish brown particles, only.

(4) 3 Coscinodiscus, and few pieces.
Pieces of Dictyocha.

(5) Pieces of Coscinodiscus, 1 entire valve.

(6) Mass of greenish brown particles, only.

(7)	1 Coscinodiscus, and few pieces. Pieces of Dictyocha.
(8)	1 piece of Coscinodiscus. 1 Distephanus.
(9)	Mass of greenish brown particles, only.
(10)	2 Coscinodiscus, and few pieces.

Copepods preserved immediately upon gathering from a deep tow, at Prince Station 6, August 17, 1926. A.M.

(1)	3 Coscinodiscus, and 1 piece.
(2)	2 Coscinodiscus, and 4 pieces.
(3)	Mass of greenish brown particles, only.
(4)	1 Coscinodiscus.
(5)	3 Coscinodiscus. 2 unicellular algae.

Eurytemora (species, herdmani and hirundoides) were by far the most voracious of the copepods, nearly always containing food. A number of Acartia (clausi) were also among those dissected, along with several Pseudocalanus, Calanus finmarchius, Temora longicornis, and a few which were not identified.

Among the recognisable contents of the digestive tract, Coscinodiscus seems to have the most important place, even though Chaetoceros and Leptocylindricus are present in the water in greater quantities. This may be due to the greater ease manifested, in ingesting the small round diatom, Coscinodiscus, than the long filamentous Leptocylindricus, or the spiny cells of Chaetoceros. Or it may be that a preference is shown for the one particular type. In any case, diatoms seem to be the predominant food of the copepod.

The mass of greenish brown particles which is always present in the pellets, must be due to the contents of the diatoms, since the latter always appear either broken or as empty shells; but it may be due in part to soft bodied organisms which leave no recognisable remains.

Some attempt was made to determine the time of day at which the copepods eat. Fifty copepods were taken at random, from each tow, and the number counted, which contained pellets of food, as seen with the aid of the binocular.

The following table gives the results:

Prince Station 492. July 22, 1926. 5 tows.

Time of day.	Depth in meters	% of copepods containing food.
3.10-3.35 A.M.	0	8
4.30-4.45 A.M.	0	2
6.02-6.07 A.M.	0	0
	5	4
	10	4
	15	6
	20	14
12.45-12.50 P.M.	0	2
	5	0
	10	8
	15	10
	20	8
10.54-10.59 P.M.	0	28
	15	16
	20	20

From this, it would appear that the greater percentage of copepods feed at night.

Miss Sheina Marshall says, concerning this subject, "The surprising 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. 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."

While dealing with the feeding habits of copepods, and their relation to light, it might be mentioned here that some work was done to ascertain the effect of light on the vertical movements of the animals. On the evening of June 30, surface tows, 5, were taken at Prince Station 492, at various intervals, and the number of copepods counted, in each. These results were compared with those obtained from tows taken on July 22, and again on July 28, 1926, at the same station. They are as follows:

June 30. No. of copepods at the surface.

7.30 P.M.	8.10 P.M.	10.48 P.M.	12.26 P.M.	2.01 A.M.
5,296	535	38,000	72,000	27,800

Sunrise, on June 30, - 4.36 A.M.

Sunset, " - 8.18 P.M.

Moonrise " - 11.53 P.M.

Moonset " - 9.51 A.M.

July 22. No. of copepods at the surface.

3.10 A.M.	4.30 A.M.	6.02 A.M.	12.45 P.M.	10.34 P.M.
95,992	17,120	532	2,680	26,624

Sunrise, on July 22, - 4.55 A.M.

Sunset, " - 8.15 P.M.

Moonrise " - 5.42 P.M.

Moonset " - 1.58 A.M.

July. 28. No. of copepods at the surface.

2.20 P.M.	7.53 P.M.	8.30 P.M.	9.15 P.M.	9.55 P.M.
6,525	1,468	10,189	313,694	367,626

Sunrise, on July 28, - 5.02 A.M.

Sunset, " - 7.59 P.M.

Moonrise, " -10.22 P.M.

Moonset, " - 8.50 A.M.

Counting about three-quarters of an hour after the sun goes down, and half an hour before the moon rises, for the light to disappear, or appear, as the case may be, we find the darkest periods in these three days to be as follows:

On June 30, between 9.00 and 11.15 P.M.

" July 22, " 2.30 and 4.15 A.M.

" July 28, " 8.45 and 10.10 P.M.

It will be noticed from the preceding tables that the greatest number of copepods are at the surface, on June 30, at 12.26 P.M., which is about an hour after the darkest period. Considering the rapid rise, however, there may have been greater numbers before the tow was taken—during the darkest period of the day.

On July 22, the greatest number appears at the surface at 3.10 A.M., which is quite within the darkest period. This also occurs on July 28, when the greatest number is present at the surface at 9.55 P.M. Although not conclusive, these results tend to indicate that copepods prefer the dark, and that light has a repelling effect.

Yet, it still remained to be seen whether or not these copepods could live on diatoms or whether the latter were merely taken in, or ingested. A few experiments were conducted to try and decide this question.

In each of two pint jars, containing 280 ccs. of sterile sea water, were placed 10 large copepods (possibly Calanus finmarchius). The first jar was then closed tightly and placed on the aquarium table, in running water. Then, to the second jar was added 10 ccs. of diatom culture—including some flagellates and small masses of green material. This jar was then closed tightly and placed beside the first on the aquarium table. In two days all the copepods in the first jar—containing only sterile sea water—were dead, while some lived in the second jar until the fifteenth day.

Another similar experiment didn't work as well, for the copepods lived longest in the sterile water; however, they lived longer in the water containing diatom material, than in filtered sea water. So that, although suggestive, the foregoing experiments are not conclusive.

Some experiments were then done, on feeding copepods pure cultures of diatoms. The animals, brought in from the tow the preceding evening, were left in cool water all night. In the morning, some of them—appearing empty—were put into a watch glass with several ccs. of material from a mixed diatom culture. After an hour and a half, they were removed, and the intestinal contents, examined. The first one contained only a mass of green material. The second showed a mass of green material in the anterior part of the mid-gut, which, when dissected out and examined under oil immersion, proved to be a large quantity of Nitzschia closterium. About 35 of the diatoms were counted just on the surface of the pellet. There were also several small pieces of Chaetoceros. Some of the Nitzschia were still living, and moving about. A third and fourth copepod, having pellets of food in the latter part of the mid-gut, showed, when crushed, and examined with oil immersion, to contain only a mass of very minute greenish brown particles.

This experiment was tried again, putting copepods into watch glasses containing sterile filtered sea water. Into each watch glass was put some diatom material from pure cultures growing on agar slants; Navicula was put into one dish, and Nitzschia into the other. They were left in a cool place for some eight hours before examination, when they were crushed, and the intestinal contents were examined under oil immersion.

The results were as follows:

From the watch glass containing Navicula:

Copepod.	Intestinal contents.
(1)	A number of Navicula. The shells could be made out entire, but appeared empty.
(2)	Several Naviculae.
(3)	The intestine was full of empty, entire Navicula shells.

From the watch glass containing Nitzschia:

(1)	The anterior part of the mid-gut was full of Nitzschia, all entire and some alive. There was also a mass of greenish particles resembling the chromatophores of the diatom.
(2)	The anterior part of the mid-gut was full of Nitzschia, all empty cells, and there were also a great many greenish brown particles.
(3)	The anterior part of the intestine was full of Nitzschia, some empty, some broken, some with chromatophores. The latter part of the intestine also contained a few Nitzschia with chromatophores.
(4)	The anterior part of the mid-gut was full of Nitzschia, mostly entire and with chromatophores.
(5)	The intestine was full of Nitzschia, some with chromatophores, some without, and some plasmolysed. There were also present some greenish brown particles similar to the chromatophores.

The fact that the diatoms appeared empty and entire, may be due to the separation of the valves and seeing only one entire valve, on its flat surface.

When the diatoms were taken in alive, and were about to pass out of the intestine as empty shells, it shows fairly well that they must serve as food.

Then, having found that diatoms were eaten, it was thought well to try and feed the copepods other plants to see whether or not they ate anything that came in their way. Several times, copepods had been brought in with algae, and it was suggested that they might get nourishment from algal spores. However, on examination of several of these copepods, they were found to be filled with diatoms. Navicula was the commonest form ingested. Most of the diatom shells were empty, in the midst of a brownish green mass.

Some copepods were then put into a watch glass with some sterile filtered sea water to which was added a quantity of fresh green Enteromorpha spores. After an hour and a half, the copepods were examined under a microscope and the pellets of food were seen to move through the intestine. The anterior part of the intestine, of all, was filled with the green spores which were entire and separate. The excreta was also a mass of the green spores, entire; a few were of irregular shape, and there were some small green irregular particles in the mass--which may be evidence of a few of the spores having been broken and partly digested. But on the whole, one could safely say that the copepods do not use algae spores as food.

August Pütter is of the opinion that the 'lower marine forms are not nourished—at least, to any great extent—by the suspended particles having their origin in marine plants, as has been assumed, but by the dissolved organic matter which is found on sea water, in great dilution and which is directly absorbed.'

Moore, Edie, Whitley and Dakin, however, have shown that Pütter's calculations for the amount of organic matter in sea water are erronious and they 'place a maximum at such a low level as to show that the organic content in solution is almost negligible, and lies within the limits of error of determination.' They also refute Pütter's statement with the argument that 'organs specially developed for the performance of such an important function as the intake of nutrition, would never have evolved to such a high degree of perfection and elaboration if they were only used occassionally as a luxury or an accessory to a main mode of nutrition in which the food was ready prepared and soluble, and capable of entering the main stream of nutrition, at once, without injury to the animal.'

They say, too, that the uniformly distributed plankton is inadequate for the support of life, but in their opinion, the food supply for the lower marine organisms lies in the unequal distribution of the plankton.

Dakin, having dissected a great many copepods and examined the intestinal contents, says, "There seems to be no doubt from the recognisable contents of the gut that Diatoms play a most important part as food of the Copepods together with species of Peridinians. Those specimens which contained large numbers of diatoms were evidently feeding upon these, but it might be said that in other cases, the Diatoms and other shelled forms were simply accidental and the food consisted of shellless lower organisms. The diatoms which occurred so frequently were small round species, very probably Thalassiosira since this was present in the plankton and these were so small that very few might be captured with a silk net."

Esterley, too, has examined the intestinal contents of several hundred copepods of different species, taken at different seasons and at different depths. From his results, he says, "The recognisable remains of organisms in the gut of Calanus consist chiefly of the shells of diatoms, of which Coscinodiscus is the most abundant. Broken or entire shells occur in most cases when diatoms are present, at all." "It seems plain enough that the copepods feed principally upon the small forms of the plankton, such as the diatoms, so far as one can judge from an examination of the intestinal contents. Only the indigestible portions of the food can be recognised, and it is certain that forms are ingested which do not have shells or skeletons. To determine accurately what is eaten and how much, it is necessary to be able to observe the animals alive, and while feeding."

Miss Sheina Marshall, likewise, makes the following statement, basing her results on the examination of over 3000 Calanus, of which 52% contained recognisable food. "The food consists mainly of diatoms. When diatoms are scarce other organisms are eaten instead. During the winter minimum a species of Radiolarian, Acanthonia mulleri, is common in the plankton, and this forms an important part of the diet, along with the winter diatoms, Coscinodiscus, and Biddulphia. 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."

"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 larvae, coelenterate nematocysts (probably ingested on other Crustaceans), Tintinnoids, bits of Algae and so on are occasionally found, but are of little importance."

Gran has an article in 'The Depths of the Ocean', dealing with the food of the Copepod. He made his study chiefly from their excrements. He found shields of the Coccolithophoridae, and some Peridineae, but in localities where diatoms predominate, the excrements consisted chiefly of bent and broken bits of diatoms. He is quite certain that the animals do feed on them, and especially when they are plentiful.

Miss Lebour, at the Plymouth Laboratory, has also made a study of the food of plankton organisms. She, too, says that the copepods depend largely on the diatoms for food. She has divided all the plankton organisms into groups according to their food. Among the diatom feeders are: Copepods, Decapod larvae, Echinoderm larvae, Mollusk larvae, Annelid larvae, and some of the transparent worms-Tomopteris, Cyphonautes and Tornaria.

If this list be true, it would seem that the diatoms must surely be all eaten. But yet a great number are known to be deposited. In certain localities on the bottom of the ocean, are found sediments consisting almost wholly of diatoms--called Diatomaceous Ooze. In order to determine the extent to which diatoms were deposited in Passamaquoddy Estuary, where were they found in the surface waters, and where the copepods were found eating them, Bottom Samples were taken at Prince Stations 496, 492, 10, and 4. By means of an apparatus specially devised—a gas pipe with outlets three inches apart—it was possible to obtain samples from different depths.

In each case, .02 grams of the sediment were weighed out, 1 cc. of distilled water was added, and the whole shaken thoroughly. Then .04 ccs. of the solution were examined microscopically with high power, on a ruled slide. All the diatoms in this quantity were counted, and noted. At least 2—and in some cases, 4—counts were made of each sample. From the average thus given, a calculation was made as to the number of diatoms per gram of sediment, in each sample, and for each genus. The water just above the bottom—termed the surface water—was also examined in the same way, by filtering, and using the sediment.

The results were as follows:

Bottom Samples. Prince Station 492.

Diatom	Number per gram. at various depths.			
	Surface water	surface	3 in.below surface	6 in.below surface
Coscinodiscus	119,160	90,510	120,540	110,030
Paralia	52,870	105,580	195,130	102,740
Melosira	148,960	130,000	179,580	279,700
Navicula	39,160	28,400	41,760	34,000
Pleurosigma	26,250	10,070	9,810	8,470
Thalassiosira	64,480	17,100	16,390	20,310
Fragillaria	20,460	9,235	14,300	10,550
Actinotychus	2,500	555	2,360	1,660
Biddulphia	2,500	2,640	780	1,950
Cocconeis	2,500	932	2,500	1,950
Chaetoceros	39,580	312		550
Nitzschia	830			
Skeletonema	8,330			
Terpinsoe	370	1,666		
Leptocylindricus			1,480	
Rhizosolenia			370	
Doubtful ?	3,700			
	534,150	397,000	585,370	571,910

Bottom Samples Prince Station 496.

Diatom	No. per gram at various depths. Surface water	surface	3 in. below surface
Coscinodiscus	59,670	103,820	74,480
Navicula	18,880	38,010	30,000
Paralia	40,972	84,950	45,600
Pleurosigma	17,780	12,040	1,850
Cocconeis	1,250	4,860	1,990
Thalassiosira	5,830	12,500	
Thalassiothrix	1,250	1,250	
Actinotychus	830	1,160	3,010
Melosira	51,850	247,490	234,190
Chaetoceros	2,220	1,110	3,330
Nitzschia	370	370	1,480
Terpinsoe	370	790	1,480
Fragillaria		11,060	9,630
Biddulphia		2,820	1,110
Camplydiscus		2,220	750
Raphoneis		740	
Total	201,070	515,190	408,900

Bottom Samples. Station 4.

Diatom	Number per gram, at various depths. surface water	surface	3 in. below surface	6 in. below surface
Coscinodiscus	126,100	129,430	81,100	65,000
Melosira	252,200	166,650	246,100	204,420
Pleurosigma	30,550	12,220	2,780	3,880
Navicula	52,770	42,770	31,100	23,330
Thalassiosira	41,660	24,440	51,660	21,660
Thalassiothrix	8,880		1,110	
Fragillaria	30,000	8,330	11,110	31,100
Paralia	41,110	13,330	38,890	11,110
Biddulphia	550	2,780	550	550
Rhizosolenia	560			
Terpinsoe	1,110	560		
Chaetoceros	12,780	2,220	1,110	1,110
Nitzschia	6,660			
Cocconeis	5,560			
Actinotychus			3,890	
Doubtful ?	550		1,110	
Total –	611,040	402,730	470,510	362,160

Bottom Samples. Prince Station 10.

Diatom	No. per gram at various depths. Surface water	surface	3 in. below surface
Coscinodiscus	62,220	26,390	50,830
Melosira	119,430	63,880	132,480
Navicula	50,000	17,780	18,330
Pleurosigma	23,890	280	1,110
Thalassiosira	9,720	3,050	560
Thalassiothrix	2,500		
Biddulphia	2,220	280	
Fragillaria	4,440	3,330	1,670
Paralia	7,770	5,000	23,050
Chaetoceros	33,880		830
Terpinsoe	280	280	830
Rhizosolenia		280	280
Actinotychus		830	280
Total	316,350	121,380	230,250

Though varying somewhat in the different localities, and also with depth, the large number of diatoms present in the sediment, shows that they are deposited fairly evenly, over a period of time, and in considerable numbers.

As regards the diatom shell going back into solution after the death of the plant, there has been no direct experimentation upon the problem. But W.R.G. Atkins who has been working on 'The Silica Content of Natural Waters' has found that there is a wellmarked seasonal change in the amount of silica present in sea water. The winter value falls appreciably in April to June. This is followed by a rise in October, and a fall again in November. These periods of dimunition of silica in solution and following increases, correspond fairly well with the maxima and minima of diatoms. It seems probable, Mr. Atkins says, that a portion of the diatom silica again finds its way into the water of the ocean, thus accounting for the enrichment of dissolved silica during the diatom minima.

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