STUDIES ON THE LIMNOLOGY OF THE LAKES OF
YATSUGATAKE LAKE GROUP—I.
OBSERVATIONS ON THE FEEDING HABITS OF
THE PLANKTON OF LAKE SHIRAKOMA

Sadami KADOTA*

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Introduction

Lake Shirakoma is situated at the foot of Yatsugatake mountain, at an altitude of 2155 m. Though it measures but 0.114 Km² in area and 8.55 m in depth its limnological significance is not the least. When the altitude is taken into account it can be said to be a fairly large lake, being the largest of the Yatsugatake volcanic lake group.

TANAKA, A. and E. UENO (1954) studied this lake. In their study, however, they seem to have laid but little stress on the biology, though noting an important fact that despite the presence of little or no phytoplankton in this lake there exists an immense quantity of *Acanthodiaptomus* and *Daphnia*. In the present study now being made of the same lake the author was struck by the same result. However, the above seems to be in no wise a rare instance, being often the case with lakes of high altitude.

During the biological study of this lake I was inevitably led to the inquiry of the food cycle of plankton i.e. the question of what is the food of *Diaptomus* (*Acanthodiaptomus pacificus*) and *Daphnia* (*D. longispina*). The problem is seemingly simple but physiologically it is so suggestive that it soon makes one call to mind Putter's theory of nutrition, which postulates the absorption of dissolved matter from without. Concerning the food habit of plankton W. J. DAKIN (1908), M. V. LEBOUR (1922), and S. M. MARSHALL (1924) made valuable contribution which the present author has referred to.

Before entering the subject the author would like to express his heartiest thanks to Prof. S. KOKUBO under whose kind direction and helpful criticism the present work was carried out.

Method

In the present study a lot of specimens was collected through all seasons of the year 1957. From these specimens 300 individuals or so each of *Diaptomus* and *Daphnia* with their alimentary canal full of food were selected. These individuals were treated in the following way.

* Department of Fisheries, College of Agriculture and Veterinary Science, Nihon University
(日本大学農獣医学部水産学科).

(1) Each individual was dissected under a binocular dissecting microscope, and only the alimentary canal was picked off, avoiding fine debris of the dissected body.

(2) The alimentary canal was transferred on to a slide glass, and the content was observed from outside. The position of food and the length of portion where the food is contained were observed from outside.

(3) The above specimens were placed on the stage of the microscope, the content was squeezed out on the slide glass by using a fine dissecting needle. After removing the emptied alimentary canal the number of individuals of food organisms was counted.

(4) Placing a cover glass on the above food material it was examined with a common microscope under a high magnification.

In some cases the same material was examined before and after the staining with neutral red.

As mentioned above the number of specimens used was about 3 hundred. But because of the difficulty of success in taking out the alimentary canal the number of specimens dissected was more than 2,500, the rate of success being less than 15%.

Results

(I) Morphology of the alimentary canal of *Diaptomus* and *Daphnia*.

In *Diaptomus* the total length of alimentary canal is about 77% of the body length, while it is about 95% in *Daphnia*, the latter having a longer alimentary canal than the former.

Fig. 1. A, Alimentary Canal of *Diaptomus*;
B, Alimentary Canal of *Daphnia*.

As is shown in Fig. 1, A and B, in *Diaptomus* the whole length of alimentary canal can be divided into three parts, i.e. anterior portion, posterior portion, and rectum, with the characteristic that the anterior portion is fairly wide. As to that of *Daphnia* the shape is apparently simple showing no partial development between oesophagus and anus.

(II) Quantity of food taken by *Diaptomus* and *Daphnia*.

Concerning the food study of *Calanus* DAKIN's (1908) result shows that not all *Calanus*, captured in townettings, are found with food in the alimentary canal. Of over 3000 *Calanus* examined at Millport 52% contained recognizable food. This percentage varied 20%-70% according to season. In contrast to the above both species of the present experiment all contained food material whether little or more in abundance.

In the present experiment the quantity of food was observed and described to find out in what percentage the content occupied the total length of alimentary canal. For

this purpose 100 individuals of both species were selected from the specimens collected from May to December, in order to assess the above percentage. Of *Diaptomus* the result showed that during summer a moderate quantity of food was found in the anterior and posterior portion of the alimentary canal occupying about 20-30% of the total length. But in no case did the food filled up the total length, in some cases being found in a small mass in each part of the alimentary tract. In process of season, however, from autumn to winter many individuals with food only in the posterior portion were also found. In short the food shows a tendency to decrease with the process of the season, but as to the posterior portion it always contained food even when nothing was contained in other portions.

Taking up the *Daphnia* next a marked difference from *Diaptomus* is seen in the point that in this species, during the season from May to August, the food is found in such an abundance that it occupies over 60% of the total length of the alimentary canal, sometimes exceeding 90%; and also that the quantity of food shows a marked difference according to season. From October on the quantity showed a marked decrease, becoming least by late December. But interesting was the presence of some exceptions which were found containing food in abundance in the alimentary canal.

In Table 1 are shown microscopic figures of the food material found in the alimentary canal of both species, including organisms and other fine debris. Most of these were matter so fine as to be smaller than 20μ or thereabout. In most cases the proportion of the quantity of these small organisms in total food materials was less than 10%.

(III) Kinds of food matter and its quantity.

In describing the food matter found in the alimentary canal unknown elements other than algae were, for the sake of convenience, classified into five kinds, in the following makeshift terms: (1) Spherical matter, (2) Elliptical matter, (3) Spines, (4) Filamentous and Rod-shaped matter, and (5) Soft debris, each having a name appropriate to its shape.

As will be seen in Table 1 the food of *Diaptomus* is composed for the most part of *Merismopedia*, a kind of *Cyanophyceae* belonging to *Chroococcaceae*, its cells measuring less than 5μ in diameter. Next to this the following species occurred in moderate abundance, as shown in the following descending order: *Chroococcus*, Spherical matter, Filamentous and Rod-shaped matter, Spines, Elliptical matter, *Dinobryon*, *Cymbella* and *Eunotia*.

In *Daphnia* the food matter contained the spherical matter in the first abundance, second to this the *Chroococcus*, Spines, Filamentous and Rod-shaped matter, *Merismopedia*, *Dinobryon*, Elliptical matter, *Eunotia* and *Cymbella* were found in moderate abundance.

Of the food materials above mentioned the one called soft debris was also found in moderate abundance in some cases. Though the true nature of this substance was

Table 1. Kinds and number of food material in different seasons.

Diaptomus (Acanthodiaptomus pacificus) Daphnia (Daphnia longispina)

	Date	<i>Eunotia</i> sp.	<i>Cymbella</i> sp.	<i>Chroococcus</i> sp.	<i>Merismopedtia</i> sp.	<i>Dinobryon</i> sp.	Spherical matter	Elliptical matter	Spine	Filamentous and Rod-shaped matter
<i>Diaptomus</i>	May 26, '57	—	—	97	—	15	20	2	7	11
	June 19, '57	—	1	209	—	20	14	4	6	18
	July 10, '55	—	—	55	—	3	5	4	19	52
	July 20, '57	—	—	51	133	—	5	3	5	16
	Aug. 3, '57	—	—	22	—	—	29	30	6	6
	Aug. 20, '57	1	4	6	440	—	7	721	14	30
	Sept. 30, '56	—	—	7	42	—	23	4	8	26
	Oct. 28, '55	—	—	—	23	—	20	14	11	22
	Nov. 24, '57	—	—	—	—	—	48	—	5	6
	Dec. 14, '57	—	—	—	—	—	36	—	3	5
	May 26, '57	21	6	139	—	110	409	—	9	19
<i>Daphnia</i>	June 19, '57	1	2	142	—	83	61	83	22	39
	July 10, '55	—	—	8	75	8	10	—	46	40
	July 20, '57	1	—	88	253	5	23	8	232	62
	Aug. 3, '57	—	—	82	—	—	20	35	7	21
	Aug. 20, '57	3	1	—	—	—	6	—	19	63
	Sept. 30, '56	—	—	—	—	—	7	2	5	68
	Oct. 28, '55	—	—	—	—	—	20	11	33	30
	Nov. 24, '57	—	—	—	—	—	24	—	13	13
	Dec. 14, '57	—	—	—	—	—	15	2	11	22

not clear its appearance made the author suspect it to be a debris derived from disintegration of the corps of *Daphnia* and *Diaptomus* themselves. It is highly probable that the debris which is suspended lightly in water is collected by the mouth appendage of *Daphnia* and *Diaptomus*, and is eaten at last.

To find in what abundance the debris is present in water if present at all, the lake water was centrifuged with the result that in water there existed an immense quantity of the debris. From this result the author was led to examine the bottom deposit to see whether it contained the same debris. As expected the deposit contained the debris in high abundance.

On the other hand it was found that in the debris collected by centrifuging the lake water no other matters such as *Trachelomonas*, Spines, and Rod-shaped matter were found, pointing to the conclusion that *Daphnia* and *Diaptomus* feed largely on the bottom materials.

As regards the quantity of the above materials it was found that in *Daphnia*, the Spherical and Elliptical matter, Spines, Filamentous and Rod-shaped matter, and *Eunotia* were found much more than in *Diaptomus* through all seasons. This may, however, be partly due to the high abundance of food matter in *Daphnia* than in *Diaptomus*. And hence the above can not be considered as being due to the difference of food preference in these two species.

In association with the above observation of food materials the author made observations on the plankton and bottom materials then collected, with the expectation that the above food matters had to come from plankton. Unexpectedly, however, no correspondence was found between the plankton and food materials. But instead it was found that the above food matter closely resembled the constituents of bottom materials, except for the fact that *Chroococcus* and *Merismopedia* in bottom materials were a little less than in the food matter. The above finding is remarkable as it led the author to conclude that these species may feed on bottom organisms instead of plankton.

(IV) Size and quantity (number) of food matter.

In the following table the size of organisms was measured in diameter in the case of Spherical or Elliptical matter, and in length in the case of Spine-like or Filamentous matter. The quantity was expressed in number because of the difficulty of measuring the volume. The number given in the upper two lines is the sum of each kind of food matter enumerated in Table 1.

From Table 2 it can be seen that the average size of food particle taken by *Diaptomus* is in a range of $4.0\text{--}37.2\mu$ in length though so long a maximum length of 238.2μ was found in the case of Filamentous matter. As for *Daphnia* the size of particulate matter was in a range of $2.1\text{--}57.0\mu$ in diameter, the maximum length measured in Spine-like matter was 311.4μ . These results show that the average size of food matter varies around 50μ or so, a size exceeding 100μ being exceptional. And still, when both species are compared in regard to the size of food particles there

Table 2. Total number and size of each kind of food material.
Diaptomus (*Acathodiaptomus pacificus*) *Daphnia* (*Daphnia longispina*).

	<i>Eunotia</i> sp.	<i>Cymbella</i> sp.	<i>Chroococcus</i> sp.	<i>Merismope-</i> <i>dia</i> sp.	<i>Dinobryon</i> sp.	Spherical matter	Elliptical matter	Spine	Filamentous and Rod-shaped matter
Number (<i>Diaptomus</i>)	1	5	447	638	41	207	782	84	192
Number (<i>Daphnia</i>)	26	6	459	328	208	595	141	397	377
Size (μ)									
	Mean								
	<i>Diaptomus</i>	20.78	19.70	4.00	29.04	9.10	9.38	37.18	27.76
	<i>Daphnia</i>	—	10.78	2.09	45.15	12.49	12.84	57.31	32.61
	<i>Diaptomus</i> and <i>Daphnia</i>	20.78	15.24	3.05	37.09	10.80	11.11	47.25	30.19
Maximum	<i>Diaptomus</i>	20.76	17.1	5.19	20.38	27.68	—	132.3	238.2
	<i>Daphnia</i>	—	17.3	4.8	45.15	27.68	41.52	311.4	193.9

seems to be a tendency for *Daphnia* to take a little bigger particle than *Diaptomus*.

In case of marine Copepoda such as *Calanus finmarchicus* the food matter taken by them consists of distinct organisms e.g. Diatoms etc. (MARSHALL et al, 1955). However, in the present case of *Diaptomus* and *Daphnia* the food matter was not so distinct ones, but consisted of minute and indistinct organisms which do not appear in ordinary plankton.

(V) Feeding ecology of *Diaptomus* and *Daphnia* in relation to season.

Comparing the food matter of both species one will note that through all seasons *Daphnia* takes almost all kinds of food except for *Merismopedia*, while *Diaptomus* takes but few kinds, the difference is observed to be especially marked during the period from May to August. But as to the seasonal change of food quantity both species showed the same tendency that the abundance was highest during June–July, decreasing from late-August on gradually. As regards the relation of food quantity to water temperature it was observed that the quantity increased from early-June on when the water temperature showed 10°C or so. After becoming maximum during summer (June–July) the quantity commenced a gradual decrease with the decrease of water temperature.

It is of interest to note that *Chroococcus*, *Merismopedia* and *Dinobryon* which comprise the major part of food are so small in quantity in plankton that their occurrence and change is not observable. But their quantitative change in food matter is very marked, showing a tendency for *Chroococcus* to occur in highest abundance during May–July, decreasing from mid-August on, and for *Merismopedia* and *Dinobryon* to culminate in July–September and in May–August respectively. Other species too show some degree of seasonal change while some show but little.

Notable is the fact that some of the food organisms are of bottom nature and are never found in plankton (e.g. *Eunotia* and *Cymbella*). This makes the author to conclude that *Diaptomus* and *Daphnia* subsist on bottom organisms. If this is so it follows that majority of these plankton must assemble on the bottom at some time of the day, thus eventually modifying the vertical migration and distribution of the plankton.

(a) Remarks on the Table 1 and Table 2. In these tables were shown many spherical and elliptical bodies which sometimes contain some lower forms of *Cyanophyceae* and *Chlorophyceae*. But the state of their cells was so defective that the identification was impossible. Among them, however, there were many tiny spherical bodies which are thought, in all probability, to be a young form of *Trachelomonas* sp. (Pl. 1). As is well known *Trachelomonas* is a bottom form and is found in plenty in the bottom fauna of lakes. As this species never appears in lake plankton the presence of this in food material is also a testimony of their being bottom feeders.

(b) Remarks on Fig. 2. Fig. 2 shows the content of alimentary canal of *Diaptomus* and *Daphnia*, in which are contained: *Diatom* and its fragments (B-23, B-29, J-3), *Dinobryon* (A-19, B-17), *Chroococcus* (A-5, E-3, E-4, G-5), *Merismopedia* (C-3, D-9)

Fig. 2. Content of alimentary canal of *Diaptomus* and *Daphnia*.

Diaptomus: (A) 1-13, 19, 20 (May 26, 1957); (B) 1-13 (June 19, 1957); (C) 1-18 (July 10, 1957); (D) 1-6 (July 20, 1957); (E) 1, 2 (Aug. 3, 1957); (F) 2-7 (Aug. 20, 1957); (G) 1-8 (Sept. 30, 1956); (H) 1-4 (Oct. 28, 1955); (I) 1 (Nov. 24, 1957); (J) 5, 6 (Dec. 14, 1957).

Daphnia: (A) 14-18 (May 26, 1957); (B) 14-30 (June 19, 1957); (D) 7-14 (July 20, 1957); (E) 3-5 (Aug. 3, 1957); (F) 1 (Aug. 20, 1957); (G) 9-13 (Sept. 30, 1956); (H) 5, 6 (Oct. 28, 1955); (I) 2-4 (Nov. 24, 1957); (J) 1-4 (Dec. 14, 1957).

and a similar *Cyanophyceae* (A-6, B-26, B-30, D-8, G-4, G-6); smashed appendages of Insects (C-10, D-10, F-1, F-3, F-5, G-10, G-12, G-13, I-1, I-3, J-5, J-6) and empty egg skin of *Diaptomus* eggs (A-15, A-16, A-17, A-12, C-14, D-1).

Summary

(1) The contents of the alimentary canal of *Diaptomus* and *Daphnia* collected from Lake Shirakoma were microscopically observed. The inquiry was of interest because the lake was quite destitute of phytoplankton, and therefore what might be the food stuff of these species was curious and important.

(2) The food of *Diaptomus* and *Daphnia* of this lake consists exclusively of bottom materials which, as a matter of course, contain bottom organisms such as lower *Cyano-phyceae*, *Diatoms*, etc. Remarkable was the fact that little or no plankton organisms were found in the alimentary canal of these species.

(3) The food of *Diaptomus* and *Daphnia* was all the same in its constituents. The quantity, however, seemed to be a little more in *Daphnia* than in *Diaptomus*.

(4) As to the size of food particle it was found that the size taken by *Daphnia* is markedly larger (maximum length-311 μ) than that taken by *Diaptomus* (maximum length-238 μ).

However, the mean size of food particle was 50 μ or thereabout, a size exceeding 100 μ (in length) was very rare.

(5) The finding that *Diaptomus* and *Daphnia* largely feed on bottom materials, at least in Lake Shirakoma, suggests the possibility of bottom materials being the cause of the vertical migration of these two species.

References

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Explanation of Plate (I)

- Fig. 1. Lake Sirakoma, the south-easterly side.
- Fig. 2. Alimentary canal of *Diaptomus*. ($\times 115$).
- Fig. 3. Alimentary canal of *Daphnia*. ($\times 100$).
- Fig. 4. *Chroococcus* sp. in alimentary canal. (10.8 μ).
- Fig. 5. *Trachelomonas* sp. (indivision) (Maximum diameter, 10.3 μ).
- Fig. 6. *Merismopedia* sp. (Length 4.0 μ).
- Fig. 7. *Dinoflagellata* ? (Length 9.7 μ).
- Fig. 8. *Dinobryon* sp. (Length 41.2 μ).
- Fig. 9. *Chroococcus* sp. (Length 13.8 μ).
- Fig. 10. Small masses of deposit. ($\times 100$).
- Fig. 11. ditto, smashed. ($\times 700$).
- Fig. 12. *Trachelomonas* sp. (indivision) (Maximum diameter, 10.3 μ).
- Fig. 13. *Trachelomonas* sp. (14.8 μ in diameter).

Plate I.