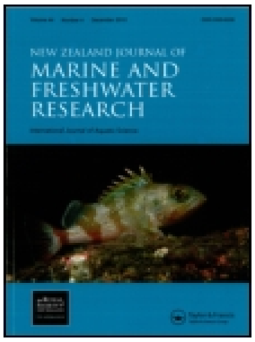

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PLANKTON OF LAKE OTOTOA, A SAND-DUNE LAKE IN NORTHERN NEW ZEALAND

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ABSTRACT

The seasonal cycles of abundance of the phytoplankton and zooplankton in Lake Ototoa, Northland, at 36° 31′ S, 174° 14′ E, are described. Concentrations of chlorophyll *a* were low (range 0.04–4.61 $mg.m^{-3}$; mean 0.97 $mg.m^{-3}$), and highest values were in winter. Phytoplankton densities were also low; an oligotrophic diatom-desmid assemblage associated with *Botryococcus, Dinobryon,* and *Sphaerocystis* was found.

The zooplankton was dominated by the calanoid copepod *Calamoecia lucasi* whose numbers remained fairly constant throughout the year, and the only other copepod found was the cyclopoid *Mesocyclops leuckarti* which was present in very low numbers. *Bosmina meridionalis* was the only limnetic cladoceran and was most abundant during autumn and spring. A number of rotifer species were also common.

INTRODUCTION

Lake Ototoa lies at 36° 31′ S and 174° 14′ E on the south head of the Kaipara harbour, in Northland, New Zealand, and is one of the extensive series of sand-dune lakes found along the western coastline of the North Island. Most of these lakes have been formed by the blocking of stream valleys by wind blown sand, and are relatively small and shallow compared with the major New Zealand lakes. Lake Ototoa, with a surface area of $1.623 \times 10^6\ m^2$ and a maximum depth of 26 m is the largest and deepest of them. Green (1975), who has described its morphometry and physio-chemical characteristics, found it to be an oligotrophic, warm monomictic lake. In the present paper the composition and overall cycles of abundance of the phytoplankton and zooplankton in Lake Ototoa between March 1969 and March 1970 are considered, and related to the present trophic status of the lake.

METHODS

Sampling visits were generally made weekly, although on a few occasions the interval was 3–4 weeks. Between 10 March 1969 and 28 April 1969 samples were taken from one station only (B) centrally located in one of the deepest areas of the lake. However after this two more stations (A and C) were established at the south and north ends of the lake respectively (see map in Green 1975).

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One-litre samples for phytoplankton counts were taken with a reversing Nansen bottle at a depth of 1 m from station B between 17 March 1969 and 21 April 1969, from stations A and C between 5 May and 11 August, and after this from all stations. No counts were made of phytoplankton during the last 3 weeks of June because of accidental destruction of the samples.

The membrane filter technique of De Noyelles (1968), modified according to information supplied by the Millipore Corporation (A.R. 81) to give permanent mounts, was used for phytoplankton counts. Samples were preserved in Lugols iodine-acetic acid (Willén 1959) immediately after collection, and stained for 24 hours with analine blue and Eosin-Y stock solutions, each containing 0.7 g stain per 50 ml of water; 6 drops of each were used per 100 ml of sample. After staining, phytoplankton (in 2 or 5 ml of water from each station) was filtered off using a Swinny filter holder and a 13 mm HA Millipore filter (0.45 μm pore size). The filter circle was then removed, its underside blotted dry with filter paper, and dehydrated in iso-propanol after a few minutes of air drying. After dehydration the filter was cleared in xylol and mounted in Canada balsam. The whole filter surface was examined and the algal cells, which totalled between 500 and 1300, were counted. To aid counting, the filter was divided into four by etching lines on the surface of the coverslip.

As only one phytoplankton sample was examined from each station, its representativeness is unknown. However, the technique shows good replicability, since in two lots of 5 replicate samples from Lakes Rotoroa (Hamilton) and Koutu (Cambridge), containing similar concentrations of cells to samples from Ototoa, inter sample variability was low (coefficient of variation 10–30%).

Samples for chlorophyll analysis were taken at weekly intervals from a depth of 1 m at each station. The samples were kept cool and away from the light, and were analysed immediately on returning from the field using the methods of Richards & Thompson (1952). Generally 3–5 litres was filtered, using a type AA Millipore filter (0.8 μm pore size). Concentrations of chlorophyll *a* were determined according to Talling & Driver (1963).

The zooplankton was sampled by a vertical net haul with a Nansen type net from just above the bottom to the surface at each station. The mouth of the net was 20 cm in diameter and behind this was a 30 cm canvas band attached to a 28-cm-long cylinder of 13 xx (100 μm mesh size) nylon bolting cloth, which was followed by a 40-cm-long cone-shaped section fixed to a 10-cm-diameter bucket. Care was taken always to ensure a slow and steady net haul, and the catches were washed carefully from the bucket and net into jars and preserved immediately with formalin.

The plankton sample was made up to a known volume in a 1 litre measuring cylinder and, after thorough mixing by inversion, a 5 ml subsample was withdrawn. This was transferred into a squared perspex counting tray mounted on the moving stage of a stereomicroscope and counted using a magnification of × 32.5. The representativeness of each zooplankton sample was estimated by counting a set of eight replicate net hauls made on 17 February 1970. Replicability was good, the coefficient of variation of total zooplankton numbers being 6.1% and ranging from 6.2% to 43.3% for the individual species.

In this paper numbers of zooplankton refer to "numbers per standard sample". Early in the study when only station B was sampled these are the numbers found in the one sample taken. For the remainder of the time when three stations were used, this figure has been arrived at by averaging the numbers in the samples taken from all three stations. The numbers per sample used in this study are fully comparable with those of Chapman (1972a) who used a net of identical design in her studies of the zooplankton in Lakes Rotorua and Rotoiti. If it is assumed that the net was 100% efficient, numbers per sample may be converted to numbers under 1 m^2 by multiplying by 31.8 and to numbers per m^3 by multiplying by 1.77.

PHYTOPLANKTON

Few studies have been made of the seasonal cycles of phytoplankton in New Zealand lakes, and of them most have been concerned only with the larger diatoms, desmids, and dinoflagellates (e.g., Flint 1938, Stevenson 1952, Cassie 1969, Fish 1975). Changes in the numbers of the nannoplankton have been recorded only rarely (e.g., Green 1974, Burns & Mitchell 1974) but in this study particular attention was paid to these smaller species because of their possible significance as food for the zooplankton. The following discussion is thus concerned mainly with overall seasonal changes in abundance, and the possible causes underlying these changes are not considered in any great detail.

Various collections (21 April 1969, 14 July 1969, 24 November 1969, 29 December 1969, 27 January 1970, and 17 February 1970) were kindly examined by Drs E. A. Flint and U. V. Cassie, who identified the main types present. These are listed in Table 1. In order to determine total phytoplankton volumes, the dimensions of 10–20 individuals of the commonest species were measured at a magnification of ×800 using an eyepiece micrometer, and their average volumes were calculated from formulae of volumes of geometrical shapes most closely resembling the species (Table 2).

CHLOROPHYLL *a*

Concentrations of chlorophyll *a* throughout the sampling period are plotted in Fig. 1. These are the average values obtained from the stations sampled on any one date.

Chlorophyll *a* concentrations ranged between 0.04 and 4.61 $mg.m^{-3}$. Maximum concentrations were found during mid winter (in late

TABLE 1—List of planktonic algae taken from Lake Ototoa between March 1969 and March 1970

CHLOROPHYCEAE

Ankistrodesmus falcatus (Corda) Ralfs
Ankistrodesmus sp.
Botryococcus braunii Ktz.
Coelastrum reticulatum (Daug) Sena.
Cosmarium sp. a
Cosmarium sp. b
Dictyosphaerium sp.
Gonatozygon sp.
Nephrocytium lunatum W. West
Oocystis sp.
Sphaerocystis sp.
Staurastrum avicula? De Bréb
S. chaetoceras? (Schroder) G. M. Smith
S. smithii? facies *triradiatum*
S. sagittarium Nordst.
S. planktonicum? Teiling.

BACILLARIOPHYCEAE

Cyclotella stelligera Cl. & Grun
Melosira sp. (*islandica* O.M.?)
Rhizosolenia eriensie H. L. Smith.
Synedra sp.
Tabellaria flocculosa (Roth) Ktz.

DINOPHYCEAE

Ceratium hirundinella (O.F.M.) Schrank.
Glenodinium sp.
Gynodinium sp.
Peridinium sp.

CHRYSOPHYCEAE

Dinobryon divergens Imhof.
D. sertularia Ehr.

CRYPTOPHYCEAE

Cryptomonas sp.
Cryptomonas? ("small monad")

CYANOPHYCEAE

Chroococcus limneticus Lemm var?

TABLE 2—Average sizes of planktonic algae from Lake Ototoa. The figures given are the means of 10–20 individual measurements (– = not applicable)

ALGA	CELL SIZE Length or Width (μm)	Breadth or Depth (μm)	CELL VOLUME (μm^3)	COLONY SIZE Length (μm)	Breadth (μm)
Cyclotella	8.5	3.4	190	–	–
Melosira	18.1	11.3	1800	–	–
Other Diatoms	27.3	7.0	1050	–	–
Rhizosolenia	40.3	8.0	2000	–	–
Cosmariun	15.8	9.8	1600	19.8	16.0
Staurastrum	7.8	3.0	70	7.8	7.5
Gymnodinium	9.8	8.3	350	–	–
Glenodinium	8.0	7.3	220	–	–
Cryptomonas	18.5	10.5	1000	–	–
Small Monad	7.6	3.2	40	–	–
Dinobryon	33.3	8.8	1350	–	–
Botryococcus cells	11.5	3.8	90	178	95
Sphaerocystis	3.5	3.5	20	20.2	20.2
Coelastrum	5.0	5.0	65	23.8	23.8
Oocystis	8.3	4.5	90	13.3	7.8
Ankistrodesmus	13.3	2.2	30	37.5	2.2
Nephrocytium	5.0	3.0	20	11.8	6.2
Unidentified unicells	4.3	4.3	40	–	–
Chroococcus	5.0	5.0	65	17.3	12.5

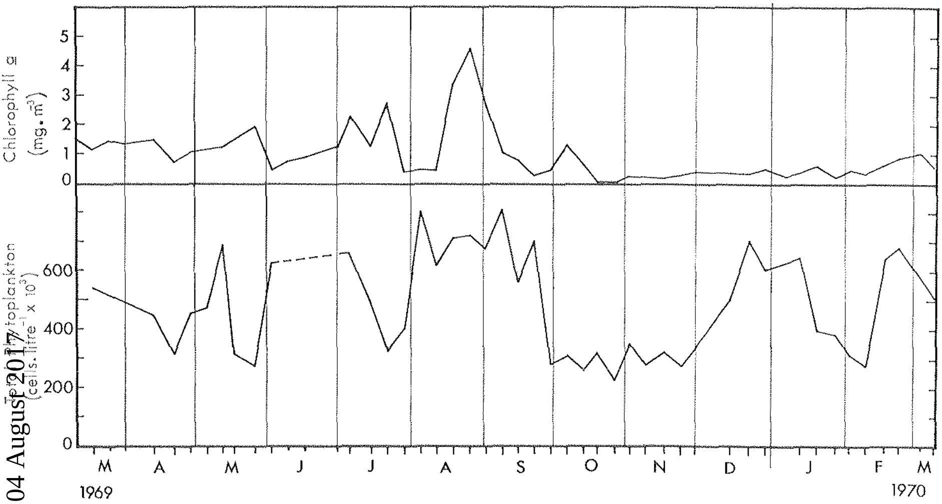

Fig. 1—Seasonal changes in concentration of chlorophyll *a* and total numbers of phytoplankton in Lake Ototoa, North Island, New Zealand. Sampling depth 1 m.

August) and resulted from large increases in numbers of *Dinobryon* (see later), and the lowest values were recorded in October.

In Lakes Rotorua and Rotoiti, Fish (1973) found highest chlorophyll concentrations in late autumn and winter, with generally lower values in the spring and summer. This was found also in Ototoa and contrasts with the cycles found by Mitchell (1971) in Lakes Waipori and Mahinerangi and Tomahawk Lagoon and Barker (1970) in Lake Pupuke. In these lakes, concentrations were low in mid winter and highest in late summer and early autumn, as they are in many lakes in other parts of the world (Hutchinson 1967).

TOTAL NUMBERS AND VOLUME OF PHYTOPLANKTON

The numbers of cells per litre plotted in Fig. 1 are the average numbers from all stations sampled on any one date.

Total phytoplankton numbers ranged between 200 and 800 × 10^3 cells per litre. Between March and July 1969 numbers were variable, with minima in late April, late May, and late July. In August and early September (late winter and early spring) total numbers were high (600–800 × 10^3 cells per litre). Numbers fell in September, and during much of the spring (October and November) the standing stock was almost constantly low at about 300 × 10^3 cells per litre. A midsummer peak occurred in late December and early January, and, after a decline in late January and early February, a further peak developed in late February and March.

Total volumes of phytoplankton (Fig. 2) showed similar trends, although the relative seasonal variation (0.030–0.417 $mm^3 \cdot litre^{-1}$) was rather greater. The Bacillariophyceae and Chrysophyceae made up the major proportions of the total algal volume throughout the year, the former being dominant in autumn and winter, the latter becoming important in late winter, spring, and summer. The other major taxonomic groups were less significant. The Chlorophyceae were important in mid summer, the Dinophyceae and Cryptophyceae in spring and early summer, and the Myxophyceae were found only in late summer and contributed only a small percentage to the total volume.

Similar changes in total numbers have been found by Cassie (1969) and G. R. Fish (Fisheries Research Division, MAF, Rotorua, pers. comm.) in Lakes Rotorua and Rotoiti. However, in these lakes the changes in numbers are much greater than in Lake Ototoa, and there is often a steady decline over the spring from high winter concentrations, and summer increases may be absent. In Lakes Hayes and Johnson (Burns & Mitchell 1974), standing crops of algae were always low in winter and increased in the spring and summer.

SEASONAL CYCLES

Apart from the macroscopic colonies of *Botryococcus braunii*, the species most characteristic of the phytoplankton of Lake Ototoa was the centric diatom *Cyclotella stelligera*, which was numerically dominant for most of the year. After decreasing in numbers between March and May 1969, it increased to maximal densities during mid winter. Numbers gradually dropped during the spring, and there were smaller increases in December 1969 and February 1970. The cycle of abundance exhibited by *Cyclotella* (Fig. 3) appears to be inversely related to that of the temperature (Green 1975). This may imply a preference for cooler waters, although the decrease during March and May 1969 and the increases during the summer do not support this. It is possible, however, that turbulence is necessary to keep cells of *Cyclotella* in suspension (Hutchinson 1967) and that the decreases in numbers in spring and summer result from settling out during the period of temperature stratification when the vertical component of turbulence is reduced. Species of *Cyclotella* are often found in unproductive lakes (e.g., Grasmere, see Stout 1969).

The desmids found in Lake Ototoa were two unidentified species of *Cosmarium* and four species of *Staurastrum*. *Staurastrum chaetoceras* and *S. sagittarium* were found very rarely, and Dr E. A. Flint (Ecology Division, DSIR, pers. comm.) notes that it is unusual to find the former species in an oligotrophic lake, but that it is very common in the eutrophic lakes of the Rotorua area. The most common desmids were the small *S. planktonicum* and *S. smithii*, which were responsible for the greater part of the changes in stock of *Staurastrum* shown in Fig. 3. As found elsewhere (Hutchinson 1967), *Staurastrum* is a summer form and in Ototoa it exhibited peaks in early December, January, and also further increases in February and March, when *S. chaetoceras* was more abundant. Throughout the rest of the sampling period numbers were low, especially during spring and autumn.

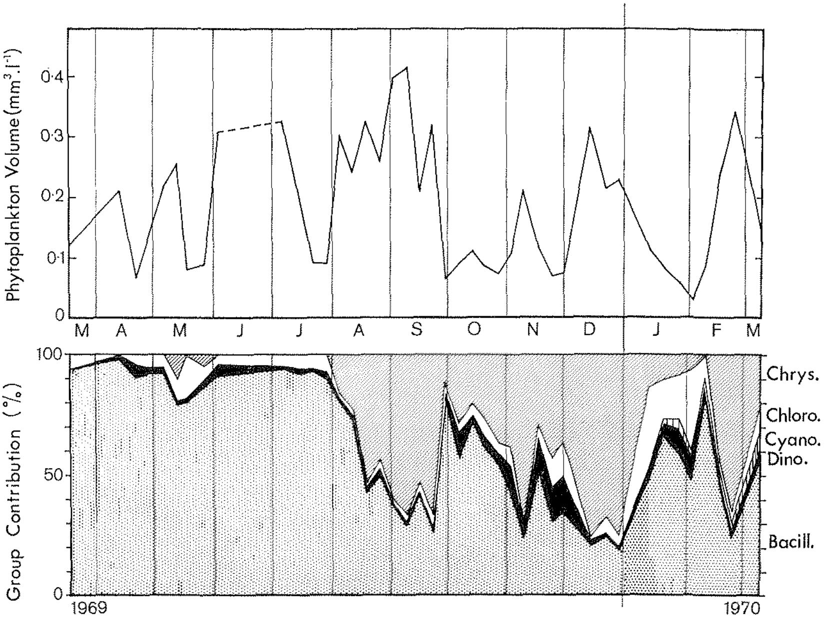

FIG. 2—Seasonal changes in total phytoplankton volume in Lake Ototoa, and the percentage contributions made by the major algal groups (Chrys. = Chrysophyceae, Chloro = Chlorophyceae, Cyano. = Cyanophyceae, Dino. = Dinophyceae and Cryptophyceae, Bacill. = Bacillariophyceae). Sampling depth 1 m.

Cosmarium was found in low, fairly constant densities during autumn, winter, and early spring, and declined to lower levels later in the spring. Numbers increased again in the summer, and during late February and March 1970 there were marked increases to densities about twice those during the rest of the sampling period.

The two commonest dinoflagellates were *Gymnodinium* sp. and *Glenodinium* sp., although very small numbers of *Peridinium* sp. and *Ceratium hirundinella* were also found on occasions. *Gymnodinium* was most common in late spring and early summer, when it was one of the most conspicuous members of the flora. After declining in numbers in December and January, it increased again at the end of the sampling period. Small numbers were also present during winter and early spring. *Glenodinium* was found in fluctuating numbers over the whole of the summer period, and in December, January, and February was the most common dinoflagellate. It also occurred in small numbers during the autumn of 1969. Dinoflagellates are allo-auxotrophic, requiring accessory organic substances for successful growth, and during November in Lake Ototoa there were increases in dissolved organic matter (Green 1975) which may have been associated with the increases in abundance of *Gymnodinium* and *Glenodinium*.

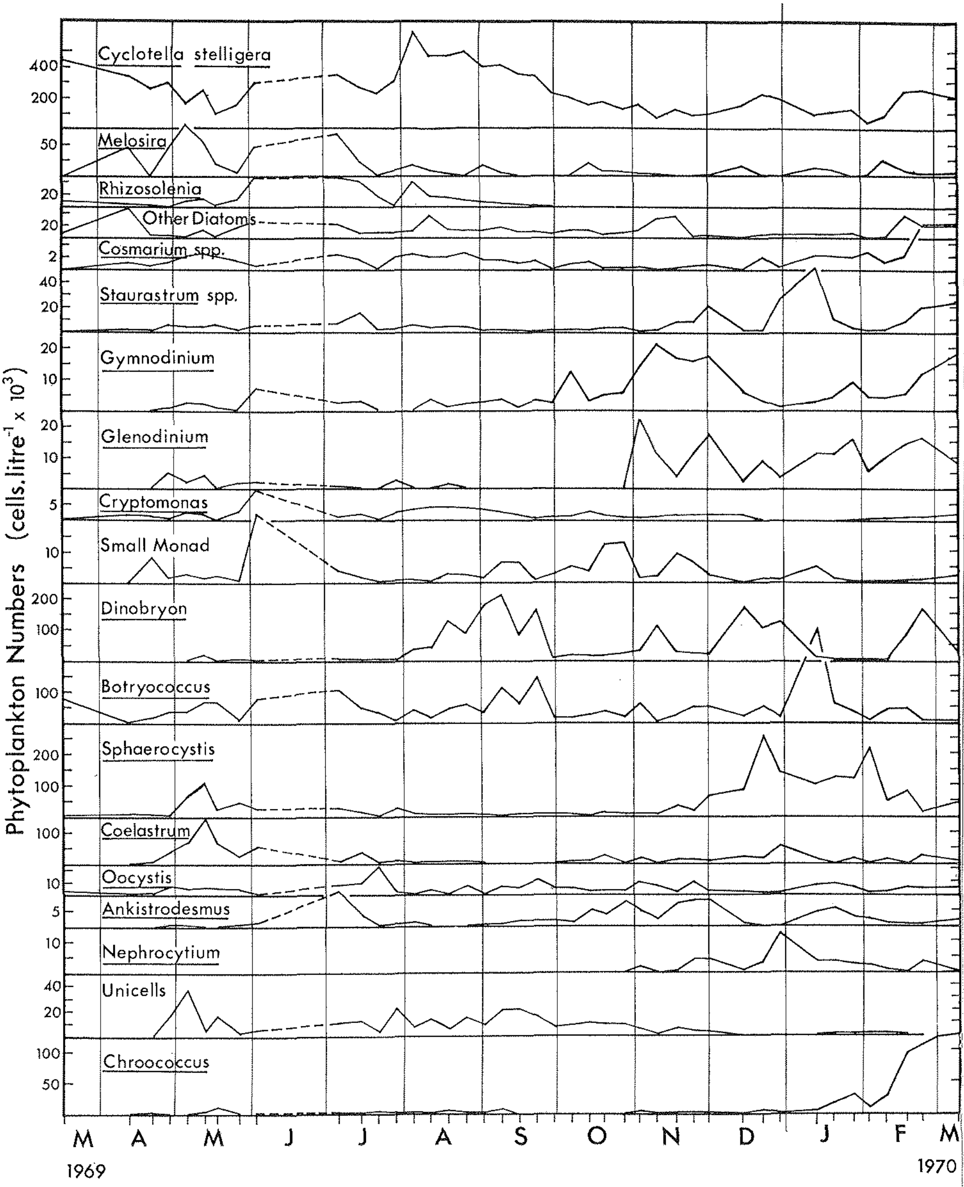

FIG. 3—Seasonal changes in numbers of individual phytoplankton species in Lake Ototoa. Sampling depth 1 m

Cryptomonas, although found in greatest abundance in late autumn, was present in rather constantly low numbers during most of the sampling period, except for a period of absence in late December and early January. Another small monad (probably a small *Cryptomonas*: Dr E. A. Flint, Ecology Division, DSIR, pers. comm.) was also most abundant in late autumn, but during the spring months it underwent a number of increases and was a conspicuous member of the phytoplankton, at times when total phytoplankton numbers were generally low.

Dinobryon spp. had three main periods of abundance. The principal one during late August and September was responsible for the main peak in chlorophyll *a* concentrations and, with increases in cells of *Botryococcus braunii* and *Cyclotella*, caused the maxima in total phytoplankton numbers during August and September. Further major increases in numbers of *Dinobryon* occurred in December and February, and there was a smaller increase in early November. In the Wellington reservoirs (Stevenson 1952) and in the Auxiliary Nihotupu reservoir in the Waitakere ranges west of Auckland, (Green 1974), *Dinobryon* was found to occur at similar times. In lakes overseas, *Dinobryon divergens* is known to increase at times of low phosphate concentrations (below 5 μg.litre^{-1}) which may occur following periods of diatom abundance in spring. Flint (1938) believed that such a relationship did not explain the periodicity of *Dinobryon* in Lake Sarah, in the South Island of New Zealand. In Lake Ototoa the main increase of *Dinobryon* in August and September did follow the main period of diatom abundance, which was between May and August 1969, but unfortunately no determinations of phosphate concentrations were made before September (Green 1975). The concentration of soluble phosphate in September was 5.95 μg.litre^{-1}, and dropped to 1.00 μg.litre^{-1} in October, when, however, *Dinobryon* numbers had also decreased. Between November 1969 and February 1970 phosphate concentrations were constantly below 5 μg.litre^{-1}, yet numbers of *Dinobryon* first increased and then declined. Thus, as in Lake Sarah, changes in phosphate concentration were probably not the main determinants of the seasonal cycle of *Dinobryon* in Lake Ototoa, at least in summer.

Colonies of *Botryococcus braunii* were always obvious in the water of Lake Ototoa, but were found only rarely on the filters during counting. The numbers plotted in Fig. 3 are those of free cells which were always present, but it is not known whether these counts reflect the true abundance of free cells in the lake water. Conceivably such cells could have become detached from the colonies after the sample had been fixed in Lugol's iodine following collection.

Sphaerocystis was mainly a summer form, although there was a small increase in May, and small numbers were present during winter and spring. During January and February the mucous sheaths surrounding the colonies contained bacterial cells orientated at right angles to the colony surface and such infestation is thought to be characteristic of a declining population (Dr E. A. Flint, Ecology Division, DSIR, pers. comm.). *Coelastrum* was most abundant in May, but was also found in smaller numbers in spring and summer. *Oocystis* occurred in small numbers throughout the whole of the sampling period, but *Nephrocytium* was found only in the summer, with peak abundance in late December–early January. *Ankistrodesmus* had three periods of abundance: July, October and November, and January. An unidentified unicell was moderately common between autumn and spring, but disappeared during the warmer part of the summer.

The only myxophycean recorded was *Chroococcus limneticus*, and, apart from some isolated occurrences in 1969, it was found only in late summer and early autumn (during February and March), when it underwent a large increase. This seasonal cycle is typical of blue-green algae, which are almost invariably found in abundance at the end of summer in association with increases in dissolved organic matter and lowered nutrient levels (Hutchinson 1967).

Cunningham *et al.* (1953) did not make any quantitative counts of the phytoplankton of Lake Ototoa during their 1952 survey. However, in a similar sand-dune lake near Wellington (Lake Kopureherehe), they found a phytoplankton assemblage similar to that reported from Lake Ototoa in this study, although in Kopureherehe the concentrations were a little lower.

Following the classification of phytoplankton associations advocated by Hutchinson (1967), the phytoplankton of Lake Ototoa would appear to exhibit features of types 1–4, i.e., an oligotrophic diatom (*Cyclotella, Rhizosolenia*)-desmid (*Staurastrum*) plankton, associated with *Botryococcus braunii, Dinobryon,* and *Sphaerocystis.*

ZOOPLANKTON

The zooplankton of Lake Ototoa was dominated by the small centropagid calanoid copepod *Calamoecia lucasi* Brady, which is widely distributed throughout the north of New Zealand and eastern Australia (Timms 1970, author's unpublished data). The cosmopolitan cyclopoid copepod *Mesocyclops leuckarti* Claus was found in very small numbers, and the only limnetic cladoceran was *Bosmina meridionalis* Sars. The other common New Zealand limnetic cladoceran *Ceriodaphnia dubia* Richard was absent, as it is from other New Zealand coastal lakes of high alkalinity. The Rotatoria were represented by *Asplanchna priodonta* Gosse, *Conochiloides coenobasis* Skorikow, *Filinia terminalis* Plate, *Synchaeta* sp., and *Hexarthra* sp.

TOTAL NUMBERS OF ZOOPLANKTON

In late March and April, i.e., during the autumn of 1969, there were two large peaks in total numbers of zooplankton, after which numbers declined considerably in May (Fig. 4); similar autumnal falls in zooplankton numbers have been reported from Lakes Rotorua and Rotoiti

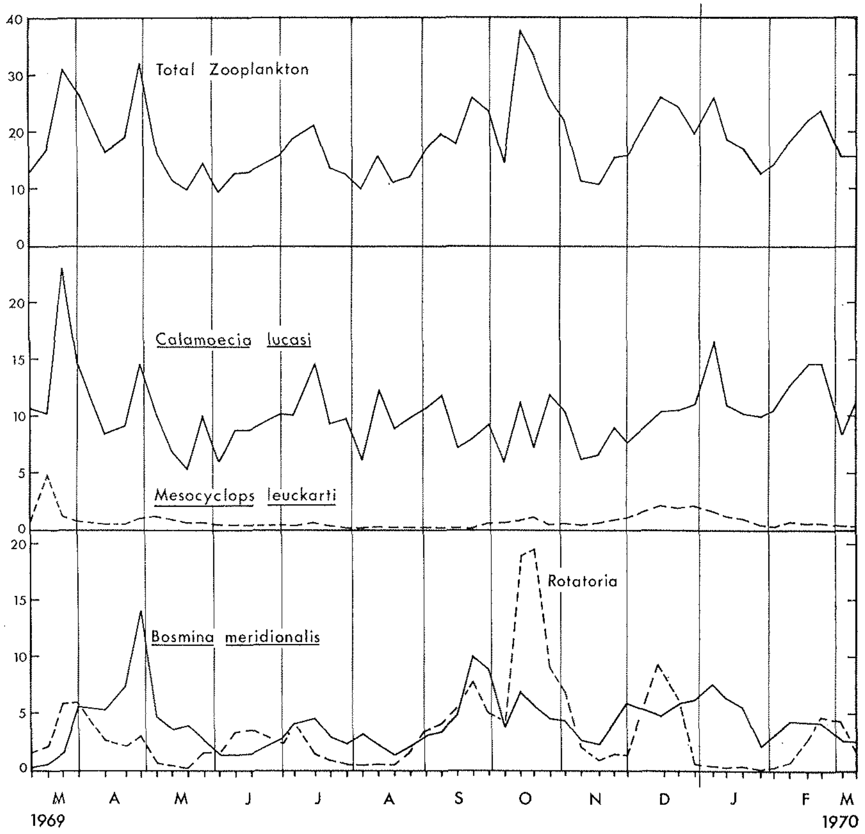

FIG. 4—Seasonal changes in total numbers of zooplankton in Lake Ototoa, and in standing stocks of major groups.

(Chapman 1972a). Numbers gradually increased to an early winter peak in July, after which they fell again to lower values in mid winter. During September and October there was a large spring outburst, caused mainly by increasing numbers of *Bosmina* and rotifers, followed by a decline in November. During the summer, numbers again increased, and there were peaks in December, January, and February. In spite of these variations, total numbers were rather constant compared with those in other New Zealand lakes for which data are available (Barker 1968, Chapman 1972a, Green 1974).

INDIVIDUAL SPECIES

Calamoecia lucasi: The biology of this copepod will be considered in detail in another paper and its seasonal cycle will only be treated in outline here.

Total numbers of *Calamoecia lucasi* showed little change over the sampling period, and many of the minor rises and falls in Fig. 4 may have resulted partly from sampling variability. The standing stock was highest during the summer of 1970 (between December 1969 and March 1970) and during early autumn 1969. From March to May 1969 numbers declined following two major peaks of abundance (in late March and late April) and during the rest of the year numbers fluctuated around a mean level of about 7000–8000 per sample. While the mean population size in Lake Ototoa ($\bar{x} = 10\,163$, $V = 31\%$) was much lower and more constant than in Lakes Rotorua ($\bar{x} = 18\,228$, $V = 50\%$) and Rotoiti ($\bar{x} = 25\,062$, $V = 39\%$) (Chapman 1972a), the broad patterns of seasonal change, with high summer and autumn and low winter numbers, were similar in all three lakes.

Mesocyclops leuckarti: The stock of *M. leuckarti* was much lower than that of *Calamoecia* at all times (Fig. 4). Numbers were greatest during the autumn of 1969 and the early summer of 1969–70. This pattern of low winter and high summer numbers of *M. leuckarti* is generally similar to that found in other New Zealand lakes, although somewhat different in detail. In Lake Pupuke, Barker (unpublished 1967) found that numbers of *M. leuckarti* increased in early August, declined, and then increased again in September. Standing stocks then returned to low levels until a further increase occurred in February and March, followed by a decline to low winter values. Green (1974) found similar patterns in the Auxiliary Nihotupu reservoir, and suggested that in northern New Zealand the seasonal cycle of *M. leuckarti* is like that found by Ravera (1954) in Lago Maggiore where *M. leuckarti* breeds mainly in the spring and summer, but is present throughout the year, with continuing slow development in the winter. Such a cycle contrasts with those found in lakes further north in Europe, where breeding occurs only for two generations in the summer. The development of the second generation ceases at either copepodite IV or V which then either go into a state of diapause in the bottom mud or over-winter in the plankton without further development until the following spring (e.g. in Loch Lomond, Chapman 1972b). In Lake Ototoa breeding probably occurred throughout the year, because even though ovigerous females were only very rarely found, cyclopoid nauplii were always present in the samples.

Bosmina meridionalis: This was the only limnetic cladoceran found in Lake Ototoa during this study. There was a large autumnal increase in the population between March and early May (Fig. 4), and numbers dropped to lower levels during the winter, although there was a slight midwinter increase during July. A large spring increase followed in September, and, after a gradual decline in October and November, there was a summer increase in December and January. For the rest of the sampling period, numbers were a little lower.

The cycle observed in Ototoa is generally similar to that found by Chapman (1972a) in Lakes Rotorua and Rotoiti. However, in these and in other lakes in the North Island of New Zealand, *Bosmina* co-occurs with *Ceriodaphnia dubia,* which often increases markedly in late spring

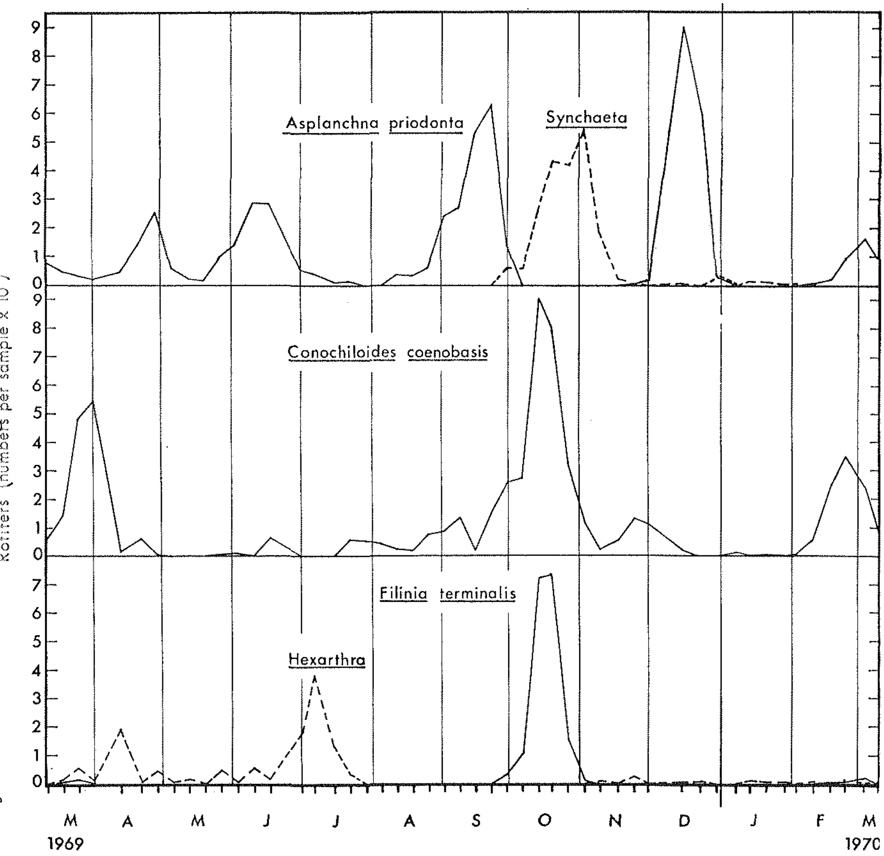

FIG. 5—Seasonal changes in standing stocks of rotifer species in Lake Ototoa.

or summer and which may replace *Bosmina* for a time; *Bosmina* either disappears from the plankton or is present in much reduced numbers (Green 1974, Chapman 1972a). In Lake Ototoa the absence of a potentially competitive *Ceriodaphnia* population may be one of the reasons why *Bosmina* maintained a moderately large population during the summer. The maximum size of particle ingested by *Bosmina* is known to be smaller than that of other Cladocera (Burns 1968), and it is probably a bacterial and detrital feeder. Such material would be in high concentration from late spring to autumn. The period of maximum abundance of *Bosmina* also corresponded with times of occurrence of many small green algae, small monads, and the dinoflagellates, some of which may have served as food.

Rotatoria: Rotifers (Fig. 5) were found in greatest abundance during the spring, but there were also smaller peaks in March, June, December, and February.

Asplanchna priodonta had two major periods of abundance during early spring (September), and in summer (December) (Fig. 5). Two other smaller peaks occurred in late April and June, and during the rest of the year it was either absent or present in only very low numbers. Such spasmodic, large increases are characteristic of *Asplanchna*, and the cycle of *A. priodonta* in Lake Ototoa is similar to that observed in Lakes Rotorua and Rotoiti (Chapman 1972a). It may be significant that its periods of maximum abundance either closely followed or coincided with periods of abundance of *Dinobryon* since *Asplanchna* is raptorial and can feed on such relatively large algae.

Species of *Synchaeta*, another small raptorial genus, are often most common during spring and summer. In Ototoa, *Synchaeta* sp. showed one pronounced period of abundance in the spring and was absent for the rest of the year, except for December and January, when small numbers were found. Elsewhere in New Zealand, species of *Synchaeta* develop during spring and summer in a similar manner (Byars 1960, Barker unpublished 1967, Green 1974).

Conochiloides coenobasis was present in only small numbers during summer and winter, but it became much more prominent in autumn and especially during spring, in October. *Conochiloides* is thought to feed on particles smaller than 12 μm (Hutchinson 1967), and algae of this size were becoming more abundant in Lake Ototoa during the spring. In New Zealand, *Conochiloides* has been recorded by Byars (1960) from a pond in Otago, where it was most abundant in summer, and by Green (1974) from the Auxiliary Nihotupu reservoir in Auckland, where its cycle was similar to that in Lake Ototoa, with maximum abundance in the spring. *Conochiloides* is also a spring form in South Africa (Hutchinson 1967). *Filinia terminalis*, another species which probably feeds on particles smaller than 12 μm, also increased markedly in October and was not found during the rest of the year, apart from a few occurrences during March of both 1969 and 1970.

The only other rotifer found was a species of *Hexarthra* which occurred sporadically in very low numbers during the summer, but was most abundant during late autumn and early winter of 1969, especially in July, when it was the dominant rotifer. A noticeable feature of the rotifer fauna of Lake Ototoa was the absence of species of *Keratella* which are generally considered characteristic of the temperate region and which are abundant in other New Zealand lakes, e.g., Pupuke (Barker unpublished 1967).

DISCUSSION

From physio-chemical characteristics, Green (1975) concluded that Lake Ototoa was oligotrophic. This is also shown by an examination of the plankton. Thus Lake Ototoa has a typical oligotrophic diatom-desmid phytoplankton and has lower concentrations and less pronounced seasonal variation of chlorophyll *a* than most New Zealand lakes. For

TABLE 3—Comparison of maximum algal numbers in Lake Ototoa with those of other New Zealand lakes

LAKE	MAXIMUM ALGAL DENSITY (cells.ml^{-1})	TROPHIC STATUS
Sarah		
Apr 1934–Feb 1936 (Flint 1938)	10.4 (Nov 1935)	Oligotrophic
Auxiliary Nihotupu		
Dec 1967–Sept 1968 (Green 1974)	80 (Aug 1968)	Oligotrophic
Rotoiti		
Jan–May 1967 (Cassie 1969)	708 (May 1967)	Mesotrophic-eutrophic
Ototoa		
(present study)	800 (Sept 1969)	Oligotrophic
Rotorua		
May 1966–May 1967 (Cassie 1969)	4550 (Feb 1967)	Eutrophic
Hayes		
Dec 1969–Feb 1972 (Burns and Mitchell 1974)	58 500 (Dec 1971)	Eutrophic
Johnson		
Dec 1969–Feb 1972 (Burns and Mitchell 1974)	96 600 (Dec 1970)	Highly Eutrophic

example, compared with the range of 0.039–4.61 mg.m^{-3} in Ototoa, Stout (1969) found 0.22–8.88 mg.m^{-3} in Canterbury mountain lakes, Barker (1970) about 2–145 mg.m^{-3} in Lake Pupuke, Mitchell (1971) 1–60 mg.m^{-3} in Tomahawk Lagoon and 1.75–14.4 mg.m^{-3} in Lakes Waipori and Mahinerangi, McColl (1972) 1.1–16.5 mg.m^{-3} in seven lakes in the central North Island, and Green (1974) 0.43–3.93 mg.m^{-3} in the Auxiliary Nihotupu reservoir.

The only other published quantitative studies made of phytoplankton numbers in New Zealand lakes are those of Flint (1938) on Lake Sarah, Cassie (1969) on Lakes Rotorua and Rotoiti, Green (1974) on the Auxiliary Nihotupu reservoir, and Burns & Mitchell (1974) on Lakes Hayes and Johnson. On the basis of maximum cell numbers, only Lake Sarah and the Auxiliary Nihotupu reservoir are less productive than Lake Ototoa (Table 3).

Another index which can be used to estimate trophic status is the maximum volume of phytoplankton which develops in a lake during the year (Vollenweider 1970): oligotrophic lakes having less than 1 mm^3.litre^{-1}, and eutrophic lakes having more than 3–5 mm^3.litre^{-1}. The volume in Lake Ototoa was always much less than 1 mm^3.litre^{-1} (mean 0.18 mm^3.litre^{-1}) in contrast with the two eutrophic Otago lakes, Johnson and Hayes, which had mean algal volumes of 3.80 and 13.64 mm^3.litre^{-1} respectively (Burns & Mitchell 1974).

The composition of the zooplankton in New Zealand lakes is generally not a good indication of trophic status, because the same species may be found in both oligotrophic and highly eutrophic habitats (e.g. Chapman *et al.* 1975). However, the total density of the zooplankton and the subdued seasonal variation in numbers compared with other North Island lakes (e.g., Barker unpublished 1967, Chapman 1972a) also reflect the low trophic status of Lake Ototoa.

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