PAP. & PROC. ROY. SOC. TASMANIA, 1945 (1ST OCTOBER, 1946)

Ecology of the Fresh Water Fauna of Lake St. Clair, particularly the Copepoda, with special reference to Diurnal and Seasonal Variations in Conditions

By

A. W. G. POWELL
Geelong College

(Read 13th November, 1945)

1. Introduction

The main object of the survey was to gain a foundation knowledge of the ecology of Lake St. Clair, especially of the Copepoda, and, to a lesser degree, the Cladocera, done primarily from the purely scientific point of view, and secondarily from the economic aspect.

Therefore the main physical and chemical conditions prevailing, the plants and animals of the lake bed, the plankton and the fish, all received some degree of attention.

Since the food of the fish consists very largely of plankton crustacea, the survey was concentrated on these creatures.

In the present report, an account is given of the species of Crustacea occurring in the plankton, their relative abundance throughout the year, and the factors having some influence on, or connection with, the variations observed.

2. Revision of Previous Work

No ecological study of the plankton in Tasmanian lakes had previously been attempted. The only systematic work on the fresh-water Crustacea of Tasmania was done by Geoffrey Smith in 1907.

Ecological work of this nature has been carried out in Europe and America for some years, and valuable guidance as to methods, equipment, etc., was gained from various reports. Without wishing to apologize for this particular effort, one could not help feeling envious when reading of the equipment and assistants available to the majority of the authors listed. Various volunteer assistants rendered valuable service, to which due recognition is given, but this could not take the place of a full-time team of specialists which the study demanded.

3. Equipment

Field headquarters were at Cynthia Bay in the south-western corner of the lake. This is the terminus of the road to the lake. Use was made of the police trooper's hut for accommodation, preserving catches, etc. The main investigations were carried out in (1) Tasmanian Museum, (2) Technical College, (3) University of Tasmania, all in Hobart, from the material collected. A large rowing boat fitted for use with an outboard motor (which was not used in this work) was used. As far as possible the apparatus used was adapted to fit this boat.

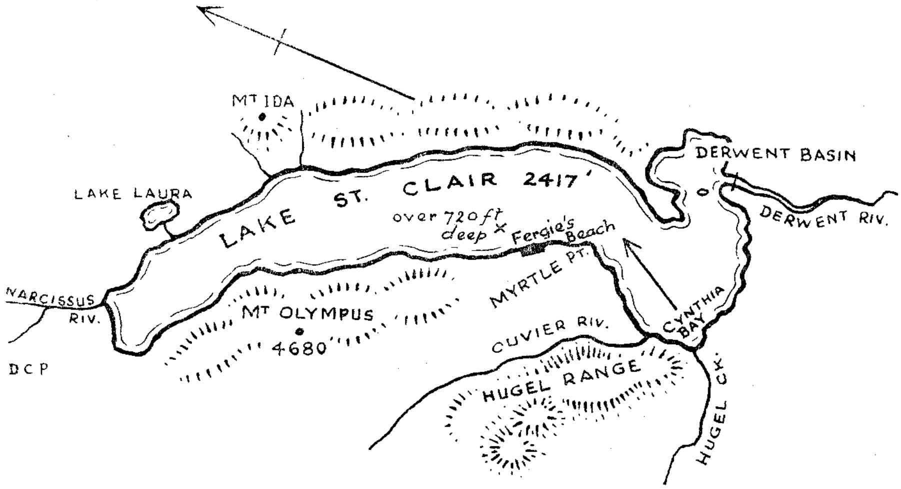


FIG. 1.—Sketch Map of Lake St. Clair Area.

NOTE.—The Cuvier River joins Hugel Creek before entering the lake.

The following equipment is required for meteorological and physical investigations—

Temperature.—Temperature readings of air and water were taken whenever possible. One thermometer was inadvertently broken at the lake, and the next, procured from the Weather Bureau at Hobart, was so inaccurate, having a broken scale, that it had to be discarded. More accurate instruments were in use during the last few months. A reversing water-bottle used for water sampling, also recorded temperatures at selected depths.

Rainfall.—This was recorded at the Hydro-Electric Commission's works at Derwent Basin, about one mile by air from Cynthia Bay, during the latter part of the investigations.

Water Level.—This was controlled by the Hydro-Electric Commission at Derwent Basin, where a dam and pumping station were being erected near the mouth of the lake at the Derwent River source.

Tow-nets of fine-mesh silk (obtained from Thomas Robinson & Son, Sydney) were used for plankton work. For obtaining plankton at a depth, a depth-net closing device was obtained. This was on the lines of that indicated in 'Discovery Reports' (1929, p. 192). The net was lowered by means of a winding drum, the cable of which operated a 200-metre wheel. This apparatus was not available until late in the survey. Pumping to obtain plankton from various depths was resorted to, using an 'Ajax' hand-pump, which brought up 0·1041 gallons per stroke. This proved very exhausting work, which was not very satisfactory in its results. These were not commensurate with the amount of labour involved, even when the pump itself functioned satisfactorily.

In addition to the above, several large-mesh dredge nets were used for collecting the bottom fauna near the lake shore. A fish trap was used at frequent intervals, but no fish were caught. However, in October, 1938, the trap was responsible for the capture, in the mouth of the Cuvier River, of a fresh-water lobster, which was identified by Miss Ellen Clark, of the National Museum, Melbourne, as *Astacopsis tricornis* Clark. As this is the largest specimen so far found, Miss Clark has redescribed the species from it in the 1938 Papers and Proceedings of the Royal Society of Tasmania. The species is known only in the Lake St. Clair region.

4. Description of Lake St. Clair Area

Lake St. Clair is 2400 ft. above sea level and covers an area of about fifteen square miles. It is rather narrow, having a length of about twelve miles and an average width of less than one mile, except at the southern end, where it broadens out into Cynthia Bay on the south-western side and Derwent Basin on the south-eastern side, the width there being about four miles.

Except at the southern end, the lake is entirely surrounded by mountain ranges, which dip steeply into it on the eastern and western shores. Numerous small streams flow into the lake. The two larger ones are the Narcissus River in the north, flowing through button-grass plains from the Du Cane and Gould Mountains, and the Cuvier River, which flows from the west into Cynthia Bay, also through button-grass plains. There are several small sandy beaches around the lake, chiefly at the southern end. Here the lake bed shelves gently, the sand giving place to sandy mud in which Chara grows freely. Between the southern beaches the shore is rocky with many large dolerite boulders, 10 ft. or more in diameter projecting from the water. The lake is very deep in its narrow part, being over 720 ft., just beyond Myrtle Point (see map, fig. 1). However, in the station where observations were made (north-east from Cynthia Bay Beach) the depth varies fairly gradually from zero to something over 100 ft., shoaling occasionally. The bottom is composed chiefly of fine, soft mud.

Lake St. Clair lies on the fringe of a small area of sedimentary rocks of Mesozoic Age, but is almost surrounded by diabase mountains formed by the lava flows at the end of that age, and is possibly of glacial origin, although this is disputed. The southern and eastern shores are of dolerite, while the northern and western shores consist of permo-carboniferous sandstones and mudstones. At the southern end, according to R. M. Johnston (1888), is a terminal glacial moraine of varied composition, giving rise to beaches. The Cuvier River circulation in Cynthia Bay causes sand suspension at times.

Weather.—Rainfall of watershed, between 60 inches and 80 inches; frost frequency, 12 months.

5. Methods and Technique

The collection of plankton by both horizontal and vertical hauls was carried out, but the regular work was done with horizontal hauls only, since these enabled more readily comparable results to be obtained.

Whereas the vertical hauls resulted in very small catches owing to the comparatively small distance through which the net could be moved, the horizontal hauls produced, as a general rule, catches which could easily be removed and examined both quantitatively and qualitatively.

The following plankton nets were used.—

Net No. 1.—This is a very fine-mesh net used only in the early stages of the work, before two nets of the same mesh were available, and at intervals later when quantitative results were not required. Diameter of ring, 30·9 cms; meshes per cm., 34.

Net No. 2.—This is a fine-mesh net. Only one was available when the work was commenced, but as soon as the second became available the two nets were used for simultaneous surface and depth horizontal hauls. Diameter of ring, 30·5 cms; meshes per cm., 26.

Each of these nets was 110 cms. long, with calico hems 17 cms. long at top (around a brass ring) and 20 cms. long at the bottom. Instead of the usual collecting bottle at the end, the open end with a diameter of 8·3 cms. was doubled over and securely closed by means of a rubber band.

Methods of Making Horizontal Hauls

(1) Surface Hauls.—The net, attached to a metal thimble by lines from three rings on the large brass ring of the net, was hauled behind the rowing boat by means of a strong ¼-inch rope. In order to prevent the net breaking surface, a small weight was hung from the thimble. As soon as the boat had been rowed a suitable distance from the shore, the net was washed out, fastened at the end with a rubber band, and thrown over the stern. It was then tugged two or three times to remove air from inside, and the rope was allowed to become taut. In this condition it was then towed at a steady rate for 15 minutes. Constant rowing over the same course resulted in the same distance being covered on each occasion, as shown by shore bearings. Rough waters and winds affected this distance to some extent, but the necessary allowance was always estimated and rowing continued or halted as required.

(2) Depth Hauls.—Depth hauls were carried out in an exactly similar fashion, a heavier weight being required, and a measured length of rope used to secure the required depth, a constant angle being maintained under calm conditions. A difference in the speed of the boat made a greater difference here, owing to the heavier weight tending to pull the net down when the boat was slowed up. However, this occurred on infrequent occasions. When steady winds were blowing, the rope was adjusted in length before rowing commenced, thus preventing any error in depth.

(3) Horizontal Hauls at Greater Depth.—A few of these were carried out near Myrtle Point, in the deeper part of the lake, using the winding gear, metre-wheel, depth-closing device and plankton-net, specially adapted for use with the closing device.

Methods of Making Vertical Hauls

For this purpose the depth-winding-gear, designed primarily for the reversing water-bottle, was used. A weighted net was attached to the end of the cable and slowly lowered, closed end first, to the required depth, as measured by a metre-wheel. From this point it was raised at a uniform speed to the surface. The following extract is taken from the author's log for March, 1938: 'The winding-gear is very heavy and cumbersome and owing to its height above the boat can be used safely only in calm weather'.

Use of 'Ajax' Pump

As already mentioned, this was a hand-pump of 0·1041 gallons per stroke, with about 30 ft. of hose attached to the inlet. Water from various depths was obtained by lowering the nozzle to the required depth after priming. The outlet nozzle was then held over a net of known mesh (one of those used for horizontal hauls) and the water strained through it over the side of the boat. By this means the plankton from a known volume of water was collected. The pump did not always function satisfactorily, however, whilst the method was far too laborious, and the apparatus too unwieldy for regular diurnal observations.

Southern and Gardiner (1926) using a semi-rotary type pump expressed a similar opinion. They state: 'The method is too slow and cumbersome for normal use in the study of the seasonal distribution of the plankton crustacea over a large area'.

Bottling and Preservation of the Catch

After each haul the nets were washed down, first from the outside, thus transferring the total catch to the closed end which was then undone over a quart-size Kilner preserving jar, into which the catch was washed. This resulted in a comparatively large quantity of water, so the next step was to reduce the water content by filtering through silk of slightly finer mesh than the collecting net. This filter net was mounted on a jam tin with holes pierced in its sides, the net being given a concave upper surface, and held in position by a rubber band. The waste water was allowed to run off, and a mass of plankton collected in the net. The plankton was washed into small bottles of about 100 cc. capacity by means of the ordinary wash bottle as used in any chemical laboratory. By this means the quantity of water added was kept to a minimum. Labels written with Indian ink were placed in each bottle and the contents were preserved with a 70 per cent solution of methylated spirits. Felt-lined boxes, holding 16 bottles, each in a separate compartment, were used to transport the catches from the lake to the Tasmanian Museum for quantitative work.

Methods of Measuring the Catch

Two methods were used:—

(1) Measurement of settled volume.
(2) Individual count of representative sample.

A sample graph comparing the total catch as indicated by the two methods is given, fig. 2, (*a*), (*b*).

Method (1).—This was soon abandoned as inadequate. The catches, each in the same volume of water, were allowed to settle for some considerable time, and the height of plankton measured, the bottles being of uniform diameter. Whilst giving some idea of the total plankton collected, this method was of no value for different groups.

Method (2).—This was developed after some experimenting. When the technique was mastered all catches, including the earlies ones, were counted by the following means:—

The catch was washed out of its bottle into a 100 cc. jar using 70 per cent methylated spirits in the standard type of wash bottle. Spirits was added to bring the level to the 100 cc. mark.

The liquid was thoroughly agitated with a shaped glass rod.

With the plankton thoroughly mixed, 10 ccs. were withdrawn by means of a wide-mouthed pipette at about 40 ccs. level, and placed in a circular glass dish of diameter 78·0 mms. This provided a thin layer of liquid with the plankton more or less evenly distributed. The dish was placed on the top of a specially ruled glass slide on the platform of a binocular dissecting microscope. The individuals of the plankton were then counted, and the numbers of different types recorded. The glass slide consisted of a lantern slide, with its gelatinous layer carefully ruled off into squares each of side 2·6 mms. and then finished off as a lantern slide. Counts were made over a number of squares, the results being averaged. The method was modified for smaller catches. An exact correspondence between these two methods cannot be expected, since larger numbers may be largely comprised of smaller individuals, thus giving a lower reading for settled volume. In view of this, fig. 2 shows that the two methods give a very satisfactory comparison in results. Where the plankton is of a uniform nature, as in this instance, the big value of estimation of quantity by settled volume is that it gives the total amount available for food.

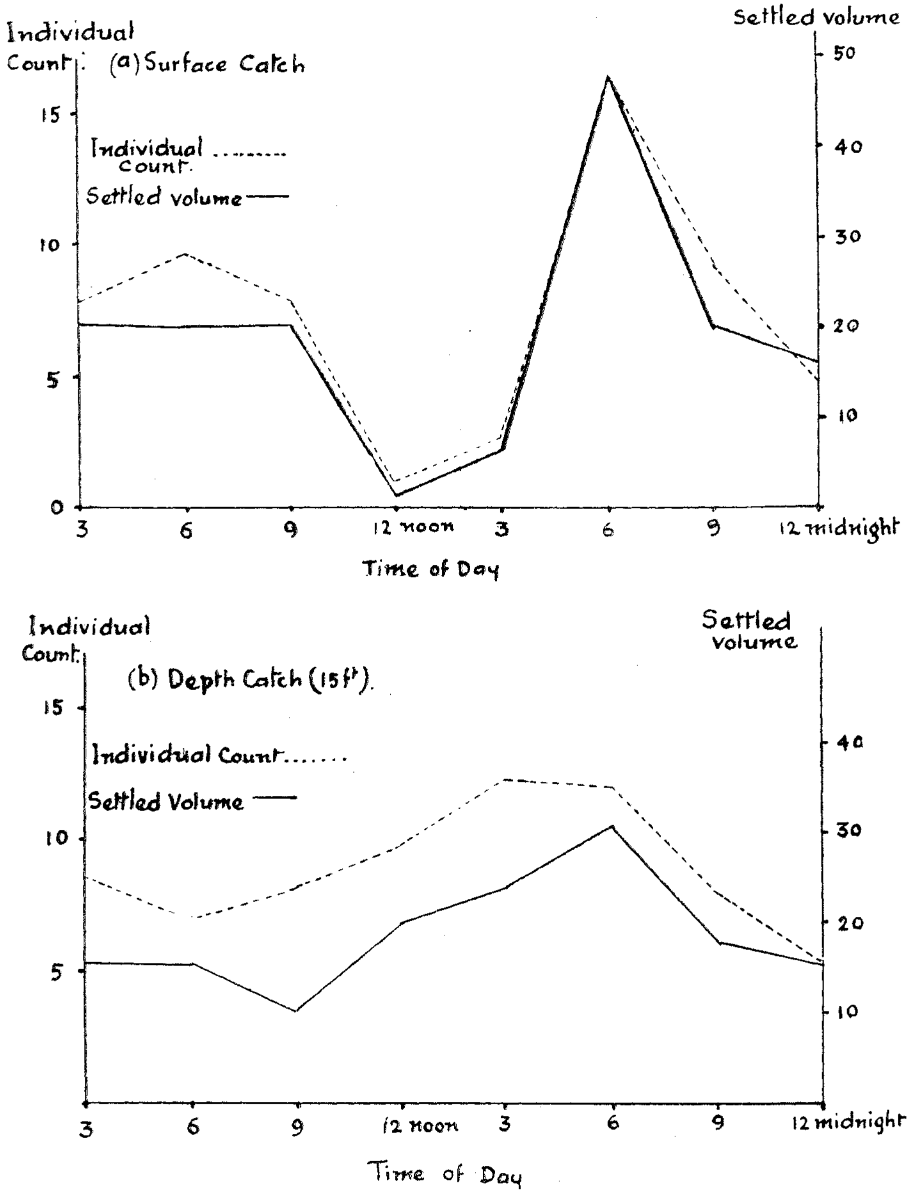


FIG. 2.—Graphs comparing total plankton catch as indicated by two methods of measuring.
(i) Measurement of settled volume (R.H. axis).
(ii) Individual count of representative sample (L.H. axis).
All samples were collected on 27th Aug., 1937.
The maximum catch, 6 p.m. surface, has been taken as the standard of comparison in selecting the scale units for the two methods.

Accuracy of Above Methods

(*a*) Medium Nets were Used.—A fine net would have lost more plankton. Small and immature species were certainly lost, but the more mature species of both Copepoda and Cladocera were retained.

(*b*) Age of Nets.—Southern and Gardiner (1926) found that older nets catch more than new ones, but the excess is within the range of normal error in sampling and counting (5-15 per cent), so that use does not materially affect the catching power of a medium silk net.

(*c*) Irregular Vertical Distribution of Plankton.—On occasions the catch was singularly small at either surface or depth. Thus a catch at one or the other was not representative of the actual concentration of plankton in the lake, but did suggest certain migrational tendencies according to conditions.

(*d*) Variations in Length of Haul.—Differences caused by disturbed weather conditions and the methods of counteracting them have already been discussed.

(*e*) Sampling at a Single Station.—Ricker (1938), having taken samples over a thirteen-year period, found that collections taken at a single station will indicate the average abundance of plankton almost as well as over the whole region.

(*f*) Errors in Counting the Catch.—The method of averages having been employed to estimate the relative numbers of the thousands caught, the error introduced here is probably small, but cannot be accurately determined.

6. Physical and Chemical Observations

A. As there was no fully-equipped weather station at Lake St. Clair, it was not possible to obtain complete observations, but from January, 1937, records of temperature, wind, cloud, and general remarks were obtained from Tarraleah, which is situated some fifteen miles away as the crow flies, and may be considered to have roughly comparable weather conditions. These figures were supplemented by personal observations at the lake itself during each trip to collect material.

B. Temperatures

(1) *General*

Thermometers proved to be somewhat uncertain instruments. The first, used for air and water temperatures, was soon broken. The second, borrowed from the Weather Bureau, was unreliable, having a broken scale; the third, a pair on the reversing water bottle borrowed from Ceylon, were very erratic, and for the most part did not synchronise.

The fourth, a pair on a second reversing water bottle (procured by the University of Tasmania for this work) proved quite satisfactory, and these were in use in the latter part of the research.

Concurrently with this, a new ordinary thermometer was used to obtain surface and air temperatures.

(2) *Air Temperatures*

The Tarraleah records, supplied by the Commonwealth Meteorological Bureau at Hobart, were by no means complete, a few days being omitted in nearly every month, but they give some idea of the temperature variations from 1937 to 1939. From the figures supplied, the following table of mean monthly temperatures in Fahrenheit degrees was derived:—

TABLE 1.

Tarraleah Temperatures in °F.

* Reading across 1 = Mean monthly maximum.
2 = Mean monthly minimum.
3 = Mean monthly temperature.

*	Jan.	Feb.	Mar.	April	May	June	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Ann. Mean
1937—													
1	61·5	66	63·5	54	50	43	47	50·5	52	57	65	63·5	56·1
2	46	49	46·5	38	37	29	34	35·5	38	42	44	45·5	40·4
3	53·8	57·5	55	46	43·5	36	40·5	43	45	49·5	54·5	54·5	48·3
1938—													
1	67	65·5	65	59·4	55·9	46·6	45·4	48·7	54·7	60·8	64·7	64	58·1
2	47	47·9	46·4	43·9	40·7	34·2	32·1	34·2	35·9	40·0	43·7	40·2	40·5
3	57	56·7	55·7	51·7	48·3	45·4	38·8	41·5	45·3	50·4	54·2	52·1	49·3
1939—													
1	71·3	75	64·8	61·1	55·1	49·7	45·6	46·6	51	58·8	57·5	11 months	58·8
2	41·6	47·4	42·4	43·2	40·2	34·7	32	35·4	36	37·9	44·1		39·5
3	56·5	61·2	53·6	52·2	47·7	42·2	38·8	41	43·5	48·4	50·8		49·2

(3) *Water Temperatures*

Table 2 gives the various surface-water temperatures obtained, together with the corresponding air temperatures (°C.).

TABLE 2

Water Temperatures (°C.)

Date	1938	1939											1940	
	18·10	25·2		26·2	12·4	13·4			20·5			21·5	16·8	30·11
Time	11 a.m.	10 a.m.	3 p.m.	11 a.m.	5 p.m.	8·45 a.m.	12 noon	5 p.m.	8 a.m.	11 a.m.	5 p.m.	9 a.m.	2·30 p.m.	3 p.m.
Air	—	14·6	14·3	10·7	16·3	12·9	11·4	11·6	9·4	10·0	9·5	8·9	11·1	23·3
Surf.	8·4	13·7	15·2	15·8	12·2	13·6	13·5	13·3	10·0	10·6	10·6	10·0	5·6	12·8

The range of water temperature here revealed is from 5·6 to 15·8°C. The lower limit was almost certainly reduced during the winter of 1937, when the work was commenced, for in May and June of that year an unusual succession of frosts was experienced throughout Tasmania, see Table 1, and, although the lake itself did not freeze, there was more than once a slight encrustation of ice around the margin of Cynthia Bay. During towing on those nights any water inadvertently splashed into the boat changed to ice before it could be brushed from the clothes.

Table 3 gives a list of the sub-surface water temperatures as measured by thermometers on the reversing water-bottles used for water-sampling.

The water temperatures given in the table were obtained from between the end of the tow-course and 'Fergie's Beach' (see map).

TABLE 3

Water Temperatures

Date	18.3.38	20.4.38	31.8.38	26.2.39	13.4.39	20.5.39	30.11.40
Time			11·30 a.m.	11 a.m.	12 noon	5 p.m.	3 p.m.
Air Temp.	17·4°C	10·6°C	9·6°C	10·7°C	11·4°C	9·5°C	23·3°C
Surface				15·8	13·5	10·6	12·8
6 Metres				13·4	13·4	10·5	
7·5 Metres							9·32
10 Metres						10·4	
15 Metres			7·1	13·2	13·3		8·35
26 Metres			6·9				
30 Metres	10·9			9·3	10·9		
38 Metres		11·6	6·9				
60 Metres	10·9*	11·0					

* Water-bottle on bottom.

In each case there is a drop in temperature from the surface downwards.

During March, April, and August, 1938, i.e., autumn and winter, there was no indication of a thermocline, the temperature being about 11° C. at thirty to sixty metres in both March and April and 7°C. at fifteen to forty metres in August. The readings for February and April, 1939, however, suggest a definite summer thermocline at a depth of fifteen metres. Below this level the water temperature probably does not exceed ten to 11°C. throughout the year, providing a refuge for fish and other aquatic organisms preferring a uniformly cool habitat [cf. Leim (1935)].

C. Rainfall and Water Level

Only Tarraleah rainfall figures are available for 1937, but the St. Clair figures are given from then onwards. A comparison of corresponding rainfalls shows that the St. Clair figures are usually 5 to 10 per cent higher than those at Tarraleah. (See Table 4.)

The water-level at Lake St. Clair was under artificial control from the beginning of the investigations owing to the construction of a dam at Derwent Basin by the Hydro-Electric Commission, from whom the figures appended were obtained. (Table 4A.) The graphs, fig. 3, show the connection between rainfall and water-level. The graphs are of the same general shape, allowing for artificial changes caused by hydro-electric requirements.

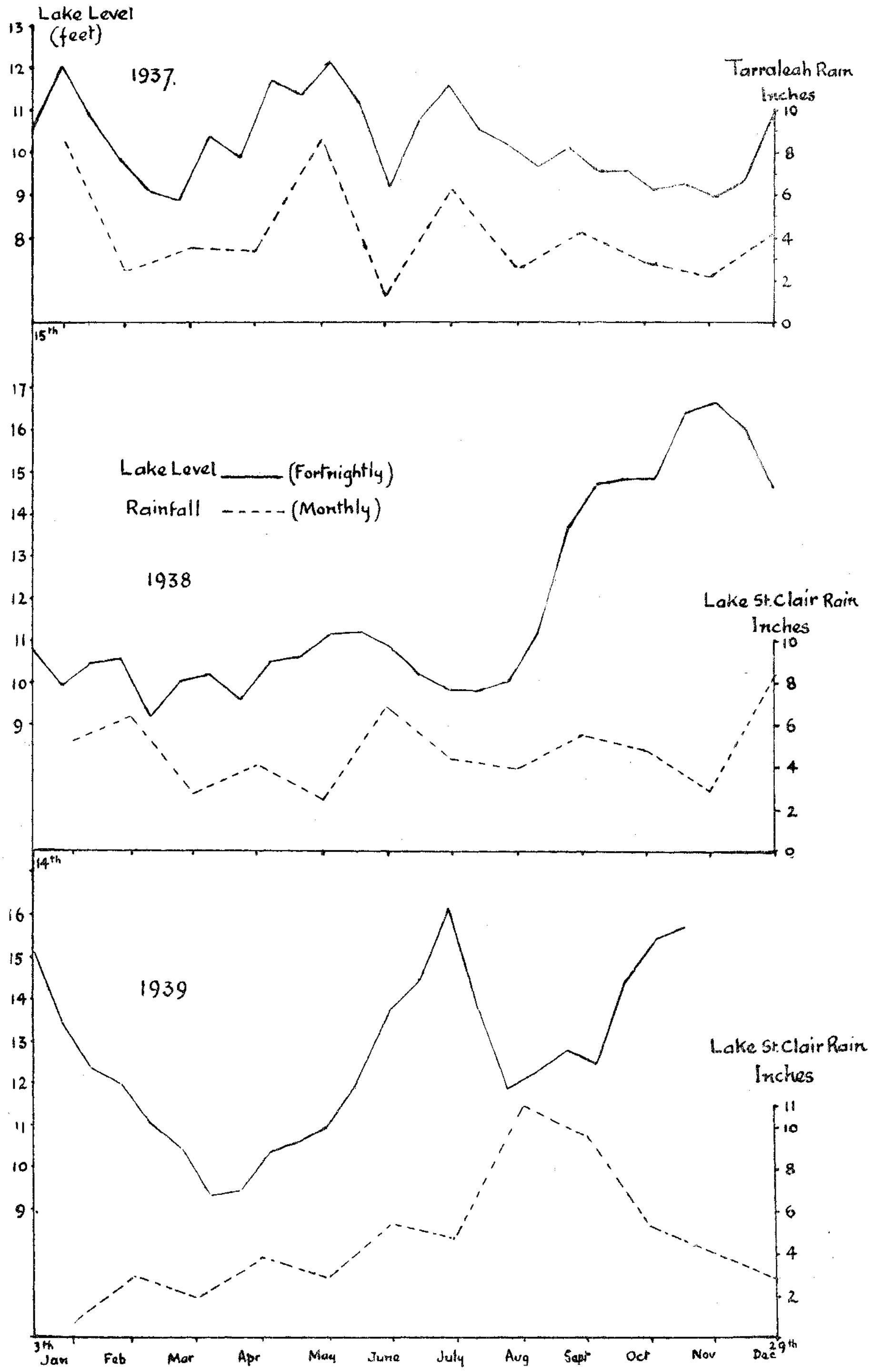
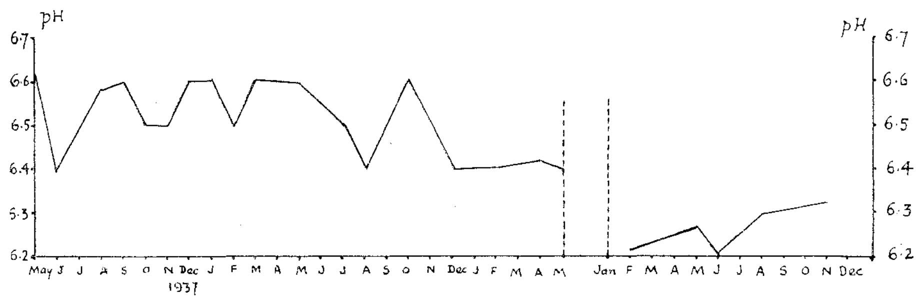
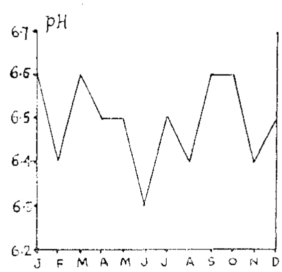


FIG. 3.—Graphs comparing lake level and rainfall (see Tables 4 and 4A).

These requirements are, of course, often unrelated to the natural changes, so that the life of the lake has in recent years been subjected to unusual conditions, not the least of which is the inundation of the shore-line to a much greater extent than was possible before the natural level was interfered with. The drowning of shore-side vegetation undoubtedly caused an increase in the acidity of the water—see pH curves (fig. 4). Heavy rainfall on occasions caused flooding of the Cuvier River, the current from which crosses south of the netting course.





pH Average (1937-40)

Fig. 4 pH Valves
Lake St. Clair, Surface.

Ueno (1939) in discussing Zitugetu-tan (Lake), the depth of which was raised in 1934 from five to eighteen metres for hydro-electric purposes, records a remarkable decrease in the number of plankton animals and the appearance of hitherto unrecorded forms. It appears that a sunken forest may completely change the lake-type. Changes in Lake St. Clair water and plankton may therefore occur, although the foreshore was not permanently inundated.

TABLE 4

Rainfall

Month	Tarraleah		Lake St. Clair			
	1937		1938		1939	
	Days	Points	Days	Points	Days	Points
January	24	858	14	517	7	63
February	10	244	8	638	8	277
March	8	354	13	263	8	185
April	18	339	16	403	15	366
May	25	873	15	237	16	280
June	13	109	23	679	26	523
July	25	631	12	433	17	462
August	21	250	17	389	31	1099
September	20	430	16	548	23	941
October	15	285	19	472	19	521
November	12	223	15	289	17	399
December	21	427	15	834	14	283

TABLE 4A

Levels of Lake St. Clair (Fortnightly)

1937	Level	1938	Level	1939	Level
1st January	no reading	14th January	2310·80	13th January	2315·20
15th January	2310·55	28th January	9·90	27th January	13·40
29th January	12·08	11th February	10·40	10th February	12·30
12th February	10·86	25th February	10·50	24th February	11·97
26th February	9·80	11th March	9·13	10th March	11·05
12th March	9·10	25th March	9·97	24th March	10·40
26th March	8·90	8th April	10·15	7th April	9·30
9th April	10·40	22nd April	9·55	21st April	9·40
23rd April	9·90	6th May	10·47	5th May	10·30
7th May	11·70	20th May	10·55	19th May	10·50
21st May	11·40	3rd June	11·13	2nd June	10·80
4th June	12·15	17th June	11·15	16th June	12·03
18th June	11·13	1st July	10·80	30th June	13·70
2nd July	9·20	15th July	10·15	14th July	14·40
16th July	10·80	29th July	9·80	28th July	16·13
30th July	11·63	12th August	9·80	11th August	13·70
13th August	10·55	26th August	10·00	25th August	11·90
27th August	10·20	9th September	11·15	8th September	12·30
10th September	9·70	23rd September	13·68	22nd September	12·80
24th September	10·15	7th October	14·70	6th October	12·47
8th October	9·60	21st October	14·80	20th October	14·40
22nd October	9·57	4th November	14·85	3rd November	15·40
5th November	9·15	18th November	16·40	17th November	15·70
19th November	9·30	2nd December	16·68		
3rd December	9·02	16th December	16·00		
17th December	9·40	30th December	14·63		
31st December	10·45				

D. Wind

As already mentioned, wind records from Tarraleah, and later Derwent Basin, were available, being supplemented by personal observations during visits. The following figures have been compiled by the use of the abovementioned records:—

TABLE 5

Tarraleah: Wind Direction: Daily Analysis

	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1937—													
N.	0	0	0	0	0	0	1	2	0	0	0	1	4
N.W.	0	1	1	0	0	0	2	1	3	1	4	7	20
W.	10	2	8	8	9	2	7	5	11	10	5	5	82
S.W.	5	1	0	0	0	1	3	2	3	2	3	6	26
S.	1	0	0	0	0	0	0	0	0	1	0	0	2
S.E.	0	2	1	0	0	0	0	0	0	1	0	3	7
E.	0	0	0	0	0	0	0	0	0	0	0	1	1
N.E.	2	0	0	0	0	0	0	0	0	0	0	0	2
Calm	13	22	21	21	22	27	17	21	12	15	16	8	115
1938—													
N.	0	1	4	3	1	0	0	0	2	0	0	1	12
N.W.	9	8	14	12	15	5	2	3	7	10	5	4	94
W.	3	7	6	7	9	8	9	11	6	5	13	9	93
S.W.	0	2	2	2	4	1	2	3	1	2	1	4	24
S.	0	0	1	1	0	0	0	1	0	0	0	0	3
S.E.	0	1	0	0	0	0	0	0	0	1	1	0	3
E.	0	0	0	0	0	0	0	0	0	0	0	0	0
N.E.	3	2	2	2	0	0	0	2	0	0	0	0	11
Calm	14	4	0	0	0	11	13	7	10	8	5	10	82
1939—												Total for 11 months.	
N.	0	0	0	1	0	0	0	0	0	0	0		1
N.W.	5	1	3	1	2	2	0	1	3	3	8		29
W.	10	6	7	6	5	0	1	0	3	0	7		45
S.W.	2	0	3	1	4	0	0	0	0	1	4		15
S.	0	0	0	0	0	0	0	0	0	0	0		0
S.E.	0	0	0	0	0	1	0	0	0	0	0		1
E.	1	1	0	0	0	0	0	0	0	0	0		2
N.E.	0	0	0	0	0	0	0	0	0	1	0		1
Calm	9	16	14	14	18	21	25	26	19	26	8		196

TABLE 6

Summary of Wind Directions (Tarraleah)

Directions	1937	1938	1939	Total
N.W. to S.W.	128	211	89	428
Others	16	29	5	50

The records supplied by the Weather Bureau were incomplete, but are sufficient to indicate the conditions. The group of north-westerly to south-westerly winds prevails over all others. Expressing these Tarraleah results in terms of conditions at Lake St. Clair, two points in topography must be borne in mind:—

1. Although the situations are topographically similar, the contours are such that winds from the west and south-west sector would be slightly more southerly at Tarraleah than at Lake St. Clair.
2. As the lake runs practically north-south between mountain ranges rising 2000 ft. above it, there is a tendency for winds from the north to north-west sector to sweep down the lake from the north.

Thus, whereas in Table 6, the majority of wind-directions is shown in the north-west to south-west quadrant, for Lake St. Clair this majority is more likely to be in the north to west quadrant. Experience at the lake proved this to be true. Not only were there very few winds from any other direction, but those that most affected the degree of calmness of the lake, and hence, as is considered in Section 9 E, the distribution of the plankton, were from the north and west.

TABLE 7

Tarraleah Wind Velocities (Estimated) Beaufort Scale

	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
1937—													
0	13	22	21	21	22	27	17	21	12	15	16	8	215
1	2	2	0	1	0	0	1	2	4	8	3	6	29
2	4	2	2	2	2	1	2	3	6	4	3	7	38
3	3	0	1	3	2	0	2	1	6	3	2	4	27
4	2	0	2	1	4	2	4	1	1	0	1	3	21
5	2	0	1	0	1	0	1	3	0	0	1	2	11
6	5	2	3	2	0	0	3	0	0	0	1	1	17
7	0	0	1	0	0	0	0	0	0	0	0	0	1
8	0	0	0	0	0	0	0	0	0	0	1	0	1
	31	28	31	30	31	30	30	31	29	30	28	31	360
1938—													
0	14	4	0	0	0	11	13	7	10	8	5	10	82
1	4	4	18	12	14	4	7	5	4	4	6	5	87
2	2	6	6	8	9	3	4	5	6	5	5	3	62
3	3	8	0	2	5	4	0	3	0	5	2	2	34
4	3	3	2	2	1	3	2	3	1	2	5	4	31
5	2	0	3	3	1	0	0	3	2	1	1	3	19
6	0	0	0	0	0	0	0	1	1	0	0	0	2
7	0	0	0	0	0	0	0	0	2	0	1	1	4
8	1	0	0	0	0	0	0	0	0	1	0	0	2
	29	25	29	27	30	25	26	27	26	26	25	28	323
1939—													
0	9	16	14	14	18	21	25	26	19	26	8	Total for 11 months.	196
1	8	5	6	2	6	1	0	0	1	0	0		29
2	3	1	5	4	3	0	0	0	0	0	4		20
3	4	1	1	1	0	1	0	1	3	4	0		16
4	3	0	0	1	1	1	1	0	1	1	3		12
5	0	1	1	1	1	0	0	0	0	0	6		10
6	0	0	0	0	0	0	0	0	1	0	4		5
7	0	0	0	0	0	0	0	0	0	0	1		1
8	0	0	0	0	0	0	0	0	0	0	1		1
	27	24	27	23	29	24	26	27	25	31	27		290

Analysis of wind velocity table—

0-4 = Calm to moderate breeze, i.e., up to 16 m.p.h.

5-8 = Fresh breeze to fresh gale, i.e., up to 41 m.p.h.

TABLE 8

Percentages of the Above.

Scale No.	1937	1938	1939
0-4	91·7%	91·6%	94·1%
5-8	8·3%	8·4%	5·9%

The following table shows the directions of the few winds which exceeded 16 miles per hour:—

TABLE 9

Wind	1937	1938	1939	Total
			(11 months)	
N.	1	0		1
N.W.	0	9	8	17
W.	20	15	7	42
S.W.	7	2	2	11
S.E.	1	0	0	1
N.E.	1	1	0	2
Total	30	27	17	74

This demonstrates that the most frequent winds are also those which blow with the greatest force in this area.

E. SUNLIGHT

No measurements as to the duration of sunlight were made at either Tarraleah or Derwent Basin, but during visits personal observations were made of the percentage of cloud at the time of each collecting trip. These are dealt with later in the report.

The following table gives an analysis of the cloud reports, most of them from Tarraleah, but the later ones from Lake St. Clair. For some of these months, complete records were not available, some figures from each of the abovementioned stations being given. These have been used to give some indication of the amount of cloud obscuring the sky, at the time on each day when the observations were made.

TABLE 10

Monthly Analysis of Cloud Percentage at 9 a.m. Tarraleah (some, 1939, at Lake St. Clair).

	J	F	M	A	M	J	J	A	S	O	N	D
1937—												
Average Daily Cloud %	68	52	55	55	75	50	70	55	71	67	54	79
Days 100%	12	4	5	10	13	9	5	11	13	12	12	16
Days 0%	2	6	4	6	1	6	2	8	3	4	10	1
Total Recorded Days	31	28	31	30	31	30	30	31	29	30	28	31
1938—												
Average Daily Cloud %	56	64	55	61	47	71	73	71	63	72	60	58
Days 100%	9	9	2	0	0	12	14	13	8	12	8	8
Days 0%	7	2	3	4	8	2	4	6	4	2	4	3
Total Days Recorded	29	25	29	27	29	25	26	27	26	26	25	28
1939—												
Cloud	43	48	59	*71	69	93	82	98	83	72	71	
Days 100%	6	9	12	14	17	19	18	24	18	17	14	
Days 0%	9	9	7	4	6	0	3	1	3	3	4	
Total Days Recorded	27	24	27	24	29	24	26	26	25	31	27	
1937-39—												
Average	56	55	56	62	64	71	75	75	72	70	62	69
	J	F	M	A	M	J	J	A	S	O	N	D

* After March, 1939, the figures are almost exclusively from Lake St. Clair.

It must be remembered that these figures have been compiled from records made at 9 a.m. each day, when morning mists, especially at this altitude, may not have cleared away. In general, therefore, it would appear that there is ample sunlight to favour the growth of aquatic plants, especially as the water is usually crystal-clear, allowing penetration of bright sunlight to a good depth. There is a direct connection between the surface zoo-plankton catch and the percentage of cloud under normal weather conditions. This is dealt with in Section 9 E.

F. CHEMICAL ANALYSIS OF THE WATER

Frequent analyses of the water were undertaken, especially with regard to certain features once a general analysis had been completed. These results are appended in succeeding sections, together with some comments as to methods. The following table gives a summary of the main constituents disclosed in the general analysis.

TABLE 11

Chemical Analysis of Lake St. Clair Water in Parts per Million

Substance	Content	Date of Taking Sample
Total solids	40	July, 1937
Ammonia (Free & saline)	negligible	July, 1937
Nitrates and nitrites	0·00	July, 1937
Mineral constituents and metals	Sulphate	July, 1937
	Fe, Mg.	July, 1937
Oxygen dissolved	10·7	Nov., 1937
Combined Chlorine	1·93	Feb., 1939
Hardness Temporary	7·8 } pts. $CaCO_3$ per m.	April, 1939
Hardness Permanent	45·0 } pts. $CaCO_3$ per m.	April, 1939
Phosphorus Soluble	0·00	Aug., 1940
Silica	1·61	Aug., 1940

G. SOLIDS IN SOLUTION AND IN SUSPENSION

1. *Total Solids*

Two tests were made, in 1937 and in 1940 respectively, giving similar results—

July, 1937. 40 mgs. per litre.
June, 1940. 31 mgs. per litre.

The dissolved mineral solids are present, therefore, within satisfactory limits.

2. *Inorganic Suspended Matter*

March, 1938. 0·1 mg. per litre.

This result seems very low, especially when compared with November, 1940, but the conditions were such as to reduce suspended matter to a minimum. After four days of fine weather and with only ' light air ' the lake was the calmest it had been for months.

3. *Total Suspended Matter*

November, 1940. 167 mgs. per litre.

Made up as follows:—

Organic suspended matter, 1 mg. per litre.
Inorganic suspended matter, 166 mgs. per litre.

The lake was calm at the time the sample was collected, but, although there had been little rain during the previous week, westerly winds up to 30 miles per hour had been blowing for two days immediately preceding the work, and this, no doubt, caused an increase in suspension of inorganic matter.

The total suspended matter is in this case rather high, but it obviously varies with weather conditions.

H. DISSOLVED OXYGEN

For the samples, special bottles were obtained from Norway. They were fitted with spring clips to prevent any movement of the stopper. Care was taken to avoid trapping any bubbles when filling the bottles, each of which had a certified capacity.

Winkler's method was employed for the chemical determination, which was preceded on each occasion by a preliminary determination of oxygen dissolved in the reagents.

TABLE 12

Dissolved Oxygen

Nov., 1937	Surface	10·7 mgs./litre	
Nov., 1940	Surface 7·5 metres 15 metres	10·6 mgs./litre 12·05 mgs./litre 11·37 mgs./litre	Temp. 12·8°C. 9·32°C. 8·35°C.

The results suggest that there is little change in the quantity of oxygen, which is present in ample quantity for fresh-water life. The higher results for depth samples may be due to the fact that these samples had to be transferred from the depth water-bottle to the sampling-bottle, the consequent agitation, perhaps, dissolving a little more air. In addition, the lower temperature favours the dissolving of more oxygen.

I. Free Carbon Dixoide

Seyler's method was used (Sutton (1924)), the water being titrated with $\frac{N}{20}$ sodium carbonate using phenolphthalein as indicator. The samples were taken in the same bottles as for dissolved oxygen, and the same remarks about the depth samples may apply. The following were the results:—

Nov., 1940	Surface 7·5 metres 15 metres	3·19 mgs./litre 3·03 mgs./litre 3·41 mgs./litre	Temp. 12·8°C. 9·32°C. 8·35°C.

Here, again, there would appear to be little difference between surface and depth conditions.

J. Determination of Oxygen Absorbed

TABLE 13

Oxygen Absorbed in Four Hours at 80°F. (in Parts per 100,000).

July, 1937	0·024
November, 1937	0·020
March, 1938	0·024
July, 1938	0·022
February, 1939	0·021
April, 1939	0·022
August, 1940	0·020
Average	0·021

The method adopted for the determination of oxygen absorbed was that outlined by Sutton (1924), using potassium permanganate. Haig Johnson (Ainsworth-Mitchell (1931)) refers to the 'regrettable absence of uniformity amongst the methods in vogue'.

The table shows that the quantity of oxygen absorbed varied very little over the period of the tests. The average of 0·021 parts per 100,000 is a low one compared with results obtained in some New Zealand streams (Phillips (1931)), and should be quite favourable for fish-life.

K. DETERMINATION OF COMBINED CHLORINE

Mohr's method was used and gave reasonably satisfactory results after the initial difficulties had been observed and overcome.

TABLE 14

Combined Chlorine in Milligrams per Litre (parts per million)

Date	1937		1938				1939		1940			Aver.
	26 July	21 Nov.	20 Mar.	20 Apr.	16 May	16 July	26 Feb.	13 Apr.	17 May	16 Aug.	30 Nov.	
Surface	1·42	1·42	3·19	1·42	3·19	3·56 3·80	1·93	0·92	1·93	2·84	3·41	2·34
6 metres..							1·56	0·99				1·28
7·5 metres											3·19	3·19
9 metres			2·84	1·93								2·39
15 metres							1·28	1·07			3·19	1·85
18 metres			3·19	3·19		4·26						3·55
30 metres							1·2	0·92				1·06

Owing to the small quantity present in the water, a fractional error in the titration would make a considerable difference in the results. Most authors consulted did not give special methods for the detection of small quantities of chlorine. From the above table, therefore, it would appear that there is little, if any, difference between the amount of combined chlorine at the surface, and at depths up to 100 feet (30 metres).

L. pH VALUE (HYDROGEN ION CONCENTRATION)

The method used for this determination was changed more than once owing to the original apparatus going out of order. The figures for May, June, and August, 1937, were determined by means of the electrometric method, using a quinhydrone electrode. Of the remaining figures, those given to the second decimal place were determined with the Du Bosc comparator, and the others by the less accurate colorimetric method using the B.D.H. universal indicator. These latter could be done at the lake-side, but the remainder had to be done at Hobart, where the apparatus was.

For transporting the water a special reagent bottle was carried in a small wooden felt-lined case. This could be locked and despatched by service-bus or lorry in safety. When water samples were wanted, other than during a collecting trip to the lake, they were obtained by the National Park ranger in this bottle and forwarded to Hobart, where the test was made as soon as possible after arrival.

The following table shows the pH values obtained during 1937 to 1940:—

TABLE 15

pH Values (Surface Water)

Month	1937	1938	1939	1940	Average
January		6·6	—	—	6·6
February		6·5	6·4	6·22	6·4
March		6·6	—	—	6·6
April		6·6	6·42	—	6·5
May	6·62	6·6	6·4	6·27	6·5
June	6·40	—		6·21	6·3
July	—	6·5		—	6·5
August	6·58	6·4		6·30	6·4
September	6·6	—		—	6·6
October	6·5	6·6		—	6·6
November	6·5	—		6·33	6·4
December	6·6	6·4			6·5

It will be observed that during the first three years (when all the quantitative plankton work was done) the pH did not change to any marked degree, although there is, perhaps, a slight downward trend. By 1940, however, after a gap of eight months, when the writer was engaged in other work at Great Lake, a considerable relative decrease in pH value was recorded, and this remained in evidence for the remainder of that year. It seems significant that the gradual change in pH value, with increasing acidity, followed the raising of the lake-level by the Hydro-Electric Commission in connection with its Tarraleah power scheme.

There is a slight annual variation, the value usually being a little lower during the winter months. The range is as follows:—

1937. 6·4 to 6·62.
1938. 6·4 to 6·6.
1939. 6·4 (only three readings).
1940. 6·21 to 6·33.

Depth Readings of pH

The following table shows the pH values of samples obtained at various depths:—

TABLE 16

pH at Depths

Date	18.3.38	20.4.38	16.7.38	31.8.38	26.2.39	13.4.39	20.5.39	30.11.40
Metres								
0	6·6	6·6	6·5	6·4	6·4	6·42	6·4	6·33
6					6·5	6·42	6·53	
7·5								6·24
10							6·45	
15				6·4	6.6	6·45		6·23
26				6·4				
30	6·7	6·4			6·7	6·49		
38				6·4				
60		6·6	6·6					

There is little variation as depth increases; the earlier figures (using B.D.H. universal indicator) show a fairly close correspondence, which is confirmed by the later readings (13.4.39 onwards) with the more accurate Du Bosc comparator.

Effect of pH on the Copepoda

The pH value does not directly affect the inhabitants, which are tolerant of changes in pH. Extreme variations may cause death, but usually only in small pools. This was stated by Saunders (1926). As the variation in Lake St. Clair is comparatively small, and the water volume large, the finding suggests that the changes observed would not have had an adverse affect on the plankton. Penelope M. Jenkin (1936) mentions that few species of Copepoda were obtained from the alkaline lakes in Kenya. Lowndes, A. G. (1936-1937), in commenting on the Cambridge Expedition to East African lakes, says that some Copepoda existed in water of pH 2·5 to 7·8 and in salt or fresh water. It would seem, therefore, that the variation in pH has no direct influence on the Copepoda. This conclusion is examined later in connection with the quantitative measurement of the plankton.

Effect of pH on Fish

The general conclusions of other writers suggest that trout favour water with a high pH, and that lack of food does not account for smaller fish in acid waters as the stomach contents are greater (Southern, 1935) (Frost, 1939). These findings, however, are for English and Irish conditions. J. S. Phillips (1931), discussing New Zealand trout, says that low temperatures make acid waters more suitable for trout. Being a high-land lake, St. Clair fulfils this requirement, and the pH readings are substantially the same as those obtained during 1939-1940 at Great Lake (6·35 to 6·67)—the latter lake being renowned for its trout-fishing—although its altitude is 1000 feet above that of Lake St. Clair and its waters therefore colder at times. (A similar paper dealing with the findings at the Great Lake will be prepared later.)

Note on Method

In order to avoid inaccuracies in measurement due to the weakly buffered lake water, it was intended to use the electrometric method throughout, but when this apparatus went out of order the colorimetric method became obligatory. Tengco's paper (1939) states that the adjustment of indicator solutions is not as necessary as has been claimed, but that the colorimetric values were usually 0·2 to 0·4 pH units lower than with the glass electrode. He also advises a preliminary comparison between the two methods. In the present work this requirement was fulfilled to the extent that the electrometric readings, which were the first obtained, were a guide to the later ones using the B.D.H. universal indicator, and these in turn checked with the later colorimetric measurements made with the Du Bosc comparator.

Red Copepods

Ueno (1939) comments on the red colour exhibited by Copepods in high altitudes, and quotes *Acanthodiaptomus yamanacensis* as being red in acid waters (pH4 to 6·8), but usually not red in alkaline waters. He found that the pigment Astacin ($C_{40}H_{48}O_4$) an acid carotene was responsible, and concludes that the Copepod gets energy when the β-carotin ($C_{40}H_{56}$) is oxidised to Astacin in the body.

Red Copepods occur in some cold mountain lakes in Formosa and Japan. In these particular lakes the water is usually acid.

From the beginning of the present study it has been noticed that some specimens of *Boeckella longisetosa*, instead of being green, were from brownish-red to red in colour. At 9 a.m. on the 18th May, 1937, for example, green colours dominated, due to the catch containing 60 per cent of Cladocerans and Cyclopoida, but the 3 p.m. catch contained 5:1 in favour of the reddish-brown Calanoida.

As the Lake St. Clair pH readings varied from 6·21 to 6·62, it would be interesting to know whether the cold acid mountain waters of Tasmania, too, are responsible for the production of the pigment Astacin in Copepods. *Boeckella rubra*, which Smith (1909) found in the cold mountain tarns of Mounts Hartz and Read, may be another example of the same type, as it is a bright red colour. (The depth of these lakes should be borne in mind.) Fairbridge (1945) discusses the possibility of coloration of *Boeckella opaqua* Fairbridge being a protection against intense light in shallow pools. This would not apply in Lake St. Clair where the depth is measured in hundreds of feet, and, in addition, red Copepods were taken in mid-winter when the intensity of light is at a minimum. In August, 1937, for example, the noon catches showed more red Copepods at a depth than at the surface, so the red pigmentation can hardly be for protection against sunlight.

7. The Fauna of the Lake

A. Animals Caught in Lake

The following is a list of the various animals seen or caught in the waters of Lake St. Clair:—

(1) Floating population (plankton)—
- (A) Copepoda
  - (*a*) Calanoida (Family Centropagidae)—
    - *Boeckella longisetosa* Smith, was very plentiful.
  - (*b*) Cyclopoida (Family Cyclopoidae)—
    - Cyclops (probably *C. albicans* Smith), relatively few.
    - Cyclops—a species not previously recorded from Tasmania—very few.
- (B) Cladocera
  - Daphniidae
    - *Ceriodaphnia hakea* Smith.
    - *Ceriodaphnia planifrons* Smith.
    - *Bosmina sorelli* Smith.
    - *Bosmina rotunda* Smith.

(2) Free swimming—
- Fish (seen, but not caught)
- Platypus (seen, but not caught)

(3) Bed scramblers—
- Cypris (one specimen only). Ostracoda.
- Shrimps—
  - *Anaspides tasmaniae* Thomson. Anaspidacea.
  - *Chiltonia australis* (Sayce). Amphipoda.
  - *Gammarus* sp.
  - *Phreatoicus* sp. Isopoda.
- Crayfish. *Astacopsis tricornis* Clark. Decapoda.
- Snails. Small f.w.sp. Mollusca.
- Insect larvae. Caddis fly. Dragon fly. Stone fly. May fly.
- Arachnida. Water mites.
- Flatworms. Planarians. Platyhelminthes.

As mentioned previously, the main study centres around the plankton Crustacea. Of these, the main member was *Boeckella longisetosa*. Of this genus, Geoffrey Smith (1909) says that it is typical of the cold highland tarns of Tasmania and characteristic of the temperate parts of the Southern Hemisphere, except South Africa. (One species of the genus has since been found in Mongolia.) Also characteristic are the genera *Chiltonia* and *Astacopsis* (or close relatives in other parts of the Southern Hemisphere).

B. Sample of Collecting Records

In order to make the figures given in succeeding sections clear, the following sample is given from the actual records made during and after each trip to the lake:—

Surface

Nov. 20th, 1937	Copepoda		Cladocera	Eggs			Index of Plankton Total Catch	Remarks
	Calanoida a.	Cyclopoida b.	c.	Cal.	Cyc.	Clad.	d.	
0.00 a.m.	35	2	4	—	—	1	8·2	98% cloud. Moon. Calm
3.00	29	2	9	1	1	1	8·0	99% cloud. Moon. Calm
6.00	32	1	3	1	1	1	7·2	Sunrise 5.00 a.m. 100% cloud. Calm
9.00	20	2	4	1	—	1	5·2	20% cloud. Slightly choppy. N. Wind
12 noon	9	0	1	1	—	—	2·0	Fine. Sunny. Slight ripple
3.00 p.m.	6	2	1	—	—	—	1·8	As for noon
6.00	40	3	7	—	1	1	10·0	Sunset. W. Wind. Confused ripples but not rough
9.00	37	5	5	—	—	1	9·4	Moon not yet risen. Fairly calm. Occasional gusts
Total	208	17	34				51·8	
Average	26·0	2·1	4·3				6·5	

Each of the figures in columns Copepoda, Cladocera and Eggs is given as a total count over five squares of the counting slide (see Section 5, G. Method (2)). These are averaged at the bottom of each column and used as an indication of the groups of plankton Crustacea present in the lake for the month of November.

As an indication of the total number of plankton in the surface waters at each of the given times, the horizontal total is divided by five, giving the average number of plankton Crustacea per square of the counting slide. From each such index the total catch may be calculated as follows:—

e.g., at 0·00 a.m. Index figure 8·2.

$\therefore$ Total catch $= 8{\cdot}2 \times 10 \times 707 = 57{,}974$.

(One-tenth of the catch was used in counting-dish, which covered 707 squares of the counting-slide.)

8. Seasonal Distribution of the Plankton

A. The Plankton as a Whole

In order to study this, Table 17 was drawn up, showing the summary of the monthly plankton catches in horizontal hauls at the surface and at a depth of 15 feet. The mean of these for each month is given in column 'e'.

The results are shown graphically in fig. 5, reading from the right-hand axis. The graph is taken for twelve months only from May, 1937, the investigations after that time serving as a check on the results obtained over this period. It will be seen from the table that there is a correspondence between the catches in the same month of succeeding years.

Table 17

Summary of Monthly Plankton Catches (Horizontal Hauls)

a. Calanoida.
b. Cyclopoida.
c. Cladocera.
d. Total Plankton (Index No.).
e. Mean Surface and Depth.

Date	Surface				Depth (15 feet)				
	a	b	c	d	a	b	c	d	e
1937—									
18-19 May	14·4	2·9	7·8	5·0	(19 June)				5·0
26 June	8·3	0·5	2·3	2·2	22·1	1·4	5·3	5·8	4·0
24 July	23·0	0·5	2·0	5·1	21·3	0·4	1·8	4·7	4·9
27 August	32·5	3·5	1·0	7·4	36·9	1·6	6·0	8·9	8·2
23 September	28·5	2·9	1·9	6·7	17·5	3·3	3·0	4·8	5·8
23 October	14·3	1·0	1·1	3·3	24·9	1·7	2·1	5·7	4·5
20 November	26·0	2·1	4·3	6·5	43·9	3·0	4·4	10·3	8·4
21 December	27·3	0·5	11·9	7·9	36·9	1·1	25·5	12·7	10·3
1938—									
26 January	17·6	0·0	68·3	17·2	17·3	0·1	75·7	18·6	17·9
11 February	4·4	0·6	47·3	10·5	4·6	0·8	43·1	9·7	10·1
18 March	53·3	1·3	14·0	13·7	50·9	2·8	19·8	14·7	14·4
20 April	4·6	2·5	10·5	3·5	9·6	3·0	10·8	4·7	4·1
16 May	10·8	1·0	9·3	4·2	14·3	0·8	6·8	4·4	4·3
16 July	2·8	0·3	5·3	1·7	2·0	0·3	3·0	1·1	1·4
30 August	6·8	3·0	6·3	3·2	13·0	3·5	9·8	5·3	4·3
*18 October	13·3	2·5	1·8	3·5	16·0	2·3	4·3	4·6	4·1
3 December	25·5	3·0	12·3	8·2	41·8	4·3	15·8	12·4	10·3
1939—									
25 February					16·4	0·2	66·4	16·6	16·6
*12 April	25·0	2·8	11·8	7·9	47·5	4·0	19·5	14·2	11·1
20 May					13·0	1·0	5·5	3·9	3·9

* No. 1 mesh. Surface.

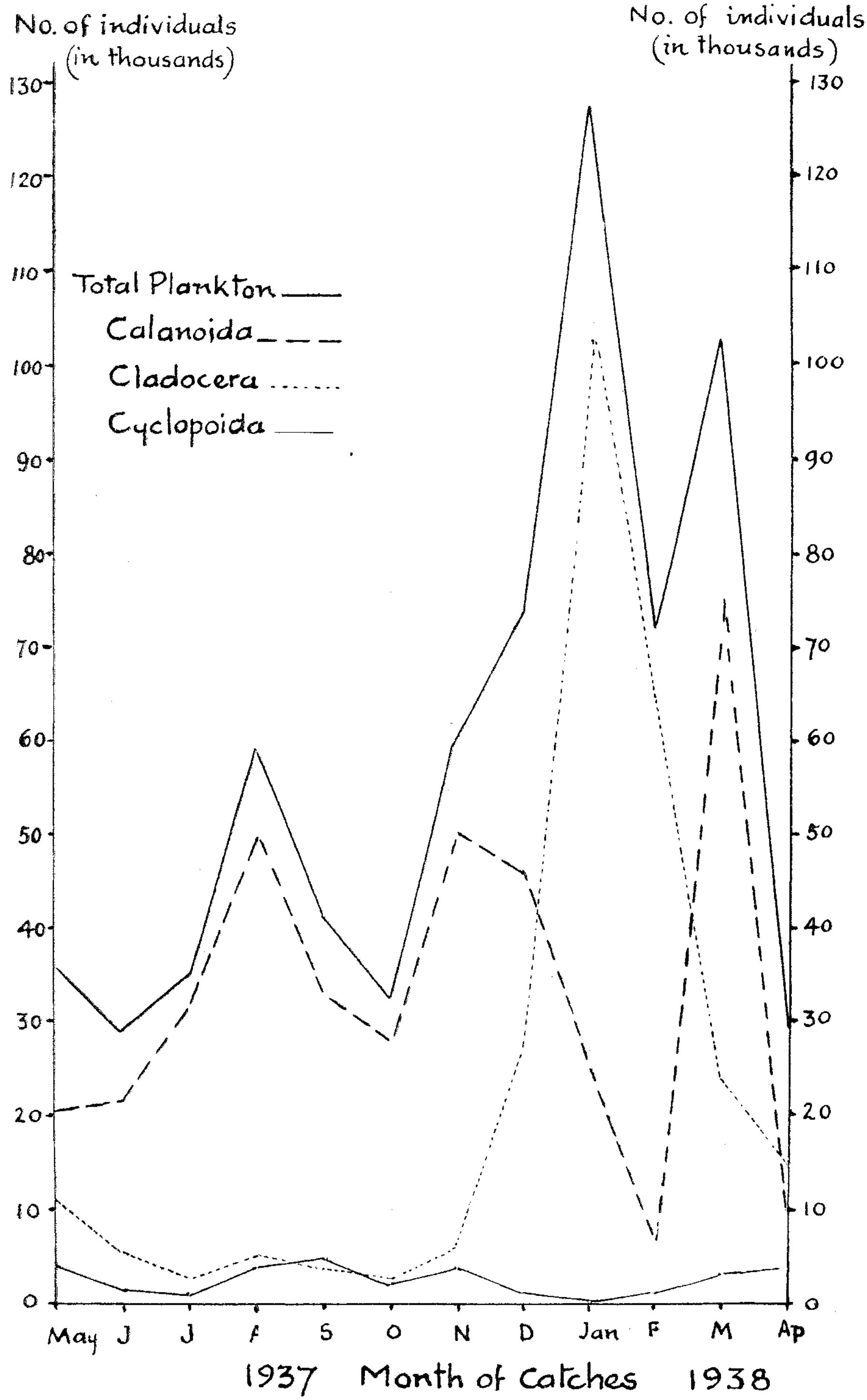


FIG. 5.—Seasonal distribution of the plankton. Mean of surface and depth horizontal monthly catches (see Tables 17 and 18).

During the first twelve months, eight tows per day were carried out on one day each month. Thereafter less tows per day (usually four) were carried out, so that the figures given from May, 1938, onwards are the average of a smaller number of tows, from which the same accuracy as for the first year cannot be expected. However, useful comparisons for checking purposes can still be made.

Plankton totals represented by values given in Tables 17 and 18.

Groups (a, b, c). Total $= \frac{a}{5} \times 10 \times 707$.

Averages (d, e). Total $= d \times 10 \times 707$.

N.B.—a, b, and c give total count over five squares, averaged out for the number of catches taken during each collecting trip to the lake.

TABLE 18

Mean of Surface and Depth Monthly Horizontal Catches

Month	a Calanoida	b Cyclopoida	c Cladocera	
1937—				
May	14·4	2·9	7·8	
June	15·2	1·0	3·8	
July	22·2	0·5	1·9	
August	34·7	2·6	3·5	*Percentages* (12 months from May, 1937)
September	23·0	3·1	2·5	
October	19·6	1·4	1·6	Copepoda 61·2% Cladocera 38·8%
November	35·0	2·6	4·4	
December	32·1	0·8	18·7	{ Calanoida 57·0% }
				{ Cyclopoida 4·2% }
1938—				
January	17·5	0·1	72·0	
February	4·5	0·7	45·2	
March	52·1	2·1	16·9	
April	7·1	2·8	10·7	
May	12·6	0·9	8·2	
July	2·4	0·3	4·2	
August	9·9	3·3	8·2	*Percentages* (for period May, 1938, to April, 1939)
October	14·7	2·4	3·1	
December	33·7	3·7	14·1	Copepoda 53·9% Cladocera 46·1%
1939—				{ Calanoida 48·4% }
February	16·4	0·2	66·4	{ Cyclopoida 5·5% }
April	36·3	3·4	15·7	
May	13·0	1·0	5·5	

The minimum average catch of about 28,000 'plankters' was recorded in June and the maximum of over 120,000 in January.

In the succeeding year, remembering that trips to the lake and the number of tows per day during those trips were not quite so frequent, the minimum of 10,000 plankters was recorded in July and the maximum of about 117,000 in February.

Thus there is a well-marked autumn or early winter minimum and a summer maximum. A small mid-winter maximum, followed by a slightly higher spring minimum, separates these major points.

Summarizing:—

Small mid-winter maximum.

Large summer maximum.

With almost equal minima in late autumn and spring respectively.

The part played by the various groups in causing these maxima and minima is examined in the succeeding sections, Table 18 having been drawn up for this purpose.

B. Seasonal Distribution of the Calanoid Copepoda

Boeckella longisetosa was the only species. The seasonal distribution of the group is given in Table 18 and graphically in fig. 5. The Calanoida constitute 57 per cent of the plankton, so that their variations exert a profound influence on the total plankton.

The Calanoida are definitely '*perennial planktonts*', their numbers remaining reasonably large throughout the year (minimum 6400). In this connection the much lower minimum of 3400 in July, 1938, should be noted.

Maxima occurred in August (49,000), November (49,500), March (73,000). At the March maximum the Calanoida constituted 72·4 per cent of the total plankton.

Minima occurred in October (28,000), February (6400), and April (10,000).

In the 1938-39 period maxima were recorded in December and April (51,000) with minima in July (3400) and February (23,000).

These do not correspond with the figures of the previous year as well as do those of the Cyclopoida, even after allowing for the reduced number of hauls made during 1938-39.

There would appear to be spring and autumn maxima with summer and winter minima, but these are not clearly defined and the Calanoida on the whole are more uniformly distributed throughout the year than are the other two groups. The low July, 1938, minimum is entirely responsible for the very low total plankton of 10,000 since the other groups were present in normal numbers as compared with the previous year.

C. Seasonal Distribution of the Cyclopoid Copepoda

Of these, the smaller species provisionally identified as *Cyclops albicans* was more plentiful, whilst a large species, probably of the same genus, was much less frequent. The graph, fig. 5, shows the seasonal distribution of the Cyclopoida for 1937-38. It will be noticed from Table 18 that this group represents only about 5 per cent of the plankton Crustacea.

Maxima occurred in May (4100), September (4400), and November (3700).

Minima occurred in July (700), October (2000), and January (140).

As a similar series of changes occurred during 1938-39, it may be stated that there are approximately equal autumn and spring maxima with winter and summer minima.

The October minimum is only relative, but should not be completely ignored as it occurred in both years.

Compared with the range of total plankton the variation in the Cyclopoida is not very great and does not appreciably affect the total.

D. Seasonal Distribution of the Cladocera

Having an annual occurrence of 40 per cent, these Crustaceans, with the Calanoida, constitute the bulk of the plankton, but the annual variation is much greater than either of the other two groups. Thus in January, 1938, the Cladocera (102,000) comprised 80·4 per cent of the total plankton, whilst in August, 1937 (4900), there were only 8·6 per cent.

It is a remarkable fact that in both 1937-38 and 1938-39 the large Cladoceran population was accompanied by a relatively low occurrence of both groups of Copepoda, especially the Calanoida.

The graph on fig. 5 (from Table 18) shows a very small late winter maximum of 4900 in August and a very large summer maximum of 102,000 in January.

The minima in winter and spring were recorded in July (2700) and October (2300) respectively.

The late winter maximum is so close to the neighbouring minima that the main variations might well be stated as a low winter minimum followed by a high summer maximum.

The corresponding extremes for 1938-39 are very similar, viz.:—

Maxima

Small late winter maximum, 12,000 in August.

Very large summer maximum, 94,500 in February.

Minima

Mid-winter minimum, 5950 in July.
Spring minimum, 4400 in October.

The correspondence in the periods of the extremes is remarkably close in these two years for the Cladocerans, so that, whilst the generalisation stated above may be accepted, the small late-winter maximum in August of both years would appear to have some significance.

E. General Discussion on the Seasonal Planktonic Distribution

The various maximum and minimum catches were further examined in order to determine more precisely which organisms contributed to each extreme.

(1) *Plankton Minimum, June,* 1937

(*a*) *Calanoids.—Boeckella longisetosa* was represented by a few large specimens, females—slightly smaller males, and many smaller specimens—apparently well-developed copepodids. Eggs were plentiful.

(*b*) *Cyclopoids.*—Cyclops species. The large species measuring about 2 mms. in length was present in small numbers.

(*c*) *Cladocera.—Bosmina sorelli* and *Ceriodaphnia hakea* were present in slightly greater numbers than Cyclops.

(2) *August Maximum,* 1937

(*a*) Boeckella was very numerous. Some fully-grown females and a smaller number of males were observed, but the majority appeared to be copepodids in their later stages. Some eggs were present.

(*b*) Cyclops was represented by the larger species in small but noticeable numbers.

(*c*) The Cladocera were for the most part conspicuous by their absence, being represented by *Bosmina sorelli* (measuring about 0·3 mms.).

(3) *Calanoid Maximum, November,* 1937

(*a*) The Calanoid maximum was caused chiefly by mature species of Boeckella. most of them being females.

(*b*) Cyclops (large) carrying eggs was observed.

(*c*) The Cladocerans were represented by all four species named in 8 (A). *Bosmina rotunda* was present in very small numbers. *Bosmina sorelli* constituted the majority with Ceriodaphnia spp. next.

Eggs.—All the above groups were carrying eggs in November. The number of eggs was at a minimum for all groups from July to October, but thereafter steadily increased into the summer of 1937-38, falling away again by May, 1938.

(4) *Plankton (and Cladoceran) Maximum, January,* 1938

(*a*) Most of the Calanoids were large.

(*b*) Only one Cyclops was seen on the counting squares.

(*c*) The plankton maximum was due almost entirely to the Cladocerans, *Bosmina sorelli,* and *Ceriodaphnia hakea,* with smaller numbers of *C. planifrons.*

(5) *Copepod Minima, February,* 1938

(*a*) The Calanoids were of normal adult size.

(*b*) The Cyclopoida included both large and small species. The 3 a.m. depth catch in this month was unique in that more Cyclopoida than Calanoida were present (ratio 3 : 1).

(*c*) The usual Cladocerans were present.

(6) *Plankton (and Calanoid) Maximum, March,* 1938

(*a*) Boeckella was present in overwhelming abundance. Some were large, and there were many large copepodids. Eggs were plentiful.

(*b*) There were a few large Cyclopoida and rather more smaller ones.

(*c*) The Cladocerans noted were *B. sorelli, C. hakea,* and *C. planifrons,* the two latter with eggs.

F. NATURE OF THE CALANOID AND CLADOCERAN PEAKS (1937-38)

(*a*) *Calanoida.*—From fig. 5, observations just reported and the note on the relative numbers of the sexes (Section 9 H) it is possible to form an opinion as to the meaning of the main peaks and troughs in the seasonal variations of the Calanoida.

Eggs, plentiful in May and June, hatched to cause the peak, of juvenile specimens, in August. Then followed a minor trough to the November peak, which consisted chiefly of adult females with some copepodids and a few males.

In January and February, with eggs at a maximum, adults only were present, to cause the summer minimum. These were breeding specimens giving rise to the large summer maximum in March, when many copepodids were accompanied by a few adult females and practically no males.

(*b*) *Cladocera*.—The following is a summary for the four species:—

(i) *Bosmina rotunda*, which was never plentiful, had a maximum in November.

(ii) *Ceriodaphnia planifrons* was most in evidence from November to April.

(iii) *Bosmina sorelli* caused a small maximum in August.

(iv) *C. hakea* and *B. sorelli* reached maxima in January.

(v) No males were observed.

Thus all four species were present in larger numbers during the summer months, *C. hakea* and *B. sorelli* contributing most of the Cladoceran summer maximum. This coincided with the highest mean monthly temperature (57·0°F., see Table 1) for the twelve months (1937-38). The summer maximum in 1938-39 showed a similar agreement with temperature (mean 61·2°F.). Thus the warmer temperatures favoured increased production of Cladocera.

G. Relation between Seasonal Planktonic Distribution and Introduced Fish

(*a*) *Brown Trout*.—The first brown trout hatch out at the time of the August Calanoid maximum and, as they feed on the plankton for only a few weeks, there is ample food available. The Calanoida are so much larger than the Cladocera that the volume of food available from this source in August compares quite favourably with that available in January from the Cladoceran maximum. This applies practically throughout the year as far as the Calanoida are concerned, except, possibly, in February, when, however, the Cladocera are still present in large numbers. The last brown trout hatch out about the middle of September and, therefore, by the end of October, when there is a plankton minimum, will have ceased to feed extensively on the plankton. For the young brown trout, therefore, the supply of food-plankton is ample.

(*b*) *Rainbow Trout*.—The rainbow trout hatch out from during October and November, feeding on the plankton until about the end of the year. They thus arrive when the numbers of Calanoida are increasing from what is only a minimum to substantially higher numbers in November and December, associated with a steady increase in the Cladocera. Thus the food-plankton available has reached very satisfactory proportions.

9. Diurnal Distribution of the Plankton

A. The Plankton as a Whole

Tables 19 and 20 set out the index figures for the total plankton catch at three-hour intervals one day per month for the twelve months from May, 1937.

Depth catches were not taken in conjunction with the surface catches in May, 1937. The other gaps are due to conditions preventing a catch being made, or to the depth net fouling the lake-bed. The letter ' P ' indicates the presence of plankton, but in numbers insufficient for counting by the method adopted.

TABLE 19

Total Surface Plankton—Index No. of Monthly Diurnal Catches

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m.	5.2	4.2	4.4	4.8	6.0	2.2	8.2	8.2	19.4	15.6	18.2	7.0	103.4	8.6
3 a.m.	7.2	1.8	6.2	7.8	3.0	5.4	8.0	6.6	15.6	13.6	14.6	4.4	94.2	7.9
6 a.m.	6.2	1.4	7.4	9.6	1.8	0.6	7.2	9.4	13.2	11.6	7·2	4.0	79.6	6.6
9 a.m.	1.0	1.2	1.0	7.8	1.0	4.4	5.2	13.2	22.0	5.8	21.0	1.4	85.0	7.1
12 noon	P	1.2	1.0	1.0	0.4	—	2.0	6.2	10.6	6.2	7.2	1.0	36.8	3.3
3 p.m.	6.6	0.6	2.0	2.6	3.4	4.8	1.8	4.6	—	8.2	7.2	1.0	42.8	3.9
6 p.m.	10.4	4.2	11.8	16.4	27.2	3.4	10.0	11.0	29.6	7.0	18.8	5.4	155.2	12.9
9 p.m.	3.4	3.0	7.0	9.2	10.4	2.2	9.4	4.2	9.8	15.6	15.4	4.0	93.6	7.8

TABLE 20

Total Depth Plankton—Index No. of Monthly Diurnal Catches

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m.		4.0	—	5.4	8.6	3.0	5.4	11.2	9.0	17.8	17.8	5.2	87.4	8.7
3 a.m.		3.6	3.8	8.6	3.4	8.4	7.0	8.0	11.8	10.8	11.0	2.0	78.4	7.1
6 a.m.		4.4	3.4	7.0	4.6	4.2	6.4	16.0	24.2	4.6	16.8	5.4	97.0	8.8
9 a.m.		3.4	4.4	8.2	2.2	7.2	13.4	21.4	14.6	10.4	12.4	5.6	103.2	9.4
12 noon		5.0	5.4	9.8	3.8	—	12.4	24.6	23.6	6.4	22.8	4.8	118.6	11.9
3 p.m.		6.8	4.0	12.2	4.4	5.8	15.2	9.8	—	8.2	17.6	4.2	88.2	8.8
6 p.m.		11.8	7.4	12.0	6.4	8.0	14.2	7.6	31.6	8.0	13.2	7.8	128.0	11.5
9 p.m.		7.0	8.8	8.0	4.6	3.6	8.0	3.0	15.6	11.4	5.8	2.4	78.2	7.1

An analysis of these tables is of less value than the examination of the tables following in parts B, C, and D of this section, where are set out the corresponding catches of each group of Crustacea contributing towards the total catches indicated in Tables 19 and 20.

The averages in Tables 19 and 20 are shown in fig. 6 by line graphs, the latter showing diagrammatically how the plankton Crustacea as a whole shunned the surface at midday but congregated there at dusk, with even distribution at midnight.

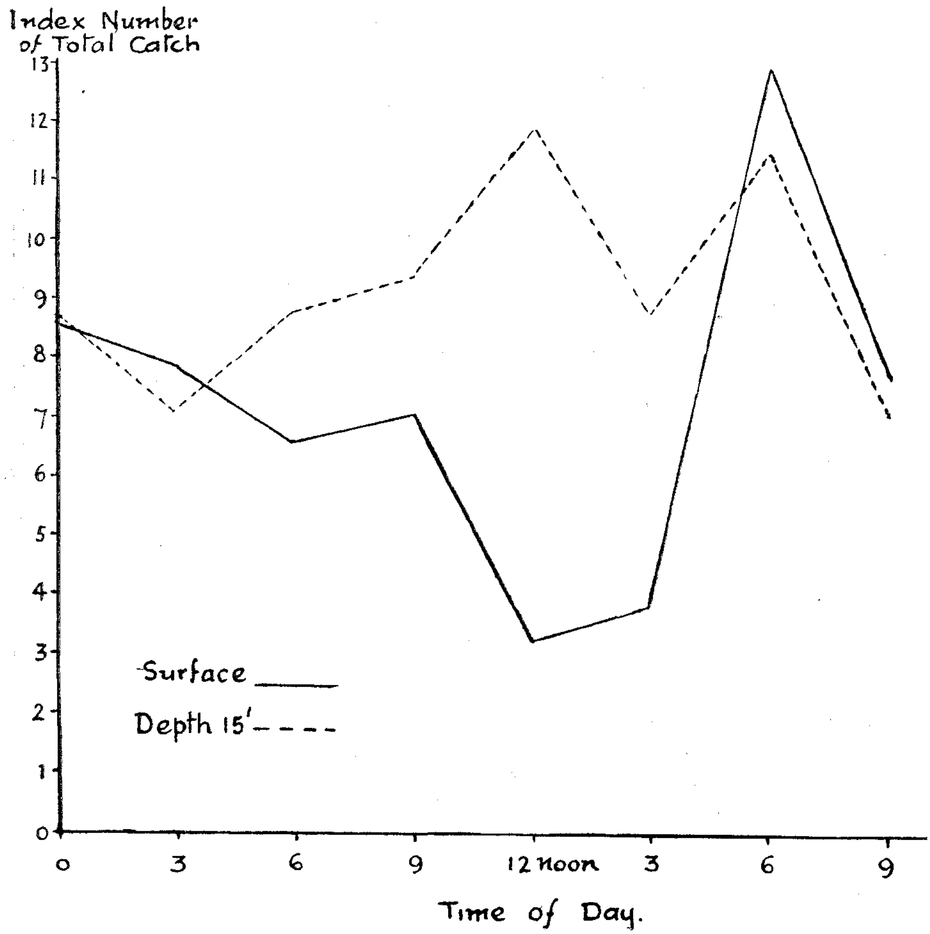


FIG. 6.—Total plankton—Average of diurnal catches over 12 months (see Tables 19 and 20).

The diurnal movement of plankton has been the subject of much investigation by Russell (1925, *et seq.*), Gardiner (1934), Johnson (1938), Shallek (1942, *et seq.*), Pennak (1944), and others. The present investigation was of too wide a nature to make possible detailed findings in this connection, but the observations for surface and depth (15 feet) plankton over so many months make some contribution towards the general pool of knowledge of diurnal migrations.

B. Diurnal Distribution of the Calanoid Copepoda *(Boeckella longisetosa,* Smith*)*

(1) *Annual Mean*

Tables 21 and 22 set out the total count over five squares of Boeckella for each diurnal catch over the same period as already given for total plankton. In fig. 7 these results are shown graphically, whilst fig. 8 compares these results for each of the three plankton groups by block graphs.

Fig. 7.—Diurnal distribution of Calanoida (Boeckella). Annual average for each time of day (see Tables 21 and 22).

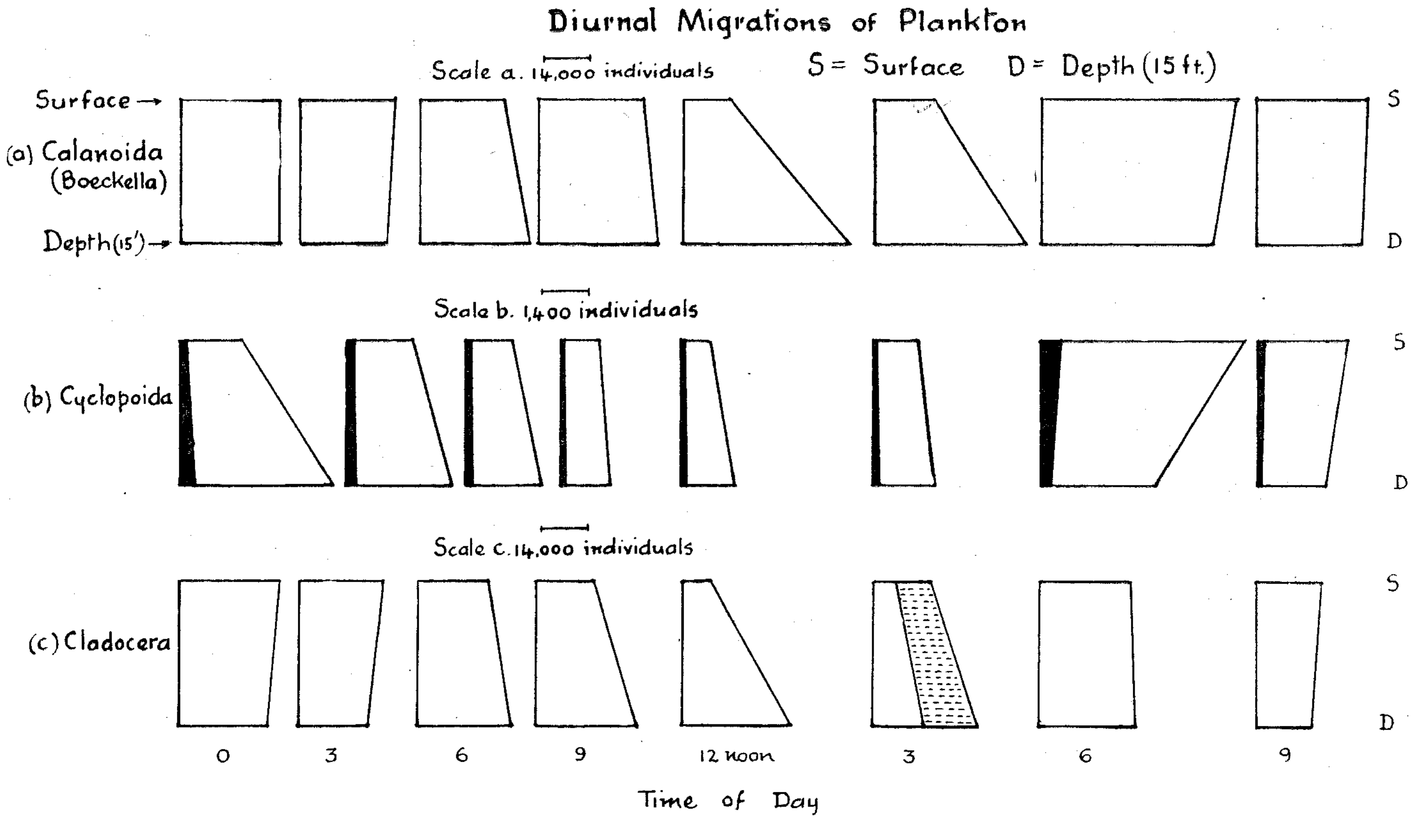


FIG. 8.—Diagrams showing the relative numbers of each plankton group at the surface and at a depth of 15 feet, obtained by averaging the catch for each time shown over a twelve-month period. Note that the scale for the Cyclopoida (*b*) is ten times that of the other two groups owing to the small numbers of the former present. The black portion represents the Cyclopoid catches drawn to the same scale as the other two groups. The dotted portion shown at 3 p.m. for the Cladocera indicates the possible catches, had one important tow not been missed (see Section 9D).

Since Boeckella is the dominant member of the plankton Crustacea, it is not surprising to find that its diurnal distribution closely approximates the migrations indicated already for total plankton—cf. figs 6, 7 and 8*a*.

The distribution may be summarised as follows:—

9 p.m. to 9 a.m., even distribution.

12 noon, minimum at surface.

6 p.m., maximum in the upper layers.

During darkness the results for surface and depth remain reasonably uniform at a figure below the maximum for either. This suggests the even distribution indicated above, especially since the maxima referred to are recorded at one time only, viz., 6 p.m. (surface and depth). Hence at 6 p.m. there is a maximum in the upper layers.

(2) *Optimum Light Intensity*

At 12 noon the depth reading is shown as approaching that of the depth maximum, whilst the surface reading has reached a minimum. Although regular readings at lower depths are not available, it seems reasonable to conclude from these observations that at mid-day Boeckella favours the light intensity at about this depth. Whether the actual depth of the optimum changes with seasonal variations in the intensity of sunlight will be considered later.

TABLE 21

Diurnal Surface Catches of Boeckella

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m.	8	20	21	19	26	9	35	27	2	2	78	5	252	21
3 a.m.	26	4	27	32	9	24	29	20	4	1	60	5	241	20
6 a.m.	17	3	33	42	6	2	32	32	22	2	16	4	211	18
9 a.m.	2	3	3	37	3	19	20	49	19	5	105	4	269	22
12 noon .	P	4	4	4	1	—	9	22	22	7	33	2	108	10
3 p.m.	29	2	8	12	16	22	6	20	—	4	24	2	145	13
6 p.m.	28	19	56	74	121	15	40	37	30	6	63	5	494	41
9 p.m.	5	11	32	40	46	9	37	11	24	8	47	10	280	23

TABLE 22

Diurnal Depth Catches of Boeckella

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m. ...		11	—	23	33	10	18	39	3	5	63	7	212	21
3 a.m.		12	17	30	12	38	26	22	4	1	32	4	198	18
6 a.m. ...		17	16	30	17	19	25	58	9	1	49	10	251	23
9 p.m. ...		12	17	24	8	31	57	62	4	5	47	8	275	25
12 noon		19	26	41	10	—	57	69	29	11	86	5	353	35
3 p.m. ...		28	18	56	19	25	68	20	—	4	70	10	318	32
6 p.m. ...		53	35	55	24	35	64	18	37	5	46	26	398	36
9 a.m.		25	41	36	17	16	36	7	35	5	14	7	239	22

(3) *Seasonal Changes in Diurnal Movements*

A further examination of Tables 21 and 22 shows that the mean diurnal distribution over the twelve-month period may be considered in two groups:—

1. April to September.
2. October to March.

Tables 23 and 24 give the analyses of the above tables in terms of these two periods. As an indication of the total numbers of Boeckella present in the upper layers, the sum of the surface and depth averages is given in the last column of each table.

TABLE 23

Totals and Averages—Diurnal Recordings of Boeckella April to September

Surface	Total	Average (S)	Depth Total	Average (D)	Total in Upper Layers (S + D)
0 a.m.	99	17	74	19	36
3 a.m.	103	17	75	15	32
6 a.m.	105	17	90	18	35
9 a.m.	52	9	69	14	23
12 noon	15	3	101	20	23
3 p.m.	69	12	131	26	38
6 p.m.	303	51	193	39	90
9 p.m.	144	24	126	25	49

TABLE 24

Totals and Averages—Diurnal Recordings of Boeckella October to March

Surface	Total	Average (S)	Depth Total	Average (D)	Total in Upper Layers (S + D)
0 a.m.	153	26	138	23	49
3 a.m.	138	23	123	21	44
6 a.m.	106	18	161	27	45
9 a.m.	217	36	206	34	70
12 noon	93	19	252	50	69
3 p.m.	76	15	187	37	52
6 p.m.	191	32	205	34	66
9 p.m.	136	23	113	19	42

1. *April to September*

The diurnal migration over this period corresponds closely with that of the annual mean (cf. fig. 8 (*a*)), showing a definite surface minimum during the early daylight hours to noon and a very definite maximum at 6 p.m. The fact that the minimum occurs in the morning suggests that thereafter the animals have adapted themselves to the light intensity nearer the surface, moving upwards as the light fades at dusk. From then on they start sinking until evenly distributed.

Summarising:—

0-9 a.m.	Even distribution.
9 a.m.-12 noon	Minimum at surface.
6 p.m.	Maximum in the upper layers.

As:—(i) The depth reading at noon is only 51 per cent of the depth maximum at 6 p.m.; and

(ii) The total numbers of Boeckella in the upper layers at noon is only 26 per cent of those at 6 p.m.,

then it is obvious that the autumn and winter broods of Boeckella prefer a mid-day light intensity at a depth lower than 15 feet.

2. *October to March*

These figures (cf. fig. 8 (*a*)) show that diurnal migrations of Boeckella are less marked during the spring and summer months and the correspondence with the annual mean is not nearly as marked as during the autumn and winter months. There is no definite minimum in the upper layers, whilst maxima are recorded in late morning and at dusk.

The tendency seems to be as follows:—

9 p.m. to 9 a.m.	Even distribution.
9 a.m. to 12 noon	Maximum in upper layers.
12 noon to 3 p.m.	Sinking to avoid strong summer sun.
6 p.m.	A near-maximum in the upper layers.

The sinking movement seems to affect only the near-surface population, as at 3 p.m. there are two-and-a-half times as many at 15 ft. depth as at the surface. Soon afterwards, as the sun's rays become less direct, a movement towards the surface sets in. Once again, therefore, as suggested by the annual mean, it seems that the region of optimum light intensity is in the vicinity of 15 ft. depth. From the groupings it would appear that the spring and summer broods prefer a higher light intensity than the autumn and winter broods.

C. Diurnal Distribution of the Cyclopoid Copepoda

Tables 25 and 26 and figs 8 (*b*) and 9 set out the diurnal results for twelve months for the Cyclopoida. The relatively small numbers present make analysis more difficult than in the other groups.

All reasonable maxima in the surface catches were recorded at 6 p.m. (one at 9 p.m.), i.e., at dusk, whereas the minima were apparently at about mid-day.

At 15 ft. depth (table 26) the minima were usually recorded between 9 a.m. and 3 p.m., i.e., during daylight, whilst the maxima were recorded between 6 p.m. and 3 a.m., i.e., during hours of darkness. This was especially noticeable during the spring and summer months (when dusk is later than 6 p.m.), the maxima being more marked and all between midnight and 3 a.m.

Adding the averages for surface and depth we get:—

0 a.m.	4·5	These figures show once again:—
3 a.m.	3·6	A minimum in the upper layers at noon.
6 a.m.	2·6	A maximum at 6 p.m.
9 a.m.	1·8	A tendency towards even distribution during darkness.
12 noon	1·7	
3 p.m.	2·2	
6 p.m.	6·7	
9 p.m.	3·4	

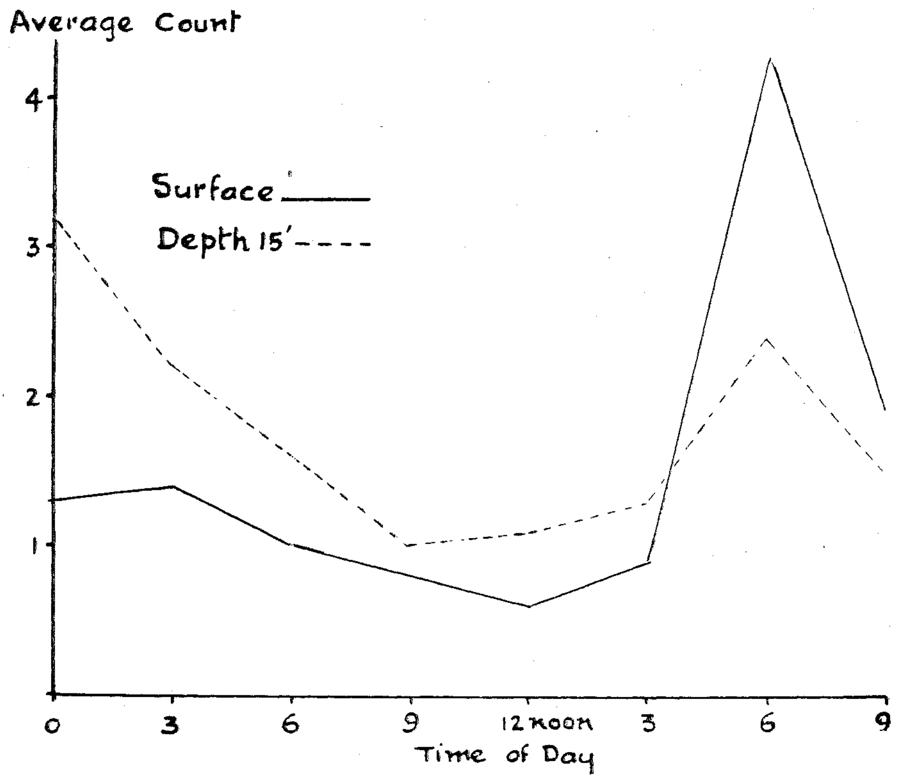


FIG. 9.—Diurnal distribution of the Cyclopoida. Annual average for each time of day (see Tables 25 and 26).

One striking feature of fig. 9 is that the surface and depth graphs follow the same general directions, whereas they take the opposite directions during daylight for the Calanoida (fig. 7) and for the Cladocera (fig. 10). On the average, from midnight to 3 p.m., the surface reading is always less than the depth reading, and even when between 3 p.m. and 6 p.m. the graphs cross for the 6 p.m. surface maximum, the depth reading shows a similar, though pronounced, upward trend; both fall again immediately.

The inference from these graphs is that the Cyclopoida dislike strong sunlight more than the other groups, and that their optimum conditions are found in the deeper water during daylight.

TABLE 25

Diurnal Surface Catches of Cyclopoida.

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m.	2	0	0	3	2	1	2	1	0	1	1	2	15	1.3
3 a.m.	2	1	1	5	2	1	2	0	0	1	1	1	17	1.4
6 a.m. ...	1	0	1	5	1	1	1	0	0	1	0	1	12	1.0
9 a.m.	1	1	0	1	1	1	2	0	0	1	0	1	9	0.8
12 noon	P	1	0	1	0	—	0	0	0	0	2	3	7	0.6
3 p.m.	1	0	1	1	0	1	2	0	—	0	2	2	10	0.9
6 p.m. ...	14	1	1	7	12	1	3	1	0	0	4	8	52	4.3
9 p.m. ...	2	0	0	5	5	1	5	2	0	1	0	2	23	1.9

TABLE 26

Diurnal Depth Catches of Cyclopoida

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m.		1	—	2	7	3	7	3	1	1	3	4	32	3.2
3 a.m. ...		2	0	2	3	2	4	1	0	3	4	3	24	2.2
6 a.m.		1	1	2	4	1	2	1	0	1	1	4	18	1.6
9 a.m.		1	1	0	1	1	2	0	0	0	4	1	11	1.0
12 noon		1	0	1	1	—	3	2	0	0	2	1	11	1.1
3 p.m.		1	0	1	1	1	1	1	—	0	3	4	13	1.3
6 p.m.		2	1	2	5	3	3	0	0	0	3	7	26	2.4
9 p.m.		2	0	3	4	1	2	1	0	1	2	0	16	1.5

D. DIURNAL DISTRIBUTION OF THE CLADOCERA

Tables 27 and 28 and fig. 8 (*c*) set out the total count over five squares of the Cladocera for each diurnal catch over the same twelve-month period already considered for the other groups. The following extract from the author's log for January, 1938, has a definite bearing on the consideration of these results:—

'The trip was, on the whole, notable for the roughest conditions so far recorded when towing. At 3 p.m. it was too rough to tow, but the boat was launched at 4 p.m. (26th January). However, there was too much debris, and the attempt was a failure.'

The 3 p.m. gap for January in tables 27 and 28 is unfortunate, as it probably throws out the averages more than a gap in any other month could have done. The catches would certainly have been large—all January, 1938, catches were. The average for the twelve months has not been adjusted to allow for this, but as the 3 p.m. average for both surface and depth would certainly have been much higher, the graph (fig. 10) ignores these low values and gives a more likely interpretation of the numbers of Cladocera present. Taking the new readings from this graph the block for 3 p.m. in fig. 8 (*c*) has been extended by dotted lines to show the same interpretation.

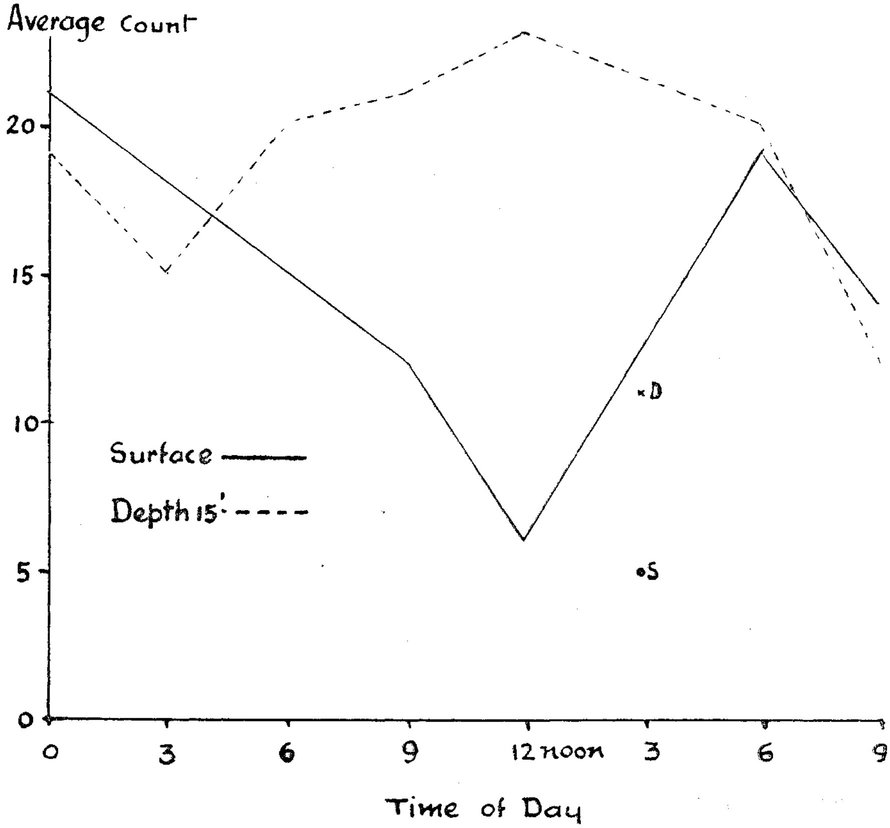


FIG. 10.—Diurnal distribution of the Cladocera. Annual average for each time of day (see Tables 27 and 28). S, D = the 3 p.m. averages have been omitted (see Section 9D).

Keeping this interpretation in mind the surface minimum is at about mid-day, whilst the maximum is recorded between 6 p.m. and midnight. The depth average minimum appears to be at 9 p.m., whilst the maxima are recorded in the daylight hours from 6 a.m. to 6 p.m. There is little difference in the congregations of Cladocera throughout the 24 hours at this depth, as, apart from the minimum already mentioned and a slightly higher minimum at 3 a.m., the range is from 19 to 23 (3 p.m. average omitted). At no time during daylight are there more at the surface than at the depth. This is true for the two seasonal groupings as well—see later.

A conclusion may be drawn that the Cladocera find their optimum conditions in the vicinity of this depth of 15 feet.

TABLE 27

Diurnal Surface Catches of Cladocera

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m.	16	1	1	2	2	1	4	13	95	75	12	28	250	21
3 a.m.	8	4	3	2	4	2	9	13	74	66	12	16	213	18
6 a.m.	13	4	3	1	2	0	3	15	44	55	20	15	175	15
9 a.m.	2	2	2	1	1	2	4	17	91	23	0	2	147	12
12 noon	P	1	1	0	1	—	1	9	31	24	1	0	69	6
3 p.m.	3	1	1	0	1	1	1	3	—	37	10	1	59	5
6 p.m. ..	10	1	2	1	3	1	7	17	118	29	27	14	230	19
9 p.m.	10	4	3	1	1	1	5	8	25	69	30	8	165	14

TABLE 28

Diurnal Depth Catches of Cladocera

Time	M 1937	J	J	A	S	O	N	D	J	F	M	A 1938	Total	Av.
0 a.m.		8	—	2	3	2	2	14	41	83	23	15	193	19
3 a.m.		4	2	11	2	2	5	17	55	50	19	3	170	15
6 a.m.		4	0	3	2	1	5	21	112	21	34	13	216	20
9 a.m.		4	4	17	2	4	8	45	69	47	11	19	230	21
12 noon		5	1	7	8	—	2	52	89	21	26	18	229	23
3 p.m.		5	2	4	2	3	7	28	—	37	15	7	110	11
6 p.m.		4	1	3	3	2	4	20	121	35	17	6	216	20
9 p.m. ...		8	3	1	2	1	2	7	43	51	13	5	136	12

Seasonal Changes in Diurnal Movements

A further examination of tables 27 and 28 shows that the mean diurnal distribution over the twelve-month period may be considered in two groups as follows:—

1. June to November.
2. December to May.

Tables 29 and 30 give the analysis of the above tables in terms of these two periods. As an indication of the total numbers of Cladocera present in the upper layers, the sum of the surface and depth averages is given in the last column of each table.

TABLE 29

Totals and Averages—Diurnal Recordings of Cladocera—June to November

Surface	Total	Average (S)	Depth Total	Average (D)	Total in Upper Layers (S + D)
0 a.m.	11	2	17	3	5
3 a.m.	24	4	26	4	8
6 a.m.	13	2	15	3	5
9 a.m.	12	2	39	7	9
12 noon	4	1	23	5	6
3 p.m.	5	1	23	4	5
6 p.m.	15	3	17	3	6
9 p.m.	15	3	17	3	6

TABLE 30

Totals and Averages—Diurnal Recordings of Cladocera—December to May

Surface	Total	Average (S)	Depth Total	Average (D)	Total in Upper Layers (S + D)
0 a.m.	239	40	176	35	75
3 a.m.	189	32	144	29	61
6 a.m.	162	27	201	40	67
9 a.m.	135	23	191	38	61
12 noon	65	11	206	41	52
3 p.m.	54	11	87	22	33
6 p.m.	215	36	199	40	76
9 p.m.	150	25	119	24	49

1. *June to November*

Fluctuations during the morning hours are very pronounced, but there is little variation from noon till midnight. Apart from maxima at 3 a.m. and 9 a.m. the numbers remain practically constant at slightly more than half the maxima. Allowing for possible experimental error, the diurnal migration of the Cladocera during the winter and spring months is not very great, although there is a definite downward trend at mid-day to avoid the sunlight.

2. *December to May*

The differences are less marked during the summer and autumn months. There is a surface minimum at mid-day with maxima likely from dusk to midnight (3 p.m. figure ignored). The small variation for the total in the upper layers suggests that the Cladocera tend to remain fairly evenly distributed at all times of the day and night. Since the depth maximum is recorded in conjunction with the surface minimum, their optimum light intensity at mid-day is not above 15 feet.

E. Examination of Diurnal Changes in Each Month

So far the diurnal observations have been discussed 'en masse'. It is now necessary to examine the actual variations for each sampling day over the period during which observations were made at Lake St. Clair, in order to see how the catches differed from the averages already determined and also to find out, if possible, what conditions other than light intensity influenced the catches.

In these results the probability of error is greater than in any of the preceding sections, because each reading is for one catch only, since a complete series of catches could be made on one day only in each month. The advantage of averaging, possible in all the early sections, is therefore lost. Gardiner (1934) mentions that netting fluctuations of $\pm$ 40 per cent are likely due to irregularity in horizontal distribution. From the general correspondence in results which, for example, made possible the seasonal groupings of diurnal readings, I am of the opinion that the fluctuations in this work were less than that figure. However, where any inexplicable divergence from what appears to be the normal diurnal variation occurs, the probability of error referred to above may be responsible.

The catches are recorded in tables 21, 22, 25, 26, 27, and 28.

May, 1937

The day for towing was preceded by eleven days of fine, clear, frosty weather.

a. Calanoida.—Small numbers of Boeckella were at the surface from 9 a.m. to noon. The maximum surface reading at 3 p.m., when the lake was choppy, was practically duplicated at 6 p.m. when it was calm and moonlight. Boeckella gradually descended until midnight, when the moon was setting, the air temperature then being 31°F. By 3 a.m., when the lake was choppy, a second maximum had been recorded, but at 6 a.m. (daybreak), with the sky clear and the lake calm, the animals were descending again.

From the general observations already made (9B) the surface maximum would be expected at dusk (6 p.m.). We find it almost duplicated at both 3 p.m. and 3 a.m. under choppy conditions.

Conclusions—

1. Vertical mixing probably occurs during disturbed conditions, since maxima were recorded when the lake was choppy.
2. Boeckella avoided the sunlight until 3 p.m. in the afternoon, by which time an adjustment to the light had taken place, perhaps combined with the effects mentioned in conclusion 1.
3. A similar, but less marked, reaction to moonlight occurred, the 3 a.m. maximum having been recorded after the moon had set.
4. There seems no reason to suppose that temperature affected the migration, as the 3 a.m. maximum was accompanied by freezing air conditions and the smaller catch at 6 a.m. accompanied milder air temperatures, the frost having thawed under the influence of a north-westerly wind.

b. Cyclopoida.—The Cyclopoida showed a decided maximum at 6 p.m. with the largest catch taken throughout the twelve months, and a definite minimum at 12 noon. For the remainder of the day the numbers were uniformly low.

Conclusions—

1. Calm conditions at the surface favoured the Cyclopoida.
2. Cyclopoida avoided the light by descending from the surface especially at noon.

c. CLADOCERA.—The Cladocera showed a minimum throughout the daylight hours, especially at noon, but increased at the surface to midnight, with a slight decrease at 3 a.m. This coincided with choppy water.

Conclusions—

1. Cladocera tended to descend when the water first became choppy.
2. Sunlight was avoided.
3. The Cladocera did not avoid moonlight since the surface numbers increased during the night.
4. Since the surface maximum was recorded when the air temperature was 31°F., the Cladocera were not very sensitive to cold surface conditions.

June, 1937

For a fortnight the lake had been perfectly calm, with clear, sunny days and extremely cold, frosty nights. As only one net of the right mesh was available on this occasion the surface and depth samples were taken on different days, so they will be discussed separately. However, the general conditions were remarkably uniform for each set of towings.

Depth Catches

The lake was calm throughout. At 9 a.m. the weather was foggy, with the air temperature at 30°F. The remainder of the day was fine and clear, with moonlight from 6 p.m. until 3 a.m. The air temperature dropped steadily from 33·6°F. at 6 p.m. to 21·8°F. at 6 a.m.

a. CALANOIDA.—Boeckella was at a maximum at 6 p.m. with moderately high numbers before and after, but a fairly steady, lower number was maintained from midnight to mid-day. This commends itself to us as possibly a typical depth variation under steady, perfect weather conditions.

b. CYCLOPOIDA.—Cyclopoida were in such small numbers that no conclusion can be drawn, except that, since most of the minima were recorded in daylight, they then prefer deeper water.

c. CLADOCERA.—Small numbers of Cladocera were recorded throughout, with maxima between 9 p.m. and midnight.

Surface Catches

The lake was calm, except between 12 noon and 3 p.m., when it was comparatively choppy. At 3 a.m. it was moonlight, with $33\frac{1}{3}$ per cent cloud. The temperature dropped from 24°F. at 3 a.m. to 20·5°F. at 6 a.m. The daylight hours were fine and clear. At 9 p.m. the moon was rising and the temperature was 26·3°. At midnight it was moonlight, but foggy, with the temperature 21·3°F.

a. CALANOIDA.—Boeckella was at a maximum from 6 p.m. to midnight and uniformly low from 3 a.m. to 3 p.m.

Conclusions—

1. Boeckella avoided the winter sunlight, coming to the surface in numbers only after sunset.
2. The moonlight had a similar effect at 9 p.m. and 3 a.m. When the maximum was recorded at midnight the moon's rays were almost obscured by fog.

b. CYCLOPOIDA.—Numbers insufficient for conclusions to be drawn.

c. CLADOCERA.—Small numbers were recorded, with maxima between 9 p.m. and 6 a.m., all during moonlight, and very small numbers during the day. The drop at midnight was accompanied by fog.

Conclusions—

1. Cladocera avoid sunlight.
2. Moonlight seemed to attract Cladocera. (However, this may be due to movement towards uniform distribution.) The numbers fell again at midnight when the moon was obscured by fog.

July, 1937

For a week past the weather had been squally and rainy. The lake was just becoming smoother on arrival. Temperatures were higher, snowy conditions replacing the still frosty weather of the previous month. Temperatures ranged from 30°F. at 3 a.m. to 39°F. at 9 a.m.. The lake was choppy for the mid-day and midnight tows. Snow fell at 1.30 p.m., 4 p.m., and during the 6 p.m., 9 p.m., and midnight tows. The depth net at midnight scraped the bottom, so the catch was valueless for quantitative work.

a. CALANOIDA.—The surface maximum was recorded at 6 p.m., when there were ripples only on the lake and the moon was just rising. There were snow squalls. Approximately equal high catches resulted at 6 a.m., with 99 per cent cloud, and 9 p.m. when snow squalls interfered with the moonlight. The daylight surface catches were all low, the 9 a.m. minimum being recorded in sunlight from a clear sky. At noon most of the Calanoids were at a depth, whilst during darkness distribution was more even. The depth catches were fairly uniform with a maximum at 9 p.m.

Conclusions—

1. External weather conditions, such as west wind, rain, sleet and snow, did not affect the normal migrational trends already recorded.
2. The contrast between 99 per cent cloud at 6 a.m. and the clear sky at 9 a.m. caused a big drop in the numbers at the surface at the latter time, i.e., the large increase in light intensity caused Boeckella to migrate downwards.
3. There was little evidence of an afternoon adjustment to light conditions.
4. Avoidance of moonlight is suggested in that the 3 a.m. catch (moonlight) is smaller than the 6 a.m. (99 per cent cloud).

b. CYCLOPOIDA.—Once again these were present in extremely small numbers, but the daylight catches were smaller than those immediately preceding and following them.

c. CLADOCERA.—Only small numbers were recorded with surface maxima from 9 p.m. to 6 a.m., all during moonlight. A drop at midnight was accompanied by choppy conditions. They avoided the sunlight.

August, 1937 (see fig. 2)

a. CALANOIDA.—Less were recorded in clear moonlight than when fog obscured the moon just at sunrise. The minimum was recorded in fine sunny conditions at noon, but overcast conditions favoured an increase from 3 p.m. to the maximum at 6 p.m. Surface catches were comparable with the depth catches from 6 p.m. to 6 a.m.

Conclusion.—The tendency for even distribution after the surface maximum at dusk seems to have been established.

b. CYCLOPOIDA.—During daylight these were at a depth greater than 15 feet, since equally small surface and depth catches were recorded. During 6 p.m. to 6 a.m., however, more were caught at the surface than at the depth, with maximum at 6 p.m., probably due to the calm conditions prevailing. Otherwise the normal tendency seems to hold, viz.:—

Darkness—even distribution.

Daylight—minimum at surface.

6 p.m.—surface maximum.

c. CLADOCERA.—Few were at the surface at any time, with a mid-day minimum. The surface maxima were recorded in moonlight.

September, 1937

The following note was made at the time:—' The outstanding catch was the 6 p.m. surface, the first calm trip, suggesting that the plankton descended to the lower levels during rough weather, but returned to the surface layers when the lake became smooth '.

a. CALANOIDA.—The catches from 3 a.m. to noon were all small, despite the cloudy conditions.

The lake was a little rougher than in previous months and had been for a week or so. This gives more data on the choppy conditions referred to in May, 1937.

Conclusion.—The process of mixing due to choppy water brought more to the surface at the same time as the usual 6 p.m. maximum—thus causing the very large maximum.

b. CYCLOPOIDA.—Similar results obtained here with small catches till 6 p.m.

Conclusions.—Slightly choppy conditions at first did not affect the migration of the Cyclopoida, but as these conditions were prolonged the Cyclopoida descended to steadier water. On the return of calmer conditions a movement to the surface occurred, this time coinciding with the normal upward movement at dusk, giving a larger maximum. From then onwards, conditions remaining calm, the normal course was resumed. In this case they moved towards nocturnal even distribution.

c. CLADOCERA.—These followed a normal sequence for both surface and depth catches, with no special evidence to suggest that rough conditions had affected the results.

October, 1937

The 12 noon gap here was caused by a northerly wind which made the lake too rough to launch the boat. Prior to this the lake had been fairly calm (choppy at 9 a.m.), but the remaining trips were all rough. This should be a good indication of the effect of rough water on the plankton, with little sunshine to influence movement during daylight.

a. CALANOIDA.—At midnight, with moonlight and a slight ripple, a small number was caught at both surface and depth. At 3 a.m., with 99 per cent cloud, the maximum catches were recorded with several times the midnight numbers at both surface and depth. The minimum catch was at daybreak, when the lake was still calm. A big increase occurred at 9 a.m., when the northerly had been blowing for nearly three hours. The sky was still overcast. The numbers remained large for the 9 a.m., 3 p.m., and 6 p.m. trips, in each case the depth catches being rather greater than the surface ones, as they were throughout the 24-hour period. By 9 p.m., with heavy rain, the numbers were smaller; the lake was still rough.

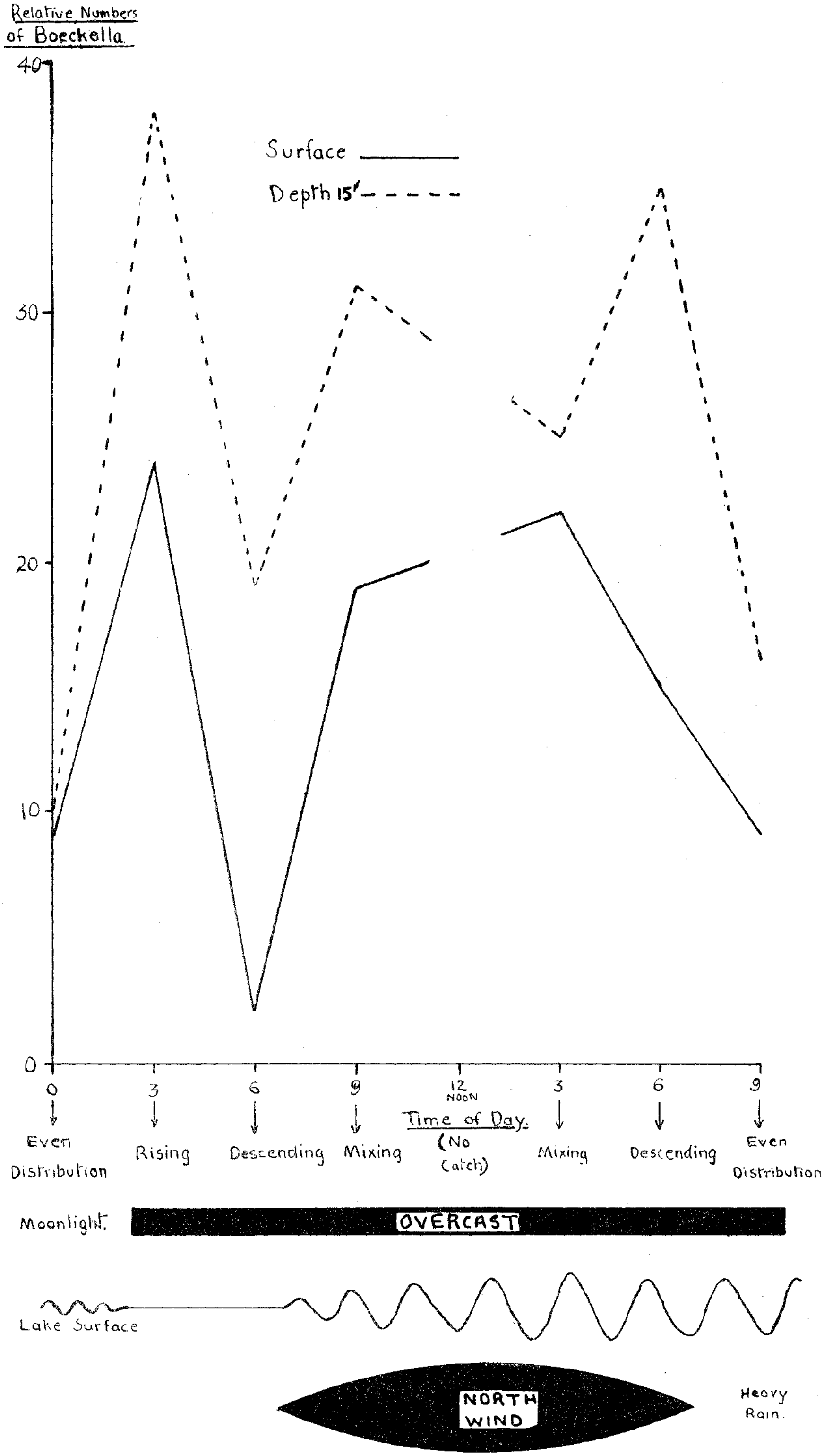


FIG. 11.—Showing response of *Boeckella longisetosa* to rough water with overcast sky, 23rd Oct., 1937 (see Section 9E). Weather conditions for each tow are indicated directly under each time of day.

Conclusions (see fig. 11)—

1. Boeckella retreated from moonlight, and more particularly from daylight.
2. Continued rough weather caused vertical mixing, and this, combined with a high cloud percentage, caused large daylight catches. (The noon catch was missed, but it seems from the graph that the catches would have been similar to those at 9 a.m. and 3 p.m., due to the influence of the northerly wind and overcast sky. Mixing had evidently been caused.)
3. Heavy rain did not affect the catch at 9 p.m., when the usual drop after the 6 p.m. catch was recorded.

b. CYCLOPOIDA.—Once again the numbers were small and *constant* at the surface. At a depth, numbers increased slightly at midnight, 3 a.m., and 6 p.m., i.e., during darkness.

Conclusion—The Cyclopoida prefer deeper water during daylight and disturbed conditions.

c. CLADOCERA.—The numbers were slightly greater than for the Cyclopoida, but with little change throughout the 24 hours. There were a few more in the depth catches. The minimum was at 6 a.m. (daybreak).

November, 1937

The weather during the preceding week had been rough and unsettled, with a heavy snowfall five days before towing was done. For towing, the weather was fine throughout and the lake at no time rough, the 6 p.m. (sunset) trip being just slightly choppy. The moon during the night was obscured by 98 to 100 per cent cloud, which diminished to 20 per cent by 9 a.m. The day was sunny. This trip furnished normal collecting results.

a. CALANOIDA.—Surface catches were fairly constant at a high figure from midnight to 6 a.m., decreasing at 9 a.m., with a big drop to noon. Minimum at 3 p.m., maximum at 6 p.m., with small drop to 9 p.m.

The depth catches were lower during the night, but considerably higher during daylight, the depth maximum coinciding with the surface minimum. The variations followed the annual average, except that the surface maximum was less than the depth maximum.

Conclusions—

1. Boeckella descended during daylight, congregating at about 15 feet and tended to distribute evenly during darkness.
2. Cloud obscuring the sunrise (5 a.m.) allowed Boeckella more time at the surface.

b. CYCLOPOIDA.—Surface catches were fairly constant, with minimum at noon and maximum at 9 p.m.

Conclusions.—As for Calanoida.

c. CLADOCERA.—Maximum surface catch was recorded at 3 a.m., the minimum at noon and high again at 9 p.m. This was a normal sequence.

Conclusions.—Similar to other two groups.

December, 1937

Rain had been falling prior to the first tow at midnight, when a west wind made the lake very rough and blew the boat well out of its course. Conditions improved thereafter, and it was almost calm at 6 a.m., although choppier for the 9 a.m. and noon tows. This is the first month of the larger catches of Cladocera.

a. CALANOIDA.—The catches were in normal sequence, except for a maximum with 65 per cent of cloud at 9 a.m. (the 6 p.m. also was large) and a minimum at 9 p.m. The maximum may be accounted for by the mixing during rough conditions as noted previously. The downward movement caused by stronger sunlight set in soon afterwards, giving much lower readings at noon, with 55 per cent cloud, and 3 p.m., with 45 per cent cloud. The substantial 6 p.m. increase usually noted took place with 100 per cent cloud. The usual 9 p.m. drop, noticeable for both surface and depth, took place under calmer conditions with 75 per cent cloud and no moon.

Conclusions—

1. Boeckella was found in larger numbers at the surface due to mixing following continued rough weather.
2. There is a direct correlation between surface numbers and cloud percentage under normal weather conditions (see fig. 12).

b. CYCLOPOIDA.—Very few at the surface, and then only at night. None at 3 a.m. (daybreak), nor until 6 p.m. (100 per cent cloud). A few more at 15 feet.

Conclusion.—Cyclops avoided the surface, especially during sunlight.

c. CLADOCERA.—These followed a normal sequence, but with maxima at 9 a.m. and 6 p.m. The 9 p.m. catch was low, both surface and depth.

Conclusions—

1. Rough water had less effect on the Cladocera.
2. As for Calanoida.

January, 1938

This has already been mentioned as notable for rough weather, due to northerly winds, with loss of the 3 p.m. catches. The only reasonably smooth trips were at 6 a.m., noon, and 9 p.m. The midnight and 3 a.m. tows were accompanied by displays of the Aurora australis in a clear sky.

a. CALANOIDA.—Minima were recorded at midnight and 3 a.m. These coincided with a heavy swell and rather rough conditions respectively, and the Aurora. Since they were very low, one wonders whether the Aurora could possibly have had some effect, since the southern sky was brightly lit with vertical bands of light. The remaining tows were all much larger, except the 6 a.m. and 9 a.m. depth catches, but there was no definite sequence indicated. The 12 noon catch was larger than is usual at this time, but two definite factors contribute to this:—1. Although the lake was smoother, mixing due to rough conditions had occurred; and 2. There was 100 per cent cloud, so that the normal movement away from sunlight was reduced.

The catches from 12 noon onwards suggest vertical mixing during rough conditions, as in October, 1937. In both these months vertical mixing followed the blowing of a north wind for three hours.

b. CYCLOPOIDA.—None was found in surface catches, and at midnight only in the depth catches.

Conclusion.—Cyclopoida favoured the deeper water.

c. CLADOCERA.—A normal sequence of catches, with minimum at noon and maximum at 6 p.m. There is little indication of rough weather affecting the migration here.

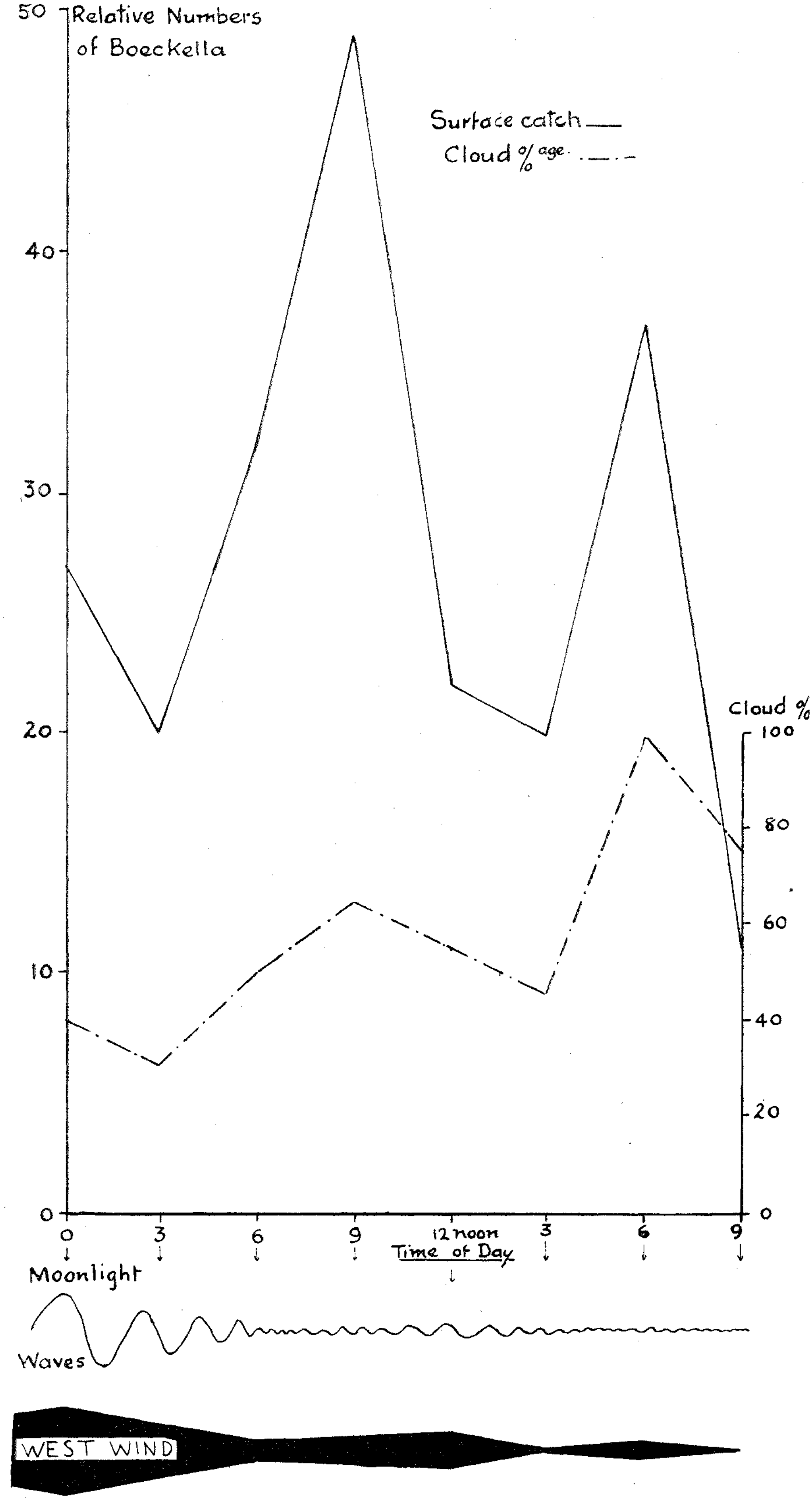


FIG. 12.—Correlation between surface catches of *B. longisetosa* and percentage of cloud, 21st Dec., 1937 (see Section 9E). Wind strength (approximate) and wave height (approximate) are indicated under each time of day.

February, 1938

Although the work was carried out under wintry conditions, the surface of the lake was only slightly disturbed, but the rain was cold and constant; the surrounding mountains were snow-covered; the last tow, 9 p.m., was carried out in driving sleet, and by next morning the shores of the lake were snow-covered.

a. CALANOIDA.—All catches were small and not comparable with any previous trip. A high reading at noon was caused, no doubt, by the heavily overcast conditions. Depth catches suggested that from midnight to 9 a.m. these Crustaceans had descended to deeper water, whilst from noon onwards they seemed to be taking up an even distribution. The erratic nature of the movements is possibly explained by the fact that a summer brood was finding difficulty in adjusting itself to wintry conditions.

b. CYCLOPOIDA.—Few were present, none being recorded at the surface or 15 feet from noon to 6 p.m., but they were fairly evenly distributed for the remainder of the day.

c. CLADOCERA.—These at the surface followed normal sequence, with numbers gradually decreasing as daylight increased, and increasing again at night.

March, 1938

The lake was the calmest for some months, with a slight ripple at noon and 3 p.m. only. The cloud decreased from midnight to 9 a.m. (50 per cent cloud). But then the cloud increased and till 6 p.m. was 100 per cent. By 9 p.m. it had diminished to 70 per cent. Light, steady rain fell during the 6 p.m. trip and a heavy rain squall preceded the 9 p.m. trip.

a. CALANOIDA.—Like December, 1937, a large 9 a.m. maximum is recorded, but this time following a 6 a.m. minimum. On this occasion, mixing after storm can have nothing to do with the maximum, as it was the fourth of a series of calm trips. Also the amount of cloud was 25 per cent less than the 6 a.m. minimum. Apart from these two trips the normal sequence was maintained. A remarkable feature of the Calanoid maximum is that no Cyclopoida or Cladocera were counted in this tow. The large catch may have been caused by the chance presence of a swarm in the towing course.

b. CYCLOPOIDA.—Once again present in small numbers, but more than since November, 1937, so that some attempt at analysis of diurnal movement can be made. Few were at the surface at midnight, none at 6 a.m., 9 a.m., or 9 p.m; more at noon and 3 p.m., with a maximum at 6 p.m. The depth catches were more uniform with minimum at 6 a.m., having maxima before (3 a.m.) and after (9 a.m.).

Conclusion.—The earlier surface minimum was due to the overcast sky at noon, permitting more Cyclopoida to reach the surface at that time.

c. CLADOCERA.—These followed a normal sequence with minimum at 9 a.m. (nil), increasing, slowly at first, to 6 p.m., with a maximum at 9 p.m.

April, 1938

The lake was the lowest level since towing was commenced twelve months ago. The day for towing was beautifully fine, although the nights were cold. The cloud decreased from midnight (100 per cent) to noon (nil), and remained so until 9 p.m., when mist was rising from the lake with the air temperature at 38°F. The day was one of normal weather conditions and should give ' type ' variations.

a. CALANOIDA.—Normal catches were taken with minima around 12 noon and maxima at 9 p.m., closely following the normal variations.

b. CYCLOPOIDA.—Normal catches were taken, with minima from 3 a.m. to at least 9 a.m. and a maximum at 6 p.m.

c. CLADOCERA.—High numbers were caught from midnight (maximum) to 6 a.m., with a minimum (nil) at noon, followed by a big increase to 6 p.m. This is a more or less normal distribution.

A full series of observations having been taken for the previous twelve months, less tows were done from May, 1938, to May, 1939. Brief comments on these are given hereunder:—

May, 1938

The towing was preceded by fine, settled weather, the night being mild, temperature 50°F. at midnight. The noon and 6 p.m. trips were carried out in rain showers.

a. CALANOIDA.—Minimum at noon, maximum at 6 p.m. with 100 per cent cloud on both occasions, but the cloud was less before noon. This is a normal variation, unaffected by rain.

b. CYCLOPOIDA.—Although only small numbers were present, the minimum at noon and maximum 6 p.m. suggest a normal distribution.

c. CLADOCERA.—Showed a minimum at noon, with a maximum at 6 a.m. (The frequency with which a late evening or early morning maximum is recorded is worthy of investigation. Evidently the Cladocera are negatively geotropic and in the absence of sunlight may move towards the surface.)

July, 1938

Following a fortnight of snowy conditions on the lake shore, the tows were carried out in calm water.

a. CALANOIDA.—Normal distribution.

b. CYCLOPOIDA.—Recorded at midnight only.

c. CLADOCERA.—There was a maximum at midnight, when it was moonlight, and at 7 a.m., with 100 per cent cloud. There was a minimum at 12 noon.

August, 1938

Snow was on the ground during the tows. The lake was slightly ruffled only, with little cloud after the 6 p.m. tow, which was the first of the series.

a. CALANOIDA.—The maximum was at 6 p.m., the minimum being recorded at 6 a.m. (sunrise, with only 2 per cent cloud). The numbers were still low at noon, when 40 per cent cloud partly obscured the sun. A correlation between catch and cloud percentage was again obtained.

b. CYCLOPOIDA.—With a maximum at 6 p.m. and a minimum at noon, these were normal.

c. CLADOCERA.—Minimum, noon; maximum, 6 a.m. (cf. July, 1938).

October, 1938

The lake was many feet above normal, having been raised by the Hydro-Electric Commission's dam at Derwent Basin. A northerly gale prevented towing until the 18th, when the lake was smoother.

a. CALANOIDA.—A maximum was recorded at 2 p.m., when the lake had become calmer. The rough conditions brought on by the northerly had caused mixing.

b. CYCLOPOIDA.—Maximum at 9 p.m. with minimum at 11 a.m. Normal migration.

c. CLADOCERA.—Present in small numbers at surface. The numbers were slightly greater at depth, where there was a maximum at 9 p.m. and a minimum at 7 a.m. next day.

December, 1938

The weather was fine with little cloud, and the water calm to choppy.

a. CALANOIDA.—Minimum mid-day; maximum at dusk. The large depth maximum at mid-day stresses the avoidance of sunlight, and that there was no objection to it at 15 feet.

b. CYCLOPOIDA.—Normal distribution.

c. CLADOCERA.—Minimum at mid-day; maximum at dusk—high again at midnight, when it was moonlight with 30 per cent cloud.

February, 1939

Drizzly conditions throughout the tow. Depth tows only were done, chiefly for comparison with the pump catches, and are dealt with in Section 10A. The weather conditions were not nearly as wintry as in February, 1938, and the catches compared more closely with January, 1938, than with February of that year.

April, 1939

Conditions were slightly rough with a north-west wind.

a. CALANOIDA.—Normal.

b. CYCLOPOIDA.—Normal

c. CLADOCERA.—Minimum at noon, high at 5 p.m., maximum at 9 a.m. Between noon and 1 p.m. three horizontal hauls at different depths were taken. The results of these are discussed later.

May, 1939

One hundred per cent cloud over the lake.

All catches compared favourably with May, 1938, the conditions of cloud, temperature, and lake surface being similar, although the wind this time was from the east (North in 1938).

November, 1940

In the middle of 1939 the author commenced visiting the Great Lake once a month for similar work, so that the visits to Lake St. Clair had to be discontinued, except for occasional work there. Water samples for analysis were obtained by arrangement with the National Park ranger.

In November, 1940, when a visit was made, water for analysis was collected and a single tow carried out at 3 p.m. at the time water samples were collected, with the following results:—

Calanoida	Cyclopoida	Cladocera	Total
198	—	141	339

The weather was fine and clear, the lake being calm. The catch was one of the smallest recorded. The most likely explanation is the effect of sunlight from a clear sky on still water, but the pH reading was lower than in the previous years and may have had some bearing on the reduced catch.

F. HORIZONTAL HAULS SUPPLEMENTING REGULAR DIURNAL OBSERVATIONS

May, 1937

These three hauls were carried out on a cold frosty morning over the usual 15-minute tow course. Table 31 shows the total count of each catch.

TABLE 31.

Time	Depth	Cal.	Cyc.	Clad.	Total	Colour of Calanoida
7.55 a.m.	Surface	4,242	2,545	3,394	10,181	Light colour
7.15 a.m.	5 ft.	54,439	0	11,878	66,317	Dark colour
7.35 a.m.	10 ft.	42,420	848	7,636	50,904	Dark colour

These hauls were taken within a few minutes of one another (only one net being available in May, 1937). They showed—

1. The movement away from the surface in sunlight.
2. That the darker coloured Copepods avoided the surface light more than the green ones (see 6L).

April, 1939

In April, 1939 (between 12 noon and 1 p.m.), three hauls were taken at different depths (see table 32). The noon hauls were over the towing course and the 36 feet depth haul was continued on from the end of this into the deeper water. The lake conditions at the time of the hauls were slightly rough, due to a north-westerly wind, with 80 per cent cloud.

TABLE 32

Mid-day Horizontal Catches on 13th April, 1939

Time	Depth	Cal. a.	Cyc. b.	Clad. c.	Index of Total Catch	Temps. °C.	
						Air	Water
12 noon	Surface	16	1	7	4·8	11·4	13·5
12 noon	15 ft.	54	5	18	15·4		13·4
1 p.m.	36 ft.	23	1	19	8·6		13·3
Totals		93	7	44	28·8		
Mean		46·5	3·5	22	14·4		

N.B.—The results shown for the three groups in table 32 are the count over five squares of the counting slide.

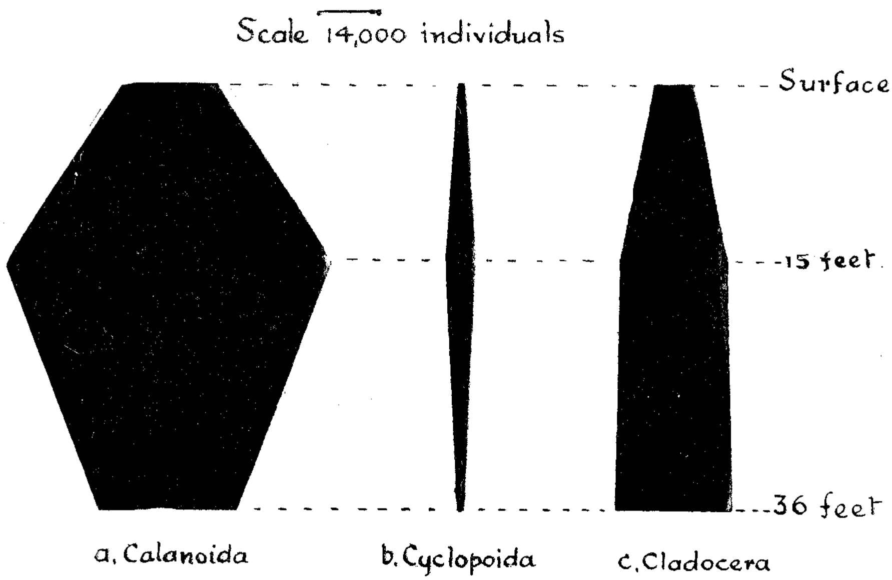


FIG. 13.—Comparison of horizontal hauls at different depths (caught between 12 noon and 1 p.m., 13th April, 1939, see Table 32). The horizontal distance is a measure of the number caught at each depth.

Figure 13 gives a picture of the probable disposition of the three groups at the time.

a. CALANOIDA.—The mean of the catches gives a result not far removed from the catch at 15 feet. This tends to confirm the conclusion already arrived at that the Calanoida have an optimum light intensity of 15 feet at mid-day in the spring and summer months.

Since these catches were made in the first half of April, practically at the junction of the two six-month periods in which the diurnal distribution of the Calanoida was considered in Section 9B, they may therefore be considered as indicative of the conditions pertaining at the end of the October-March period referred to as spring and summer months.

b. CYCLOPOIDA.—From the evidence here shown, the impression might be gained that the Cyclopoida congregate at about 15 feet at mid-day. But most of the available evidence suggests that they prefer a lower light intensity, so that a conclusion from this isolated example would be dangerous.

c. CLADOCERA.—The picture of the mid-day catches of the Cladocera (fig. 13 (*c*)) shows a distribution rather different from the other two groups, in that the numbers are much the same at 36 feet as at 15 feet. The inference is that, although the Cladocera descend to, probably, 15 feet to avoid the mid-day sunlight, they do not congregate there but distribute more or less uniformly below that depth. This accords with the suggestion in 9D 'that the Cladocera tend to remain fairly evenly distributed at all times of the day and night'.

Results of Horizontal Haul at 100 feet (30 metres)

This was carried out on 13th April, 1939, shortly after 5 p.m., giving the following *total count*:—

Calanoida	Cyclopoida	Cladocera	Total
1697	85	848	2630
65%	3%	32%	

The majority of the Cladocera present were *Ceriodaphnia* spp.—only 10 per cent were not.

During this tow the net scraped the bottom, which was soft mud, bringing up a little debris, amongst which the following were seen:—

1. A small univalve Mollusc (1·4 mms. long).
2. Seven specimens of *Phreatoicus* sp.
3. One specimen of *Chiltonia* sp.
4. One Cypris—the only one recorded in four years' work at the lake.
5. Two mites of different species.

The haul was made immediately after the 5 p.m. surface and depth (15 feet) hauls, by continuing to row out to the deeper part of the lake. All hauls were of the same duration. Although the catch was extremely small, its measurement has been expressed in the same unit as the others for purposes of comparison (table 33).

TABLE 33

Comparative Figures—Horizontal Hauls, 13th April, 1939

Time	Depth	Cal.	Cyc.	Clad.	Index of Total Catch	Temps. °C.	
						Air	Water
5 p.m.	Surface	36	3	14	10·6	11·6	13·3
	15 ft.	76	2	13	18·2		
	100 ft.	1·2	0·06	0·3	0·31		

The usual afternoon movement to the surface had set in in preparation for the dusk maximum. The numbers at 100 feet were very small indeed by comparison with the upper layers, but the significant feature of these results is that the relative numbers of the three plankton groups at the same depth are in approximately the same proportion as in the upper layers. This means that regular horizontal hauls nearer the surface gave a true interpretation of the relative numbers of each plankton group in the lake. In particular, the results confirm the smaller percentage of Cyclopoida (4 per cent of total in upper layers—3 per cent of total at 100 feet) by showing that they were not simply in the deeper layers, which would have prevented them being accurately sampled by the regular hauls.

G. Changes in Light Intensity

Johnson (1938) found that the greater the increase in light intensity the further down the Copepod, *Acartia clausi,* went. This finding is examined for Boeckella.

TABLE 34

Relation of Boeckella to Light Intensity

Month	Time	Surface Catch	Conditions	Catch Reduction Ratio	Light Intensity
1937— May	6 a.m.	17	Calm, clear, no moon	—	Increase in light itensity
	9 a.m.	2	Sunshine	0·118	
June	6 a.m.	3	Calm, clear, moon	No reduction recorded	No change indicated by smaller change in light intensity
	9 a.m.	3	Sunshine		
July	6 a.m.	33	99% cloud	—	Greater increase in light intensity
	9 a.m.	3	Sunshine	0·091	
August	9 a.m.	37	Fine, clear, sunny	—	Larger increase in light intensity
	noon	4	Maximum sunlight	0·108	
September	3 a.m.	9	Choppy, misty rain	—	Steady reduction as daylight increased to a maximum
	6 a.m.	6	Choppy	0·33	
	9 a.m.	3	Choppy	0·33	
	12 noon	1	Choppy	0·33	
October	3 a.m.	24	Calm, 99% cloud	—	Increase reduced by cloud
	6 a.m.	2	Calm, 50% cloud	0·083	
November	6 a.m.	32	Calm 100% cloud	—	Shows preference for higher light intensity by summer brood
	9 a.m.	20	Slightly choppy, 20% cloud	0·875	
	12 noon	9	Slight ripple, 0% cloud	0·45	

The table is self-explanatory, amplifying the information given in the previous portions of Section 9, and shows how Boeckella reacts in a similar manner to *Acartia clausi* in response to sunlight.

H. RELATIVE NUMBERS OF SEXES (CALANOIDA)

Unfortunately, time did not permit a detailed analysis of the relative number of males and females in the catches. No males were observed in the Cyclopoida and Cladocera. Appended is a table showing the obversations made.

TABLE 35

Percentages of Males and Females (Boeckella longisetosa Smith*)*

Month	Time	Depth (feet)	% Males	% Females
July, 1937	noon	Surface	0	100
		15	13	87
September, 1937 ..	noon	Surface	0	100
		15	8	92
	6 p.m.	Surface	52	48
December, 1937 ...	noon	Surface	10	90
		15	11	89
March, 1938	9 a.m.	Surface	0	100
	noon	Surface	0	100
		15	0	100
	6 p.m.	Surface	0	100
Average			9	91

All the above readings, except for March, 1938, show that the males are more sensitive to sunlight than the females, and retreat from it until the approach of dusk. This is the opposite of Johnson's (1938) findings for the Copepod *Acartia clausi* (Gesbracht), but agrees with Russell's (1928) findings for *Calanus finmarchicus*. The above table enables the following tentative conclusions to be drawn:—

1. Males have a lower optimum light intensity than females; therefore they are lower during the day but move up at dusk.
2. Males may disappear at the seasonal peaks (cf. fig. 7). They may have descended into deeper water.

I. NEGATIVE GEOTROPISM OF THE CLADOCERA

In Section 9E, dealing with May, 1938, the frequency with which a second surface maximum occurred after 6 p.m. was mentioned. Worthington and Ricardo (1937) say that Cladocerans showed negative geotropism after removal of the light stimulus. The second surface maximum occurs, practically without exception, between 9 p.m. and 3 a.m. At the same time the depth reading is usually quite high and, on occasions, exceeds that of the surface maximum (see tables 27 to 30).

Thus, whilst negative geotropism does seem to be indicated, it is not sufficiently marked to upset completely the theory of uniform distribution.

J. GENERAL CONCLUSIONS AS TO DIURNAL MIGRATION

a. CALANOIDA *(Boeckella longisetosa)*

1. The position of optimum light intensity at noon sinks from the surface, particularly in clear sunshine, in both summer and winter, being not above 15 feet depth in the summer and rather deeper in the winter.

2. An adjustment to light intensity takes place early in the afternoon, so that Boeckella is found nearer the surface. A maximum is reached late in the afternoon (dusk in the autumn, darkness in mid-winter). Then follows a tendency for even distribution.

3. A similar, but less marked, reaction to moonlight occurs. (There is also a suggestion that the Aurora australis caused a downward migration.)

4. The effect of clouds is to reduce the light intensity, causing Boeckella to rise. When conditions otherwise are normal, there is direct correlation between surface numbers and cloud percentage. This effect, therefore, influences also the degree of vertical mixing.

5. Vertical mixing occurs during disturbed conditions, usually brought about by north to north-west winds, especially if these conditions are prolonged, and the normal migration is upset. Larger numbers than usual are then found at the surface. Two factors combine to cause this:—

(i) The actual movement of the water.

(ii) The resultant increase in suspended matter—the finely-divided material tending to screen out the light.

6. Males have a lower optimum light intensity than females, and do not move to the surface in numbers until dusk.

b. CYCLOPOIDA

1. Since the larger surface catches, *without exception*, were taken in calm conditions, these evidently favour the Cyclopoida.

2. The position of optimum light intensity recedes from the surface at noon, and is probably below 15 feet depth (i.e., Cyclopoida avoid the surface during daylight and during rough weather).

3. The normal migration is as follows:—

During daylight—downward movement.

Late afternoon—upward movement.

Darkness—uniform distribution.

4. The presence of cloud reduces the effect of sunlight.

c. CLADOCERA

1. The position of optimum light intensity at noon is not above 15 feet depth, and the tendency is for even distribution below this level rather than to congregate at any particular level.

2. Adjustment to light intensity early in the afternoon causes a rise to the surface, bringing a maximum in the late afternoon. Then follows a tendency for uniform distribution with slight fluctuations which sometimes cause an early morning surface maximum, showing a preference for darkness and suggesting negative geotropism.

3. Cloud reduces the reaction to sunlight.

4. Moonlight has less influence on the Cladocera than on the Calanoida, as numbers remain high during moonlight.

5. The Cladocera tend to descend when the water first becomes choppy, but vertical mixing follows. Nevertheless, of the three groups studied, the Cladocera are least affected by disturbed water.

d. CONCLUSIONS COMMON TO ALL THREE GROUPS

1. Under fine, calm, clear weather conditions all three groups (Calanoida, Cyclopoida, and Cladocera) react very similarly, especially during daylight.

2. Diurnal changes in temperature are comparatively small and have no apparent effect on the migration of the plankton.

3. Rain, sleet and snow, in season, do not affect normal migrational tendencies, but the two latter in particular, associated with colder temperatures, may cause unusual fluctuations out of season.

10. Other Observations

A. PUMP CATCHES

The 'Ajax' pump was not obtained until February, 1939, after which is was used in the remaining trips to the lake during that year. The following table sets out the results of its use:—

TABLE 36

Pump Catches at a Depth of 20 *Feet* (1939)

Date	a	b	c	Total	Strokes	No. per gallon Approx.	No. per 10,000 Litres Approx.	Comments
25 February 0 a.m.	12	—	48	60	200	3	6,600	Smooth swell. Light N.W. wind. Pump leaking
10 a.m.	314	—	628	942	200	45	99,100	100% cloud. Choppy swell
3 p.m.	393	—	943	1336	200	64	141,000	
12 April 5 p.m.	2828	471	707	4006	400	96	211,560	
19 May 6 p.m.	471	157	236	864	200	42	92,500	Much debris from bottom

In every catch the plankters were much mutilated and in only one observed specimen (a Cladoceran, 19th May) were the eggs still attached.

Gibbons and Fraser (1937), in describing their experiments with plankton collecting by pump, state that in 1897 Dr. Frenzel considered that a large volume should be filtered (minimum 500 litres). The largest volume pumped at Lake St. Clair was 190 litres (12th April) and, as even this small volume took 15 minutes, it will be seen that regular diurnal observations with this pump (especially working single-handed) would not be possible.

Gibbons and Fraser used a two-inch petrol driven centrifugal pump capable of 1800 revolutions per minute on a small research steamer. They found that a volume of 2700 litres of water took only 10 minutes.

Summing their observations they found the pump 'efficient, self-priming, and reliable'. The 'Ajax' pump used at the lake worked reasonably well (although sometimes it leaked), but was not self-priming. As it had to be transported from the police hut to the boat on each excursion to the lake, the weight of the pump was a distinct disadvantage. The length of the handle made it necessary to stand when pumping so that use in other than calm water was impossible.

The authors mentioned above do not recommend the use of a pump where the plankton frequency is less than one of the species per five litres of water. As the smallest catch recorded (25th February, 0·00 a.m.—see table) was equivalent to eight plankters per five litres, making no allowance for the fact that the pump was leaking, and the quantity of water per stroke consequently reduced, the method was quite suitable in this respect.

TABLE 37

Comparison of Plankton Catches by Net and Pump

Date	Time		Percentages		
			a	b	c
February 25th.	10 a.m.	Net	20	—	80
		Pump	33	—	67
	3 p.m.	Net	20	—	80
		Pump	29	—	71
April 12th	5 p.m.	Net	65	6	29
		Pump	70	12	18
May 19th	6 p.m.	Net	64	7	29
		Pump	55	18	27

These percentages do not agree completely, but the general trends are the same, and absence of Cyclopoida (*b*) on some occasions is confirmed. Whereas the pump operates at one selected point only, the net collects over a distance and may well pass through areas where the plankton may be scarce or abundant, so that exact correspondence cannot be expected from the two sets of catches even if the methods are otherwise completely comparable.

B. VERTICAL HAULS

16th July, 1938; 3.30 p.m.

This was a particularly interesting haul in that it was carried out off the western shore just beyond Myrtle Point, near ' Fergie's Beach ', where the lake is probably deepest. On this occasion, with the cable out at its full length of some 720 feet, the lake-bed was not reached. The test of depth having been made, a vertical haul, with the end of the net weighted, was carried out from a depth of 214 metres (702 feet) to the surface. The catch was as follows:—

Calanoida	Cyclopoida	Cladocera	Total
701	41	82	824

31st August, 1938; 12 noon

The haul was carried out at the end of the tow-course from a depth of 38 metres (125 feet) where the water temperature was 6·9°C. The catch was as follows:—

Calanoida	Cyclopoida	Cladocera	Total
4171	—	495	4666

These hauls were carried out with the same net (No. 2. See Section 5B) as the horizontal hauls.

11. Summary and Conclusions

In this summary the numbers used are the same as the sections to which they refer. The main conclusions are indicated.

1. The main object of the work was to investigate the conditions of life and behaviour of the plankton Crustacea, particularly the Copepoda.

2. This was the first ecological study of the Tasmanian fresh-water plankton. It was beyond the capacity of one individual to make a thorough ecological study.

3. Description of the equipment used.

4. Description of the geography and geology of the Lake St. Clair region, and of the area at the southern end where most of the observations were made.

5. The plankton of the lake was examined quantitatively, chiefly by horizontal hauls at the surface and at a depth of 15 feet., using silk nets having 26 meshes per centimetre. The nets were towed behind a rowing-boat for 15 minutes on each occasion, making allowance for weather conditions. A hand-pump was experimented with for plankton sampling, but, owing chiefly to difficulty in handling, was not favoured. Methods of counting the catch are discussed: if large, an individual count of a representative sample of the total catch was taken; if small, a modification of this method was used.

6—A. As there was no fully-equipped weather station at the lake, records of temperature, rain, wind, and cloud, &c., for Tarraleah (the nearest station), and the few available records for Lake St. Clair, were obtained from the Commonwealth Meteorological Bureau at Hobart.

B. The air and water temperatures obtained from the above source, and by personal observation, are tabulated. There is evidence of a summer thermocline at 15 metres.

C. Graphs comparing water-level and rainfall show a general correspondence, except where the lake level was artificially controlled by the Hydro-Electric Commission for constructional work.

D. The prevailing winds were north-westerly to westerly and these had most effect on the diurnal distribution of the plankton.

E. Cloud percentages for Tarraleah and, when available, for Lake St. Clair are given as a guide to the amount of sunlight.

F. A chemical analysis of the water is given.

G. The amount of suspended matter may vary considerably with weather conditions.

H-K. Dissolved oxygen, free carbon dioxide, combined chlorine, and the oxygen absorbed showed comparatively small variations, either at the surface or, for the first three named, at various depths.

L. The pH value ranged from 6·4 to 6·6 during 1937-39, but was a little lower in 1940. The possibility of cold, acid, lake-water causing the reddish-brown colour of some Copepoda is discussed.

7. A list of animals seen or caught is given. This includes a Copepod (of the family Cyclopidae) not previously recorded in Tasmania.

8. The survey covers the period May, 1937, to November, 1940, the most intensive collecting work being carried out in the first twelve months.

A summary of the monthly horizontal surface and depth hauls is shown. To minimise errors due to irregular vertical distribution the mean of surface and depth readings is taken as a measure of the total plankton present at any given time.

The Copepoda constitute the majority of the plankton, *Boeckella longisetosa* being the dominant species. The Cladocera (represented by four species) are about 40 per cent of the total. Reasonable correspondence is found in the numbers present in succeeding years.

The winter maximum is brought about almost entirely by the Calanoid Copepod—*Boeckella longisetosa*—which remains present in reasonably large numbers throughout the year, reaching a large maximum in the summer, due to the presence of immature specimens, with breeding specimens causing the minima.

The Cyclopoid Copepoda are present in small numbers, with cyclic variations in each year.

The numbers of Cladocera vary much more than the Copepoda, with a very large summer maximum (higher temperatures).

The seasonal distribution demonstrates that there is ample food-plankton available for the brown and rainbow trout at their normal hatching season.

9. Tables of the daily catches are given and analysed for each plankton group. The various factors which may have influenced the diurnal variations are discussed. The conclusions are given in full in Section 9J.

10. The pump catches are tabulated and compared with horizontal hauls. The specimens were mutilated, but the catches were useful in that they confirmed the silk-net catches.

The results of the vertical hauls are given. One of these was carried out from a depth of 214 metres at a point where the sounding-line ran out to 220 metres (about 720 feet) which is the deepest point so far found in Lake St. Clair.

12. Acknowledgments

From 1938 to 1940 the collection of material was made possible by a yearly grant through the University of Tasmania under the Commonwealth Grant for Research in Biology.

I also wish to express my gratitude to the following institutions for financial and/or material aid:—

Tasmanian Museum and Art Gallery (Dr. J. Pearson).

Tasmanian Biological Survey (Captain D. C. Pearse).

University of Tasmania (Chemistry Department, Prof. E. E. Kurth; Biology Department, Prof. V. V. Hickman).

Tasmanian Police (Use of hut at lake).

National Park Board.

Commonwealth Meteorological Bureau, Hobart.

Hydro-Electric Commission.

Mr. A. D. Ferguson, of Lake St. Clair, and the volunteers who, by assisting me with the collection of material, made the '24-hour tows' less arduous.

References

BREHM, V., 1936.—Ubr die tiergeographischen Verhailtnisse der circumantarktischen Suss-wasserfauna. *Biol. Rev. Cambridge Philosophical Soc.*, vol. XI, No. 4, p. 477

*CHANDLER, D. C., 1944.—Limnological Studies of Western Lake Erie (IV). Limnological and Climatic Factors and Phytoplankton of 1941. *Trans. American Micros. Soc.* 63 (3).

CLARK, ELLEN, 1938.—Tasmanian Parastacidae. *Papers and Proc. Roy. Soc. of Tasmania*, 1938.

DAKIN, W. J. and COLEFAX, A., 1940.—Plankton of Aus. Coastal Waters off N.S.W. Publn. of Univ. of Sydney. *Dept. of Zool. Mono.* 1 Aug., 1940.

DAVIS, H. S., 1938.—Instructions for Stream and Lake Surveys. *U.S. Dept. of Commerce. Bureau of Fisheries. Fishery Circ. No.* 26 Washington, pp. 1-53.

ELTON, C. S., 1924.—Periodic Fluctuations in the Numbers of Animals: Their Causes and Effects. *Brit. J. Exp. Biol.* Vol. II, No. 1, Oct., 1924.

EVANS, J. W. and KERR, R., 1942.—The Food of Trout in Tasmania. *Salmon and Freshwater Fisheries Commission*, pp. 1-12.

FAIRBRIDGE, W. S., 1945.—West Australian Fresh-Water Calanoids (Copepoda). *J. of Roy. Soc. of W.A.*, Vol. XXIX, 1942-3, pp. 25-89.

FROST, W. E., 1939.—R. Liffey Survey II.—The Food Consumed by the Brown Trout in Acid and Alkaline Waters. *Proc. Roy. Irish Acad.*, Vol. 45 (B), No. 7, pp. 139-206.

GARDINER, A. C., 1934.—Variations in the Amount of Macroplankton by Day and Night. *J. Mar. Biol. Assn. of U.K.*, Vol. XIX, No. 2

GIBBONS, S. G. and FRASER, J. H., 1937.—Centrifugal Pump and Suction Hose as Method for Collecting Plankton samples. *Journal du Conseil. Permanent International pour l'exploration de la Mer.* Copenhagen. Vol. XII, No. 2.

HAIG JOHNSON, 1931.—Recent Advances in Analytical Chemistry. (Ed. by C. Ainsworth Mitchell). *Churchill*, London, Vol. II.

HENRY, M., 1922.—Monograph of F.W. Entomostraca of N.S.W. (ii). Copepoda. *Proc. Linn. Soc. N.S.W.*, 1922. Vol. XLVII, Pt 4, pp. 551-570.

HIGGINS, E., 1927.—Studies on Interior Lakes. Report by Prof. Juday, U.S. Dept. of Commerce. *Bureau of Fisheries.* Doc. No. 1044. Washington. pp. 242-245.

JENKIN, PENELOPE M., 1936.—Percy Sladen Expedition to Some Rift Valley Lakes in Kenya, 1928. Summary of Ecological results with Special Reference to the Alkaline Lakes. *Ann. and Mag. Nat. Hist. Lond.* Ser. 10, Vol. XVIII, No. 104, pp. 160.

JOHNSON, W. H., 1938.—Effect of Light on the Vertical Movements of *Acartia clausi* (Geisbrecht). *Biol. Bull.* LXXV, No. 1. United States.

JOHNSON, W. H. and RAYMOND, J. E. G., 1939.—The Reactions of the Planktonic Copepod *Centropages typicus* to Light and Gravity. *Biol. Bull.* LXXVII, No. 2. United States.

JOHNSTON, R. M., 1888.—Geology of Tasmania. *Government Printer, Hobart.*

KEMP, S., HARDY, A. C., and MACKINTOSH, N. A., 1929.—Discovery Reports. Vol. I, pp. 141-229.

LEIM, A. H., 1935.—Water Temps. in Grand Lake, Nova Scotia. *Proc. Nov. Scotian. Inst., Sc.* 18 (4), 1933-34 (1935).

LOWNDES, A. G., 1928.—Fresh Water Copepoda and Hydrogen-Ion Concentration. *Ann. and Mag. Nat. Hist. Lond.* Ser. 10, Vol. I, No. 4, p. 457.

——————, 1936-37.—Scientific Results of Expedition to the East African Lakes, 1930-31. The Smaller Crustacea. *Journ. Linn. Soc. Lond. Zoo.* Vol. XL (1936-9), pp. 1-31.

*MOOKERJEE, H. K. and GHOSH, S. N., 1944.—Culture of Daphnia. *Science and Culture.* 9 (12), pp. 558-559.

*PENNAK, J. S., 1931.—Diurnal Movement of Zooplankton in Some Colorado Mountain Lakes. *New York.* 25 (4), pp. 387-403.

PHILLIPS, J. S., 1931.—Conditions Affecting Well-being of Trout in New Zealand. *N.Z. Marine Dept. Fisheries Bull.* No. 3.

*RICKER, W. E., 1938.—Quantitative Sampling and Seasonal and Annual Variations. *J. Fish. Res. Bd.* Canada. 4 (1), pp. 19-47.

RUSSELL, F. S. and COLEMAN, J. S., 1931.—Great Barrier Reef Expedition, 1928-29. *Brit. Mus. (Nat. Hist.).* Vol. II, No. 2, pp. 5-35.

RUSSELL, F. S., 1925-34.—The Vertical Distribution of Marine Macroplankton. *J. Mar. Biol. Assn. of U.K.*

——————, 1925, I.—An Observation on Diurnal Changes. Vol. XIII, No. 4.

——————, 1926, IV.—The Apparent Importance of Light Intensity as a Controlling Factor in the Behaviour of Certain Species in the Plymouth Area. Vol. XIV, No. 2.

——————, 1928, VII.—Behaviour of *Calanus finmarchicus.* Vol. XV, No. 2.

——————, 1931, X.—Notes on the Behaviour of Sagitta in the Plymouth Area. Vol. XVII, No. 2.

——————, 1931, XI.—Further Observations on Diurnal Change. Vol. XVII, No. 3.

——————, 1934, XII.—Vertical Distribution of *Calanus finmarchicus* in Relation to Light Intensity. Vol. XIX, No. 2.

SAUNDERS, J. T., 1926.—H-Ion Concentration of Natural Waters. 1. Relation of pH to Pressure of Carbon Dioxide. *Brit. J. Exp. Biol.* Vol. IV, No. 1.

SHALLEK, WILLIAM, 1942.—Vertical Migration of the Copepoda *Acartia tonsa* under Controlled Illumination. *Biol. Bull. United States.* Vol. LXXXII, No. 1.

——————, 1943.—The Reaction of Certain Crustacea to Direct and to Diffuse Light. *Biol. Bull. United States.* Vol. LXXXIV, No. 1.

SMITH, G. W., 1909.—The Freshwater Crustacea of Tasmania. *Trans. Linn. Soc. Lond.* Ser. 2, Zool., Vol. XI, Pt. 4, pp. 61-92.

SOUTHERN, R. and GARDINER, A. C., 1926.—1. Seasonal Distribution of the Crustacea of the Plankton in Lough Derg and the River Shannon. *Fisheries, Ireland Sc. Invest.* 1926, I, pp. 1-170.

SOUTHERN, R., 1935.—Food and Growth of Brown Trout from Lough Derg and the River Shannon. *Proc. Roy. Irish Acad.* Vol. XLII (B), No. 6, p. 87.

SUTTON, F., 1924.—A Systematic Handbook of Volumetric Analysis. Lond.

TENGCO, RUSTICO, 1939.—Notes on the pH Measurement of Natural Waters. *Philippine J. of Sc.* Vol. 69, No. 1.

UENO, MASUZO, 1939.—Plankton Studies in Formosan Inland Waters. *Philippine J. of Sc.* Vol. 69, No. 1.

WARD, H. B. and WHIPPLE, G. C., 1918.—Fresh Water Biology. New York.

WELCH, P. S., 1935.—Limnology. *McGraw-Hill Co.* New York and London.

WORTHINGTON, E. B. and RICARDO, C. K., 1936.—Scientific Results of the Expedition to the East African Lakes. No. 17. The Vertical Distribution and Movements of the Plankton in Lakes Rudolph, Naivasha, Edward, and Bunyoni. *J. Linn. Soc. Lond. Zool.* Vol. XL (1936-9), pp. 33-69.

* Abstracts only of these Papers were available.