General limmological survey of lake Cunningham, a brackish lake in the island of new providence, Bahamas

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GENERAL LIMNOLOGICAL SURVEY OF LAKE CUNNINGHAM, A BRACKISH LAKE IN THE ISLAND OF NEW PROVIDENCE, BAHAMAS.

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GENERAL LIMNOLOGICAL SURVEY OF LAKE CUNNINGHAM, A BRACKISH LAKE IN THE ISLAND OF NEW PROVIDENCE, BAHAMAS.

OBJECT OF THESIS.

When the first beginnings of this work were made in 1939 investigation of all the available literature ~~and~~ on the Natural History of the Bahamas served to show that while some aspects had been covered in great detail others had been touched not at all. For example, marine life was well known and had been well studied but, as often happens in the opening up of Natural History of a new region, the lakes had received but very scant attention. In illustration, I have found nowhere more than one reference to such a common alga as Spirogyra and yet I have found a number of different species of this alga in small pools quite incidentally while engaged on other work.

It seemed obvious therefore that any work of a limnological nature should be aimed at a general survey of the lake types rather than any attempt at a more specific problem. The main difficulty, however, was the nature of the Colony. The vast majority of the lakes are in the so-called "out islands" i.e. islands other than New Providence on which the Colony's capital, Nassau, is located. Being separated from New Providence and from one another by sea they are not easy of access. The only possibility therefore was to investigate one lake in the island ~~and~~ of New Providence and to determine, by such means as were possible, how far this particular lake was typical of the Bahamian lakes in general.

/The

The object of this work then is to outline the general limnology of Lake Cunningham, on the island of New Providence. The scope of the survey has included the marginal land flora peculiar to the lake, what small amount of macrophytic flora exists in the lake itself and the nature, amount and periodicity of the plankton. Free swimming Copepoda are included in the plankton. The animal life was also studied and included fish, and examination has been made of the physical and chemical conditions obtaining in the lake over the whole period with a view to comparing general conditions and seasonal variation in this lake with such lakes as have been studied elsewhere. By this means it may be possible to assign this lake to one or other lake types existing elsewhere either in the United States of America or Europe. This work may also assist in illustrating the affinities of the Natural History of the Bahamas with surrounding land masses. Finally, as much data as possible concerning other Bahamian lakes has been collected and examined in comparison with the results of the work on Lake Cunningham.

PREVIOUS WORK ON BAHAMAS.

The outstanding work is that of the Bahama Expedition usually referred to as the Shattuck Expedition sent out by the Geographical Society of Baltimore in 1903 under the direction of George Burbank Shattuck a Professor of Geology in John Hopkins University. Although this is now nearly 40 years ago it is still the outstanding work on Natural History of the Bahamas. The results of this work were published as a large volume (1905) and include chapters on the Geology of the Bahamas, Climatic observations, Soils, Vegetation, Mosquitoes, Batrachians and Reptiles, Birds, Fish and Mammals. The only references to lakes, however, are incidental in the description of the vegetation types and refer solely to marginal flora. The fish described are all marine.

Another outstanding contribution to Bahamian Natural History is the Bahama Flora compiled by Britton and Millspaugh (1920). This comprehensive Flora collected together, confirmed and corrected much scattered work on the flora done by various workers. It contains an exhaustive list together with distribution, of Angiospermae, Gymnospermae, Pteridophyta, Bryophyta, Fungi and Lichenes. Consideration of Algae is comprehensive only as regards larger marine genera. Miscroscopic marine forms and inland types are recorded only from odd collections made with no systematic thoroughness.

C.M. Breder (1934) describes the findings of an expedition to the island of Andros in 1932 and, although the monograph deals expressly with the fish fauna of a fresh-water lake, it also includes mention of plants and invertebrate fauna of brackish lakes there. He discusses the question of the adaptability of marine fish to varying degrees of fresh and brackish water.

Vaughan (1914) described the nature of the limestone rock which constitutes the whole of all the islands in the Bahamas group and later (Vaughan 1918) examined the marl or so-called "mud" which covers large areas of the sea-floor in the shallow seas on the Great Bahama Bank, On the basis of mechanical and chemical analyses he distinguished four main categories of bottom

/deposits.

deposits. This work is of interest in so-far as precipitation of marl takes place in many of the inland lakes.

Drew (1914) on the basis of a study made on the "mud" ~~or~~ calcareous deposits on the West coast of Andros postulated the precipitation of calcium carbonate by action of bacteria chief among which was Bacterium calcis. This hypothesis was extended by Kellerman and Smith (1914) and Bavendamm (1932) who attributed a major part in the precipitation to ammonifying bacteria.

Smith (1940) made systematic analyses of ocean water in the region of Andros Island and comparison will be made with similar analyses of the water of Lake Cunningham. Smith also investigated calcium carbonate precipitation in the shallow Bahamian seas and here again comparison will be made with similar precipitation in Lake Cunningham. He interpreted this precipitation from a purely physico-chemical stand point and considers Drew's (1914) bacterial hypothesis of calcium carbonate precipitation as being unnecessary.

PREVIOUS WORK ON LAKES OF RELATED TYPE

Welch (1935) gives a resume of the theories of the mechanism of marl precipitation and also describes the general unproductivity of marl lakes.

Bass Lake near Ann Abbor, Michigan is described by Raymond (1937) as a concretion forming marl lake. He describes the plankton in some detail both qualitatively and quantitatively and attempts an explanation of the relative unproductivity of this lake.

/Welch

Welch (1935) discusses the general features of false bottoms due to considerable bottom deposits. Later (1939) he investigated thermal conditions in such false bottoms in some Michigan lakes. His references are to bog-lakes.

Whereas biological conditions of fresh water lakes have now received as much attention as ocean and sea water the problem of brackish lakes has received little attention either in the United States or elsewhere.

Carl (1937) describes the flora and fauna of a lake in Vancouver, British Columbia. This lake was formerly a part of the sea but was cut off by an embankment in 1916 and has since gradually decreased in salinity due to continuous inflow of fresh water.

Subsequently (1940) Carl outlines the physico-chemical conditions obtaining in this same brackish lagoon over a period of two years.

Moore (1940 unpublished) gives a comprehensive survey of some 42 saline lakes in the Province of Saskatchewan. In an ingenious representation of the solutes of these lakes he graphs the relative abundance, in terms of percentages of total solutes, of the important ions as milligram equivalents and, by arranging the lakes in decreasing order of salinity, reveals some interesting facts about occurrence of solutes in these lakes. He further describes the plankton of the lakes.

ACKNOWLEDGEMENTS.

My sincere thanks are due to Sir Harry Oakes, Bart. for

/assistance

assistance in this work especially by the loan of a suitable boat for use on the lake and by permission to use his property.

Valuable assistance was rendered throughout by Messrs. John S. George, Ltd., who constructed various pieves of apparatus. The plankton trap was constructed by Mr. Wm. Brisco, engineer on I.L.T. "Firebird".

Dr. R.R. Langford of Toronto University gave helpful advice on many methods used in the survey and in addition he identified the Copepods. In addition, my thanks are due to the Staff of the Department of Biology of Toronto University who extended the use of laboratory and equipment both in Toronto and in the Ontario Fisheries Research Laboratory in Algonquin Park and provided library facilities during my visit to Canada in the summer of 1940.

Dr. C.S. Dolley, emeritus Professor of the University of Pennsylvania, gave helpful suggestions throughout and also indentified the Molluscs and the Polychaete Annelid.

In the matter of indentifications gratitude is owed to:

Dr. Francis Drouet of the Field Museum of Natural History, Chicago who indentified the Myxophyceae;

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Professor Wm. Randolph Taylor of University of Michigan,

Ann Arbor who kindly arranged for the identification of the algal planktonts and himself identified some of the groups.

/I

I am very grateful to Dr. H.H. Brown and the Staff of the Sponge Fisheries Investigations Department who, in offering advice, by the loan of apparatus and especially in compiling this thesis, rendered invaluable assistance.

STRUCTURE OF THE BAHAMAS.

The Bahama Islands lie on a submarine platform which arises steeply from the surrounding ocean floor of the Atlantic. In one instance in the east there is a rise of 15,000 feet in less than 25 miles. The depth of water on the shelf is little varying from a few feet to a few fathoms. Coral activity is common giving rise to only slightly submerged reefs. These reefs are of more recent date geologically speaking than the main island-masses themselves.

The land forms are for by far the greater part mostly aeolian. The sand bordering the islands is very calcareous and this is blown by wind to form dunes on the sea-front which support a characteristic dune vegetation. These dunes gradually harden into limestone rock and thus the tendency is for the dunes to increase in height rather than to migrate inland. The low ridges further inland were formed in this way their aeolian origin being evident in the cross-bedding to be seen in section in various cuts, such as roads, made through them. In addition fossil land shells and casts of roots etc.,are to be found in this limestone. These deposits are found generally to rest on older marine deposits containing fossils of marine origin. These deposits may lie 15 to 20 feet above sea-level thus indicating uplift. This is further supported by the presence of raised

/beaches

beaches backed by raised sea-cliffs. Further evidence of land movement is said by Miller (Shattuck 1905) to be the presence of ocean holes on land containing salt water which rises and falls with the tide. These are supposed to be connected with similar ocean holes in the sea floor and reported by Agassiz to be at least 300 feet deep. Miller states that these must have had their origin at sea-level thus indicating a time when the Bahamas were 300 feet higher than at the present time. Depression of about 300 feet was followed by uplift of some 15 to 20 feet. The present tendency is not known though it is interesting to note that bench marks set up by the Shattuck Expedition at the beginning of the century established "Low water mark ordinary spring tide" at a level to which water in Nassau harbour falls only on very rare occasions, probably less than once a year on an average, when an extraordinary spring tide coincides with wind in such an arc as to blow water out the harbour. This would seem to indicate a subsidence, of the island of New Providence at any rate, of about 1 - 2 feet in the last 38 years. However, a definite statement of this fact is left to expert geologists.

One other geological fact to which reference will later be made is the presence of deposits on the bed of the sea of finely divided calcareous mud known as white marl. It has the consistency of chalk and it occurs most extensively on the west shores of Andros and Abaco where it is the main habitat of sponges in the Colony.

/Climate

CLIMATE.

Of the climate it is sufficient to say that it is sub-tropical being considerably modified by maritime influences. The annual range of temperature is little over 10°F between the limits 70 - 83°F. The minimum temperature ever recorded was only slightly less than 50°C and therefore there is never any frost.

The average rainfall is 50 inches per year, four-fifths of which falls in the months May - October.

The prevailing winds are Trade winds being mostly in a due east direction.

LAKES OF BAHAMAS.

A considerable proportion of the total area of the islands is occupied by inland lakes. There are varying numbers of lakes on all of the larger islands but the character of them varies considerably. Many are quite large. "The Lake" on Inagua is 18 miles long and half as wide. Another large one is the "Great Lake" on Watling's Island or San Salvador (the land fall of Columbus) and it is believed to be the one seen by Columbus on the morning of the day he landed there. At the other extreme are very small bodies of water or ponds. A few of the lakes are quite deep whereas many are so shallow as to pass over imperceptibly into swamps or "swashes" with here and there a patch of open water. Such is Lake Killarney on the island of New Providence. A few of these lakes contain water fresh enough to drink while at the other extreme are "salt pans" with a salinity exceeding that of sea-water.

/Mention

Mention should also be made of the ocean-holes which are not particularly big but are very deep and contain salt water and support marine life. The level of these rises and falls with the tide and here again there are all possible gradations from these very deep ocean holes to much shallower "banana-holes" which may be 25 feet deep and which may or may not contain water but which usually contain humus and black soil.

In the matter of tidal ebb and flow, again there are many gradations between those which are definitely tidal through those in which the tidal effect is less pronounced to those such as the particular lake under consideration in which connection with the sea cannot be deduced from any ebb and flow because this does not occur. As a result it is not surprising that a considerable amount of popular misconception exists concerning this matter of diurnal variation of the level of Bahamian lakes.

The lakes also vary in respect of precipitation of marl. There is usually marl present but the amount varies from only a little to many feet, in many cases displacing the water itself and changing the lake into a swamp.

It is interesting to conjecture just how far these various gradations of lake characteristics may be indicative either of the course of the development of any one advanced or senescent lake or the future changes likely to occur in any one relatively young and undeveloped lake.

Usually there is not any surface outflow by which they are drained nor yet is there any surface inflow such as a stream or river such geographical or phyiographical features being comparatively unknown to the Bahamas though a few are said to exist on the west side of Andros but even these flow only at certain times in the year.

It would be instructive to have some data on the heights above sea level of these lakes but at the moment no such facts are available.

Commonly the margins are surrounded by mangroves, buttonwood and other plants typical of lake or marsh borders. Many of these are also common to the sea-shore.

There is very little other information available concerning the flora of these lakes and of their margins. It is presumed that the fauna is considerably varied but local knowledge of this matter is not to be relied on and there is a lamentable lack of reliable literature dealing with it.

POSITION OF LAKE. (See Fig. 1 on page 13)

Lake Cunningham lies in the middle of the length of New Providence which is less than 20 miles long (E to W) and about 7 miles broad (N to S) at its widest point. The lake lies in longitude 77° 30' W and latitude 25° 0' N. It lies in a WNW - ESE direction about 1 mile from the sea on the north side between two ridges both of which are fossilized sand-dunes. To the north is Prospect Ridge running parallel to the lake and nowhere exceeding 60 feet in height and on the South are the Baillou (or, erroneously, Blue) Hills which in places reach an elevation of 100 feet.

/The

The maximum length of the lake is 4030 yards or just over $2\frac{1}{4}$ miles. This is from the extreme east end to the extreme west end of the South Arm which is some 2300 yards long and separated by a narrow peninsula from the North Arm which is 1300 yards long. In direct line with this peninsula and 150 yards from its east end is a small island, Burnside Cay, which is 300 yards long. The width varies but is about 300 yards or slightly more at its widest. The area of the lake exclusive of Burnside Cay is 518 acres or 0.81 square miles. This data has been taken from United States Hydrographic Chart of New Providence No. 1377 the authority for which is British Admiralty Chart No. 1489.

The depth of the lake will be described in detail later suffice it to say here that the maximum depth of water above the false bottom of marl is 13 feet.

METHODS.

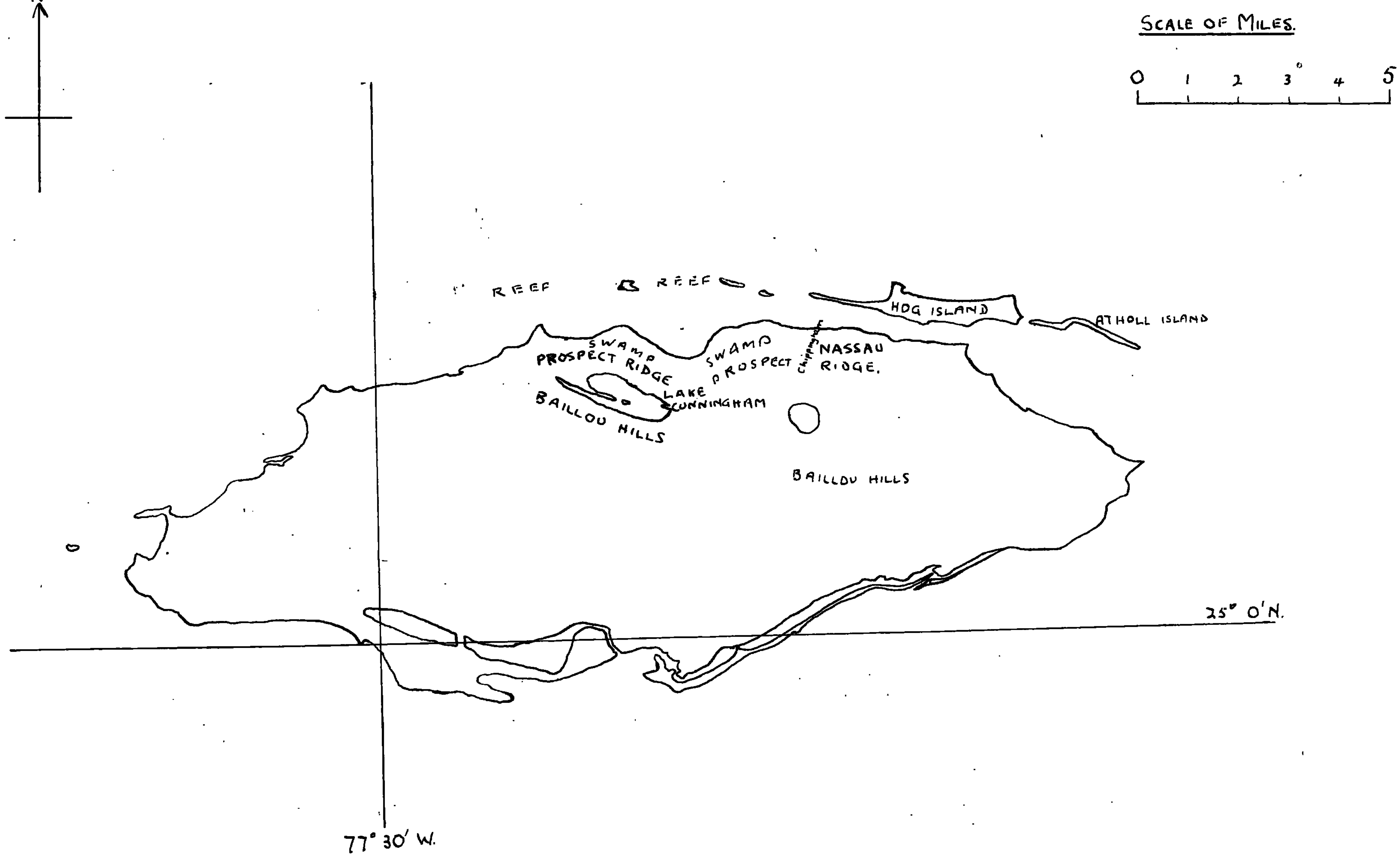
Sounding

For this purpose a brass chandelier chain about 20 feet in length was used with a suitable weight attached to the end. The chain was marked at intervals of one foot with brass discs with the depth impressed on them. Where possible traverses were made across the lake between points whose positions could be accurately located on a map. Convenient marks were the east and west ends of Burnside Cay and the east end of the peninsula and on the north shore, the east and west boundary walls of three private lots of land as well as a road. Apart from these fixed points which were located in too small an area to be of very much help it was impossible to find any salient features in the surrounding land the location of which could be set down on a

/map

FIGURE 1.

NEW PROVIDENCE.



FROM "MAPS OF THE BAHAMA ISLANDS"
PRINTED BY
STANFORD'S GEOGRAPHICAL ESTMENT.
LONDON
1926.

FIGURE 1.

MAP OF NEW PROVIDENCE.

The difficulty was solved as well as possible by commencing from one or other of these known fixed points, setting the boat on a straight course on the lake and reading the direction of the course from a small mariner's compass fixed in the boat for the purpose. On reaching the opposite shore the boat was set on a new course for the opposite shore. By making a series of such courses and by observing the direction of the course each time on the compass, progress was made along the lake either to the east or to the west and finally ending at a point on the shore which could be located on the map - such as the south-east corner. On the return trip a series of courses was set as far far as possible to criss-cross with the first series. It was obviously necessary that each series should begin and end at some point whose position could be definitely set down on the map so that any error in reading the compass (accuracy was possible only within a margin of about 2° on each side) could be evenly distributed among all the traverses in one series in the manner of "closing" a surveyor's traverse on land.

In order to operate this system satisfactorily four people were necessary. One kept the boat on a course by picking out a suitable mark such as a conspicuous tree and made the observations with the compass. A second in the bow called out the time from a stop watch at intervals of 20 seconds. The third took soundings by swinging the lead forward in approved fashion and the fourth recorded in a book the soundings made and the direction of the course. By going at full speed with a half to one horse power engine it was possible to make a maximum of 16 to 17 soundings in a single traverse across the lake at its widest point.

/Water

WATER-LEVEL.

For a time a convenient mark was made on a fixed iron post in the water and the level above or below this mark was measured by ruler and recorded as "+x" or "-x" inches. Later a suitable piece of wood was painted and marked off in intervals of 1/8th" and fixed to a private wharf. As the height of the lake above sea-level is not definitely known the figures on this scale were purely arbitrary. It was believed to be more convenient to retain the first method of writing down levels and an average level was established and called zero. Levels are therefore recorded as being above (+) or below (-) this zero mark. This method gives a much clearer impression of the relative level of water than the use of any arbitrary numbers.

TRANSPARENCY, TEMPERATURE AND DENSITY.

An ordinary Secchi disc was used in the usual manner. Temperatures were recorded (a) air temperature in the shade (b) surface water temperature in the shade of the boat (c) water temperature on bottom by sending the thermometer down inside the apparatus for obtaining oxygen samples (described below) and by reading it while still in the water immediately on fetching the apparatus to the surface. As the depth was not great no appreciable change in temperature of the bottom sample took place before the thermometer was read. These temperatures were always made in duplicate and no discrepancy was observed. All temperatures were recorded to 0.1C°. They were later transposed to the Fahrenheit scale.

/Density

Density was measured by a floating hydrometer graduated in thousandths from 1.000 to 1.100. The temperature of the water at the time of this observation was also recorded.

HYDROGEN ION EXPONENT (pH) AND OXYGEN.

The pH was found to lie in the range of Thymol Blue (alkaline range 8.0 - 9.6) and so this indicator was used. In the absence of a series of buffer solutions of known pH (comparator tubes) an attempt was made to use a Colour Chart of Indicators, a reprint from "The Determination of Hydrogen Ions" by W.Mansfield Clark and prepared by the Williams and Wilkins Company of Baltimore, U.S.A., in which the colours of comparator solutions is recorded on paper with printer's ink. This method is most unsatisfactory and cannot be used with accuracy within 0.1 pH. It was therefore judged useless to keep any number of such observations.

Dissolved oxygen was estimated by the Winkler method as outlined by Thresh, Beale and Suckling (1926) and the samples were taken with the usual precaution to avoid contact with air in the apparatus illustrated in Fig. 2 on page 17.

The apparatus was lowered by chandelier chain marked off in feet from the level of the inlet.

A difficulty that was encountered upon occasion - chiefly after prolonged wind when the water was stirred up was that the addition of acid liberated carbon dioxide from the particles of

/marl

FIGURE 2.

OXYGEN SAMPLING APPARATUS.

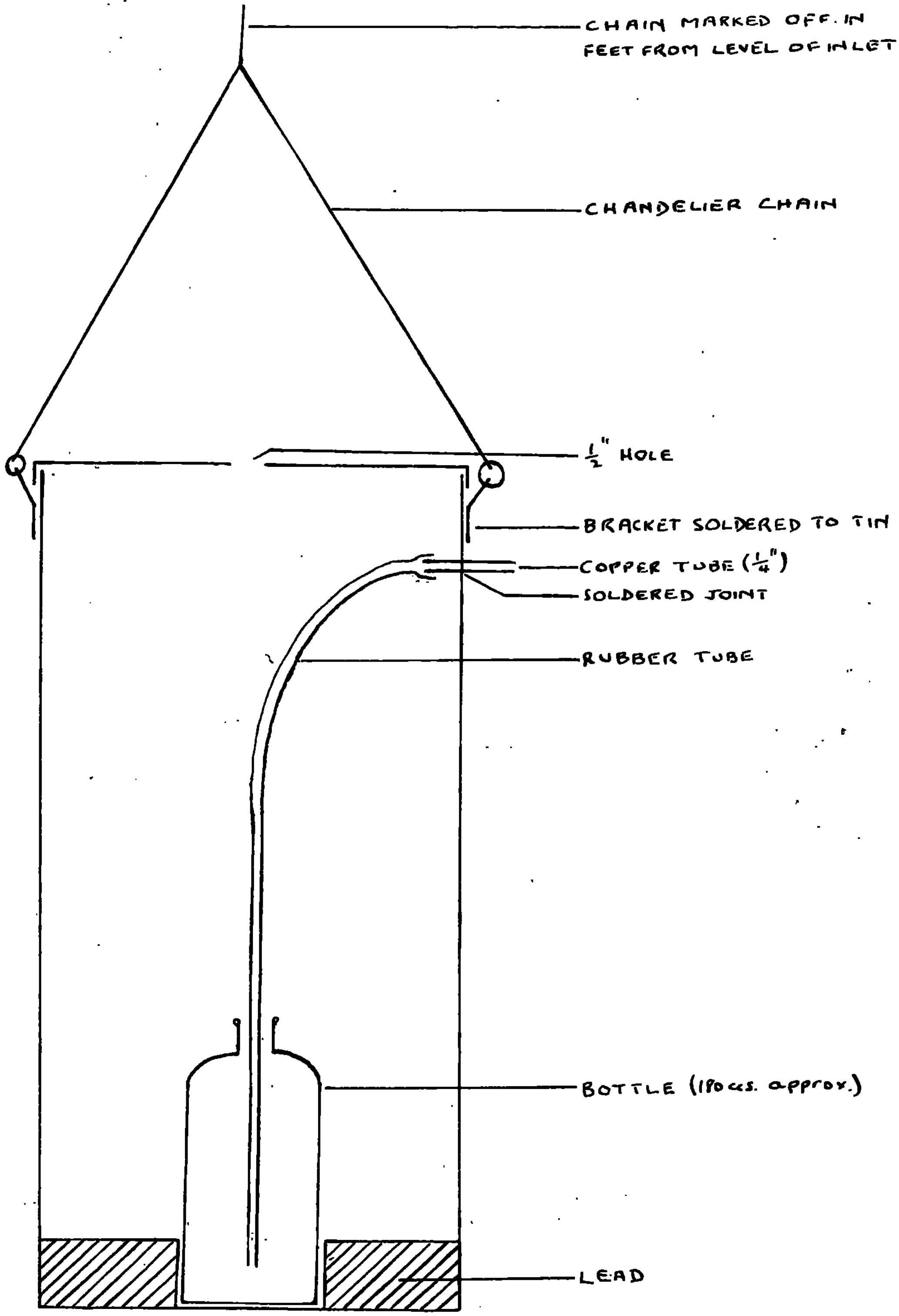


FIGURE 2.

OXYGEN SAMPLING APPARATUS.

marl in suspension. How far this affected the accuracy of the estimation is not known but fortunately is occurred rarely and it was always possible to repeat the analysis a few days later after the suspended material had settled.

CHEMICAL ANALYSIS FOR SOLUTES.

In all these analyses the methods outlined by Thresh Beale and Suckling in "Examination of Water and Water Supplies" (1926) were followed with a few exceptions as indicated.

Total Solids. were determined by evaporation of 50ccs. of water and by drying the residue at 180°C. First attempts revealed that the residue was so hygroscopic that any degree of accuracy was impossible. Various modifications were attempted and finally the method of precipitating soluble salts of calcium as carbonate and magnesium as basic carbonate by the addition of sodium carbonate was adopted. It was found by practice and by calculation that 1 gram of sodium carbonate was a sufficient excess. Accordingly, to every 50ccs of water 10ccs of a 10% solution of sodium carbonate were added and a deduction made from the weight/(omission) about 0.002 grams and therefore all results were recorded to the second decimal place.

Ammonia Free ammonia was estimated by distillation and Nesslerization of the distillate and albuminoid ammonia by distillation, after addition of alkaline potassium permanganate, of the residual water after estimation of free ammonia.

/Nitrates

Omission:
"of the residue. This method was found to be accurate to within.."

Nitrates. These were reduced by zinc-copper couple and estimated as ammonia. After deduction of free ammonia the result was converted to (NO_3) by multiplying by 3.648.

Phosphates. These were determined by Denigès colorimetric method as modified by Florentin and Atkins. As the water is practically colourless very little difficulty was encountered in colour comparison with standards.

Silica was estimated by ammonium molybdate and sulphuric acid, comparison of colours being made as usual with picric acid solutions.

Chlorine as chlorides was present in such large amounts that the method adopted was to titrate only 10ccs of water against standard silver nitrate solutions of strength 1cc ≡ 10 mgs. Cl this being ten times stronger than the solution suggested by Thresh Beale and Suckling. Potassium chromate was used as indicator.

Free CO_2 was determined by titration with N/20 sodium carbonate solution using phenolphthalein as indicator.

Combined CO_2 was estimated as outlined in the American Public Health Association's "Standard Methods for the Examination of Water and Sewage" (1939). 100 ccs of the water is titrated with N/50 sulphuric acid, first of all to an end point about pH 8.0 using phenolphthalein and then to an end point about pH 4.0 using methyl orange. The relative amounts of half-bound and bound carbon dioxide were computed from the volume of acid required in each titration. Since in this case the phenolphthalein alkalinity was less than half the methyl orange or total alkalinity the

/value

Value of normal carbonate present expressed in terms of parts $CaCO_3$/million was equal to twice the titration phenolphthalein alkalinity, and the bicarbonate present expressed in terms of $CaCO_3$/million was calculated from the formala (T - 2P) where T = total alkalinity and P = phenolphthalein.

The respective values of $[CO_3'']$ and $[HCO_3']$ were then computed and also the amount of CO_2 present in the form of normal carbonate and bicarbonate. From this the bound CO_2 was computed by adding the CO_2 present as (CO_3) with one-half that present as (HCO_3). The half-bound CO_2 was equal to half that present as (HCO_3).

<u>Sulphate</u>. The amounts of sulphates present were found to be so considerable that it was most convenient to estimate them gravimetrically. The method used was that outlined by Newth in "Chemical Analysis, Qualitative and Quatitative". The method consists essentially in precipitating the sulphates with barium chloride in the presence of ammonium chloride to coagulate the precipitate, filtering and incinerating. The weight of the residue is multiplied by 0.412 to obtain the value of SO_4''.

<u>Calcium</u>. Again the method outlined by Newth was used. The

<u>Omission:</u>

<u>Magnesium</u>. The gravimetric method according to Newth is to precipitate the magnesium (from the filtrate after removal of calcium) by disodium hydrogen phosphate, filter and incinerate. The weight of the residue multiplied by 0.2162 gives the value of Mg. in grams.

~~all other ions from the total solids present.~~

/Sulphuretted

Sulphuretted Hydrogen was tested for with lead acetate and estimated by titration against N/100 iodine solution in the presence of starch as indicator. 1cc of N/100 iodine is equivalent to 0.17 mgs H_2S.

BIOLOGICAL EXAMINATION.

PLANKTON. Qualitative samples were obtained by drawing a townet of bolting cloth (175 meshes to the inch) behind the boat with engine running at very slow speed.

Quantitative samples were taken by passing 16 jars full (40 litres) of water through a smaller net with (166 meshes to the inch). 40% formaldehyde was added equal in volume to 1/10th. total volume of liquid thus preserving the organisms in a 4% solution. The plankton was counted in the following manner. The catch was well shaken and a glass tube inserted vertically in the liquid and resting on the bottom of the jar. A finger

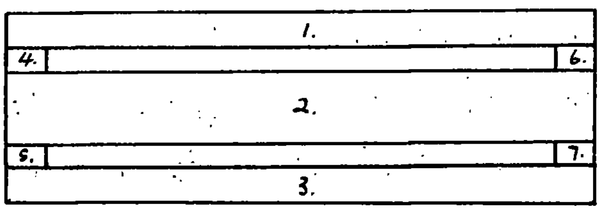
Omission:
"removed to a small test tube. By this means a constant and definite proportion of the total volume of the catch was....."

this depending on the fact that the area of the cross section of the glass tube bore a fixed definite ratio to the surface area of the jar containing the catch. As both jar and glass tube contained the same height of liquid the volumes were also in the same ratio. Very conveniently a length of glass tube was used the whole time which removed exactly 1/100th. part of the catch every time this simple operation was repeated. A counting cell was made from two ordinary microscope slides, one being cut with a diamond, such that it had two parallel troughs in depth equal to the thickness of one slide. These were filled with the liquid, drawn by the tube from the catch, by means of a fine

/pipette.

pipette. In the absence of a mechanical stage the slide was moved over the stage by hand so that every part of each trough was closely examined. The numbers of organisms counted in this 1/100th. part were then divided by 0.4 to obtain the numbers of organisms per litre of lake water.

COUNTING CELL. Fig. 3.



ACTUAL SIZE.

No's 1 - 7 indicate pieces of slide cut with a diamond and cemented to the lower slide with Canada balsam.

Although all the plankton counts were made from catches taken in this way it was realized that this method cannot be accurate as far as the free-swimming organisms were concerned. In the first case most if not all of the catches were taken in the afternoon in bright sunlight when such free-swimming organisms would tend to move down to a lower level in the water. Secondly, what free-swimming organisms did remain in the top 12 inches of water would be caused to move away from the spot where the sample was being taken by the strong water currents inevitably caused by plunging in the jar, violently filling it and removing it on 16 consecutive occasions.

NEW TYPE PLANKTON TRAP.

To eliminate errors from both of these sources experiments

/were

were made latterly with a plankton trap demonstrated to the writer in the summer of 1940 by Dr. R.R. Langford of the Department of Biology, University of Toronto at the laboratory of the Ontario Fisheries Research Board on Lake Ospeongo in Algonquin Provincial Park in Ontario, Canada. At that time Dr. Langford was himself experimenting with the trap and had not yet perfected it. (Diagrams of the trap are on Fig. 4 on page 25).

It consists essentially of a rectangular copper or galvanized iron box M 11" tall x 5½" square with a recess on one side 1½" deep to accommodate the door N when open. The door is 6½" x 5¼" and is pivoted on a brass rod R. Soldered to both ends of this rod outside the box are two levers L attached by strong springs S to two pegs P soldered to the other end of the base opposite the pivoting bar. These springs cause the door to fly shut when the catch holding the door open is tripped. The bottom of the box carries a square hole leaving a narrow flange around the outside ¼" wide except at the side near the pivoting bar where it is 1½" wide. The joint between door and flange is made water tight by 1/8" sheet rubber C fastened to the flange on the inside. The door carries a circular hole with a circular band D soldered to its circumference 4½" in diameter. To this is fastened, the upper end of a bolting cloth cone of No.18 cloth F which bears at its lower narrow end the bucket as described by Ward and Whipple in "Fresh Water Biology", from the Wisconsin plankton net designed by Professor E.A. Birge. Lest the weight of the bucket when suddenly dropped (when the catch is tripped) should tear the net it is supported from the metal band D by two strings. To the upper end of the box is attached by a

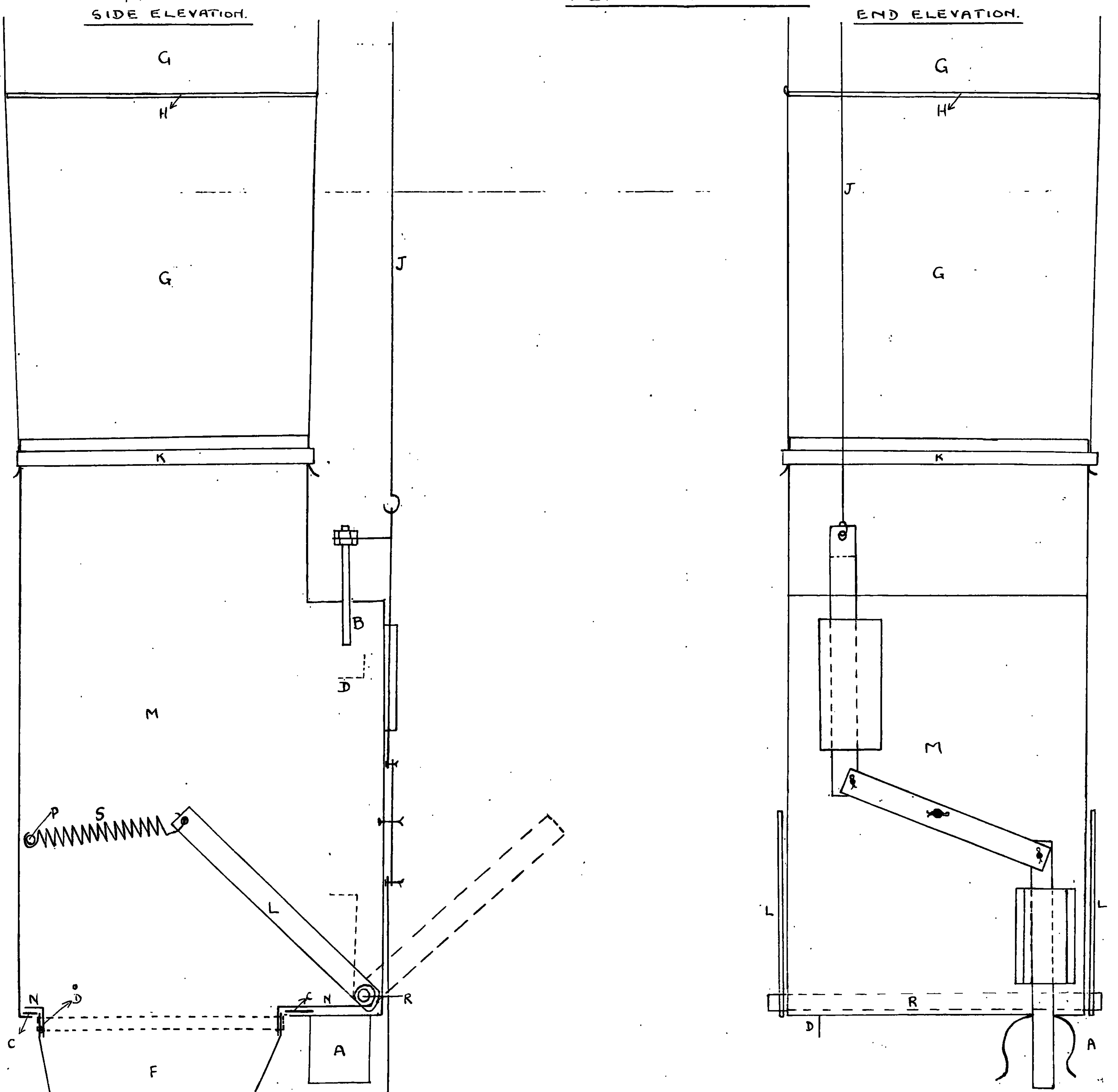
/metal

metal band K a long cylinder G of heavy unbleached cotton, 6" in diameter and supported by metal rings H sewn to the inside at intervals of 6". Before being used the door is opened and held open by the rod B and the bucket is clamped in the bracket A. The box is lowered gently (to avoid causing too much current in the water) into the lake, followed by as much of the cylinder as is necessary to carry the box to the desired depth. By pulling a string J the catch B is tripped thus releasing the door which is immediately closed by the spring S and at the same time, by a series of levers whose action can be seen from the diagram, the bucket is shot out of the bracket A. A column of water of known diameter and known height is therefore enclosed in the trap and as the trap is slowly removed from the lake this column of water is filtered by the cone F and bucket. The volume of the filtered water may be calculated and the organisms counted in the usual way. By this apparatus a sample of plankton may be taken from the whole depth of a lake of moderate depth or from whatever stratum of water is desired in a lake of any depth. In this particular lake a sample representative of the total plankton population is obtained no matter what the temperature or insolation or resultant vertical distribution of organisms. At the same time, by virtue of the fact that there is nothing to cause a great current of water as the trap is lowered, (as there is in the Wisconsin plankton trap), the error due to moving away of free-swimming organisms is reduced to a minimum.

/Collection

PLANKTON TRAP

FIGURE 4.



SCALE.

½ ACTUAL SIZE.

FIGURE 4.

PLANKTON TRAP.

COLLECTION OF INSECTS

Adult forms of insects were trapped as they emerged from pupal skins at the surface of the water. A frame of wood (see Fig. 5 page 27) 2 feet square was constructed and floated by means of two cylindrical tin cans (with lids and joints soldered to make them water-tight). These were attached at opposite sides by brackets fitting into slots so that they could be quickly and easily detached to lift the trap out of the water. Two lengths of 1/8" wire were bent into the form of two arches from corner to corner. Across these was stretched tightly a double thickness of cheese-cloth (or butter-muslin or mosquite netting) and tacked by drawing pins to the wooden frame. The trap was set where desired and kept in position by a rope attached to an anchor, the rope being connected to both buoys so that these did not float away when the trap was lifted. When emptying the trap the frame and "tent" was lifted from the water into the boat and rested on a wide seat. The insects were removed by tilting the frame on one side and touching the insects lightly with a small wad of cotton wool soaked in alcohol attached to the end of a stiff wire. They were immediately transferred to alcohol.

COLLECTION OF FISH.

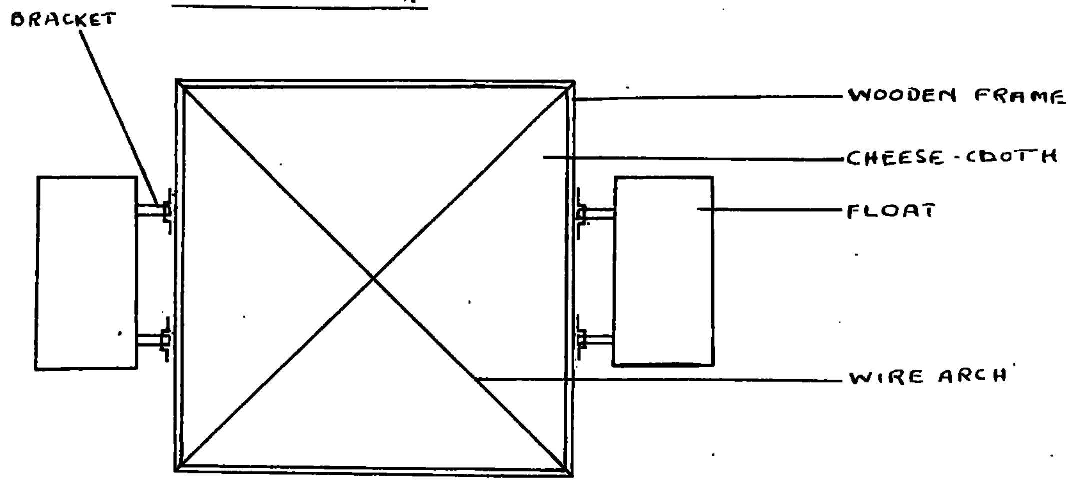
These were collected in a trap (see Fig 6 on page 28) A frame was made of three circular 3/8" galvanised iron rings 8" in diameter and soldered to three 3/8" iron bars 24" long in the form of a cylinder. This frame was covered with mosquito wire screening made of a special anti-rust wire (Monel). At one end was made a cone of this wire with the wide end soldered

/to

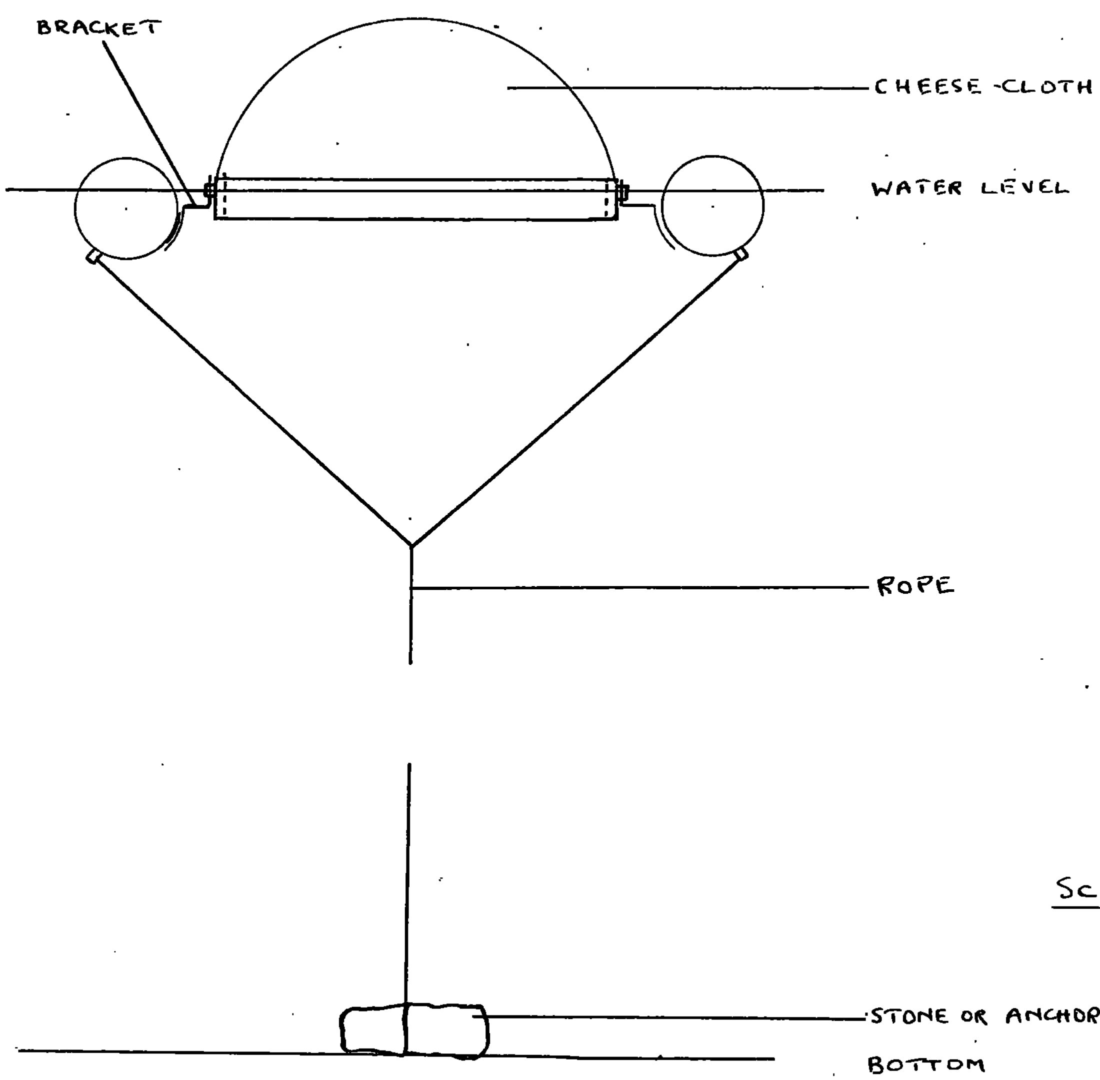
FIGURE 5.

INSECT TRAP

TOP ELEVATION.



SIDE-ELEVATION



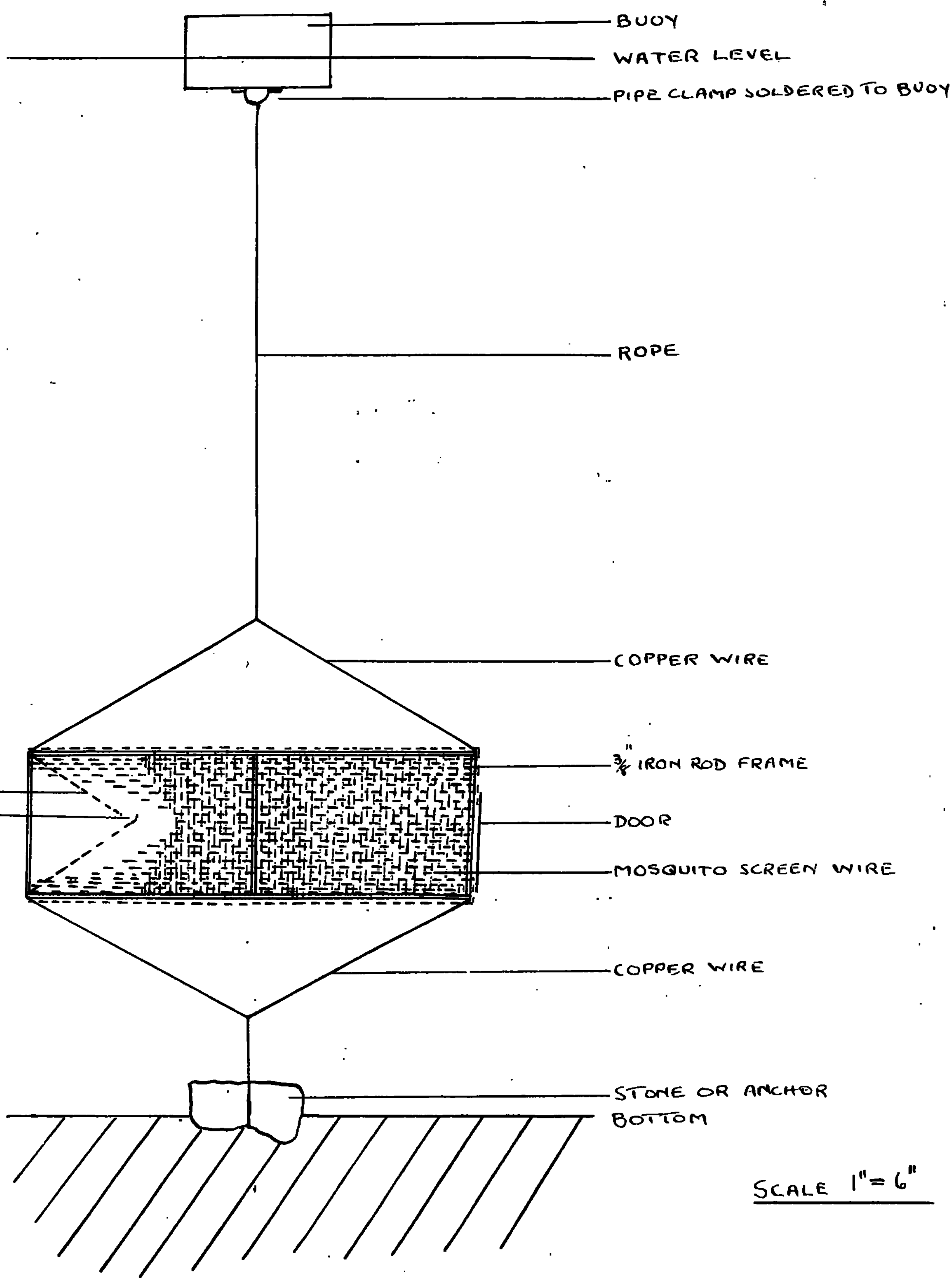
SCALE 1" = 1'

FIGURE 5.

INSECT TRAP.

FIGURE 6.

FISH TRAP.



SCALE 1" = 6"

FIGURE 6.

FISH TRAP.

to the end ring and the narrow mouth (1" wide) directed inwards. Fish tend to follow the sides of the cone and so enter the trap and are not able to find the way out. The other end of the trap is closed by a hinged door which can be opened to empty the trap. An anchor attached by a very short rope to the lower side of the trap keeps it stationary and a rope fastened to a buoy suspended the trap just above the bottom and, at the same time, marked its position. For counting purposes the trap was emptied into a large bucket and the fish removed with a net, sorted and counted.

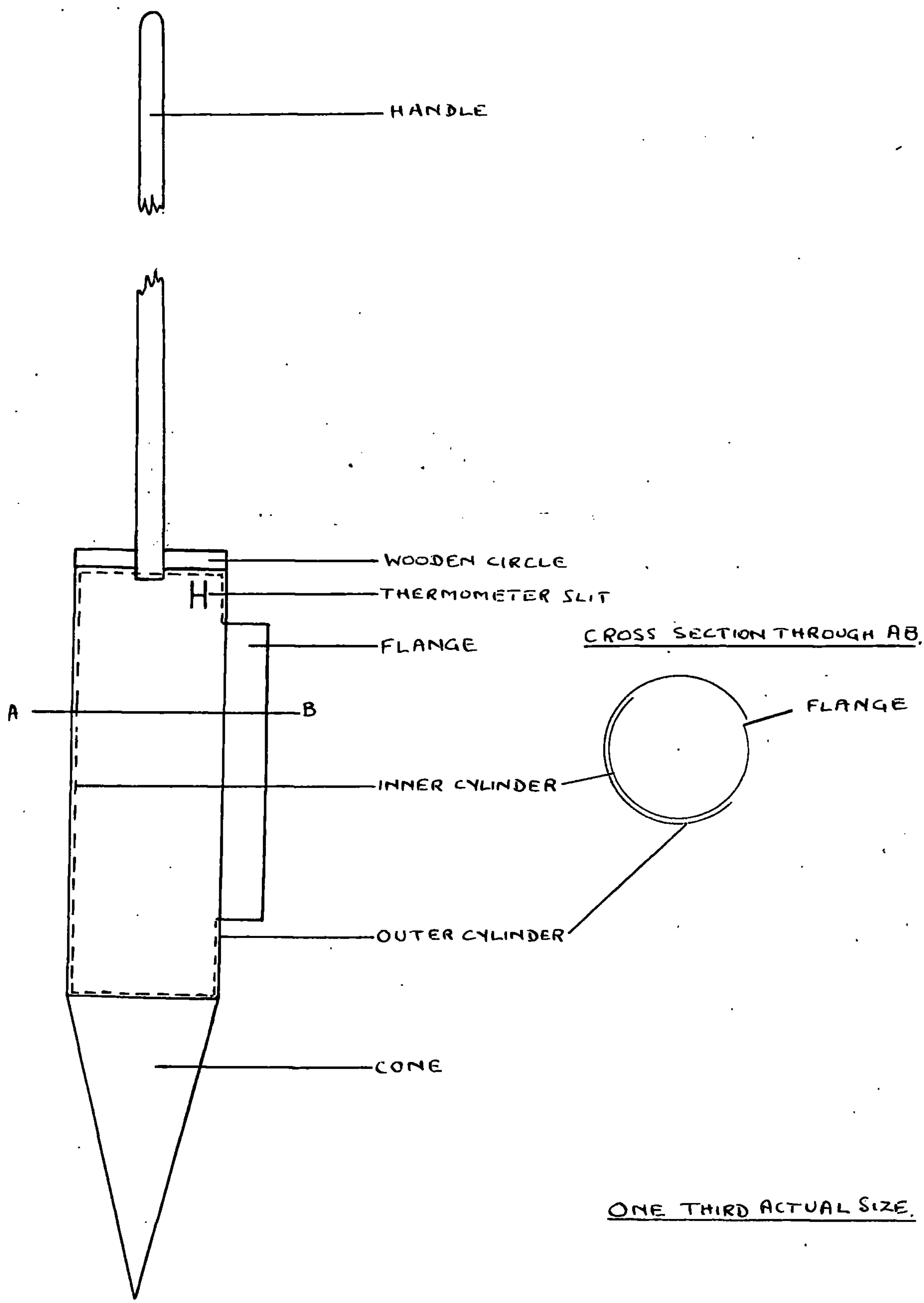
BOTTOM FLORA AND FAUNA.

The plants growing on the bottom were obtained by means of a dredge of common type.

The bottom fauna consisted chiefly of bivalve molluscs and these lived in the mud. The dredge simply scraped the surface and brought up an add assortment of broken scraps of shells. An apparatus (see Fig. 7 page 30) was therefore constructed to obtain mud samples at any required depth. It was also used to record temperatures at varying depths in the mud. A cylindrical tin about $2\frac{3}{4}$" inches diameter and 9 ins. long (such as is used for packing tennis balls under pressure) was used and a piece cut out of the side $2\frac{1}{2}$" x 6". A smaller concentric cylinder rotated inside and had a flange which protruded through the "window" in the outer jacket, this flange being about 6" x 2". The window could be closed or opened by rotating the inner cylinder. A pointed cone 6" long and of the same maximum diameter as the tin was soldered to the lower end and the top was closed by a

/circular

MUD SAMPLING APPARATUS.



ONE THIRD ACTUAL SIZE.

FIGURE 7.

MUD-SAMPLING APPARATUS.

circular piece of wood in which was fitted a wooden handle 8 feet long marked off in ½ feet. Before being driven into the mud the window was closed and when the desired depth was reached a twist of the handle caused the door to open as the flange was held by the mud and prevented the inner cylinder from turning. By continuing this twist the flange scooped mud into the sampler. The sampler was closed by a quick backward twist and then lifted. If necessary a temperature of the mud was taken immediately by inserting a thermometer into the middle of the mud through an H shaped slit bored in the side of the tin. The mud was then sieved through wire mosquito screen.

THE RESULTS.

I. Higher Plants.

The paucity, and in many places, complete absence; of littoral vegetation is very pronounced. The only emergent hydrophyte (the classification used by Welch in "Limnology" is here referred to) is the common mangrove, Rhizophora Mangle (L). This forms a belt of varying width around the lake but its width is most commonly narrow, amounting to only a few feet and in many places, especially at the western end of the lake and the eastern end of Burnside Cay and the eastern end of the peninsula where the shore is mostly bare rock, it is absent for considerable distances. Except where the belt is absent as just mentioned, the width of the zone seems to bear direct relationship with the depth of the water near the shore. Thus the greatest development is found at the east end and on the north shore particularly east of Anderson's Wharf, the north shore of the south arm and at the west end of Burnside Cay. In these places there are isolated patches extending 30 to 40 feet into the lake. The mangrove flourishes where the

/water

water is not more than 3 feet deep and the locations described have a greater area of inshore water of this shallow depth than the south shore of the lake where the bottom slopes more quickly. There are instances on the north shore where an isolated shelf of rock extends some distance into the lake 2 - 3 feet below the surface of the water to the lakeward side of which is a steep drop. On these shelves the mangrove grows out into the lake ceasing where the shelf ends.

The reason for this distribution is fairly obvious. Baillou Hills to the south have a steeper slope, which is continued into the lake, than Prospect Ridge to the north. Complete absence of the mangrove from the west end of the north and south arms and the east end of the peninsula and the cay is no doubt due to the fact that prevalent winds are easterly and wave action in the localities removes any bottom sediment that might offer a foothold to the roots. This also in some part explains the narrowness of the belt of mangrove along the southern shore which, due to the WSW - ESE direction of the lake, experiences more wave action than the north shore. This wave action is beautifully evidenced by the line of foam built up along the whole of the south shore and in the other localities moved by a fresh breeze.

Of Welch's "floating hydrophytes" there is no example at all either rooted or free-floating.

There are but three submerged hydrophytes. The commonest is the tufted alga Batophora Oerstedi. The occurrence of this is influenced largely by wave action. It grows abundantly wherever there is opportunity for attachment and not sufficient movement

/of

of water to wash it away. As a result it grows densely in those same localities where mangrove occurs. The aerial roots of the mangrove are covered with it right up to the surface of the water. In small sheltered bays on the north side east of Anderson's Wharf where the water is always clearer the bottom is densely covered with a luxuriant growth of this alga. The other submerged plant is Chara Hornemannii (Wallm) which is less common than Batophora, but which occursin very similar situations. Although the most abundant growth of both these plants occurs in shallow water they appear to be able to grow at any depth found in this lake. Isolated patches a few feet in diameter are a common sight in deeper water and a dredge seldom fails to bring up a few pieces of one or other of these plants though more commonly the Batophora is the plant appearing in such dredging.

Immediately behind the mangrove belt and very often mixed in with it is a very varied collection of plants which, though not covering a great area, is of exceptional biological interest. For in this narrow belt there are to be found herbs and shrubs with hydrophytic adaptations and with xerophytic adaptations, plants commonly associated with sand-dunes and plants associated with inland flora, plants associated with marshes and swamp flora, parasites, semiparasites, vines, saprophytes, saprophytes and epiphytes. The zone is reached by what is described in Shattuck (1905) as Coppice. We are not concerned here with a description of the Coppice growth suffice it to say that the slopes of Baillou Hills are covered with High Coppice while on the north Prospect Ridge supports Low Coppice. Plants of the Coppice are frequently found down near the water's edge.

/Most

Most conspicuous in this marginal belt is Conocarpus erecta(L), Buttonwood, which for the most part is merely a shrub. Associatedd with it in no regular manner are the shrub. Baccharis angustifolia (Michx) and the sedge Mariscus jamaicensis (Crantz) Saw-grass; the fern Acrostichum aureum (L) and the low grass Distichlis spicata (L). Outstanding are the scattered specimens of Sabal palmetto (Walt) the characteristic palm of wet places. There are occasional specimens of Coccothrinax argentea (Lodd) which are strays from the coppice behind which is their usual habitat.

Perculiar to marshy and wet habitats but occurring in less abundance are Annona glabra (L) Pond-apple; Eustoma exaltatum (L), Marsh Gentian; Lippia stoechadifolia (L); Aster Bracei (Britton), an endemic species; Agalinis spiciflora (Engelm); Rynchospora sp; Beaked rush; Dichromena colorata (L), White-headed Rush; Chrysobalanus Icaco (L), Cocoplum.

This seems to be the ideal habitat for the epiphyte Tillandsia which grows in great profusion on the branches of the mangrove. The following species were found; T. Balbisiana (Schultes), T. fasciculata (Sw) and a T. aloifolia (Hook). To overcome the lack of water resulting from their habitat the bases of the leaves are convex and closely appressed thereby acting as a very efficient receptacle for the storage of water falling as rain. Their boots serve the function of anchorage solely, being so tightly bound around the branch of the tree that often the easiest way of taking a specimen is to break the branch. In addition to these habitual epiphytes there are occasional specimens

/of

of Ficus epiphytic only in the younger states. Another epiphyte usually found on Sabal is the Serpent fern Phlebsodium aureum (L). An occasional epiphytic orchid is found.

The trailing and climbing vines show gradations from self-sufficiency as far as food is concerned to a state of complete parasitism as in the case of Cassytha americana (Nees), Love-vine, whose slender stems often form such a dense mat on the host plant as to obscure it almost completely. Cuscuta is not found in this habitat nor indeed on the island of New Providence at all though it does occur on other Bahamian islands. Other vines growing in this belt are Philibertella clausa (Jacq.), milk-vine; Mikania scandens (L); Rhabdadenia paludosa (Vohl). Both of these are peculiar to wet places. Others which occur in a greater variety of habitats are Rajania microphylla Knuth; Smilax sp.; Cryptostegia grandiflora (R).

Shrubs and herbs of the common to this habitat and sand-dunes are; Borrichia arborescens (L), Bay marigold; Rachicallis americana (Jacq Scaevola Plumierii (L), Inkberry; an occasional Casasia Clusiaefolia (Jacq.); Chrysobalanus Icaco (L), Cocoplum; Erithalis fruticosa (L), Black-torch.

Occurring here and generally throughout the island there are a number of plants which may be considered as having strayed into this marginal zone from the coppice behind and are able to withstand the additional dryness occasioned by more rocky soil but chiefly due to salt water, These include Metopium toxiferum (L), Poison-wood; Cassia bahamensis (Mill), Stinking Pea and other

/Cassia

Cassia spp; Leucaena glauca (L); Pithecolobium guadalupense (Chapm), Ram's-horn; Zanthoxylum Fagara (L), Wild-lime; Agava sisalana (Engelm), Sisal, an escape from cultivation; Mimusops emarginata (L), Wild Sapodilla; Coccolobis sp., Pigeon plum; Acacia choripphylla (Benth) Cinnecord; Myroxylon ilicifolium (Northrop); Anemia adiantifolia (L); Calyptranthes pallens(Poir), White Stopper.

Saprophytes were represented in this all-embracing marginal belt by an occasional bracket fungus (unidentified) and other agarics (unidentified).

MARSH AT EAST END.

At the east end of the lake is a large area of flat ground surrounded on the north, east and south by honey-comb rock and bordered on the west by the lake. After a few days of rain the whole of this area becomes swampy and a large part of it has water above the soil. Alternating with this totally water-logged condition, evaporation by the sun dries out the top few inches of soil leaving it cracked into small slabs, in appearance much akin to an enormous jig-saw puzzle.

Here in this marsh as nowhere else around the lake the vegetation is marked-ly zoned. These zones were measured approximately by pacing and a map of this marsh was drawn (see Fig. 8 page 39). Walking east from the margin of the lake along a line continuous with the long axis of the lake the following zones may be described. Immediately bordering the lake and for the most part growing in it was the usual zone of Rhizophora. The width of the zone here varies. It is very narrow at the

/SE corner

SE corner, about 10 yards wide in the middle of the east end and increasing to 50-100 yards in a few places along the north shore where the mangroves extended into the lake as previously described. Immediately behind this zone was a zone resembling the marginal zone described previously, being here a confused mixture of Rhizophora, Conocarpus and Baccharis all three being covered densely with the parasitic Cassytha. The lower stratum of vegetation included Borrichia, Acrostichum, Mariscus, Aster, Eustoma and Agalinis. In the middle of the east end this zone is about 10 yards wide but around the NE corner and along the north side it increases to 50 yards and then fairly quickly narrows into the usual width of a few yards as around the rest of the lake. To the east of this zone is a zone about 64 yards wide containing only two plants ~~each~~ growing in two distinct layers. The large one was the shrub Baccharis and the lower Mariscus. At the NE corner the Baccharis disappears and the Mariscus continues, merging into the next zone. This is a peculiar zone in which there is a reappearance of Rhizophora and Conocarpus forming clumps like islands standing up in a sea of Mariscus. This zone extends east for 89 yards but at the north east corner the clumps of Rhizophora and Conocarpus abruptly disappear and the remaining Mariscus merges into the Mariscus of the previous zone to form a wide zone of pure Mariscus which quickly narrows and finally merges into zone 2 which continues along the north side of the lake. To the east of zone 4 is a curious area of some considerable size (105 yards wide in the middle). By far the greater area of this zone is completely devoid of vegetation the surface being either under water or alternately

/cracked

cracked into irregular blocks by desiccation by the sun. There are very infrequent patches of very poor and dwarfed Mariscus, Rhizophora and Conocarpus. This zone disappears abruptly to the north.

East of this region of bare soil is zone 6 covered fairly densely with a rush, a species of Rychospora, with dwarfed Rhizophora and Conocarpus again forming isolated patches. It is 63 yards wide and it disappears abruptly when the soil suddenly ceases and is replaced by honey-comb rock. Here there are two zones 37 yards and 22 yards wide respectively and differing only in the occurrence of Inodes with an occasional Coccothrinax in the eastern one and in the absence of these palms in the western one. The rest of the vegetation is very low and dwarfed and includes Rachicallis, Myroxylon, Scaevola, Dichromena, Mariscus, Conocarpus, Aster, Metopium and the parasitic Cassytha.

To the east of this zone is a Pine zone, Pinus bahamensis extending some considerable distance east far beyond the road. To the south of this on the slopes of Baillou Hills there is High Coppice while to the north of the marsh the Pine is not replaced by, but mixes with, the Low Coppice covering the slopes of Prospect Ridge.

The deposits of this marsh are of two kinds. In the margin of the lake is the familiar soft yellow marl and a similar marl covers zones 5 and 6. But between zones 4 and 5 is a very, distinct dividing line with a black soil, apparently with very, high humus content, covering zones 1 to 4.

/It

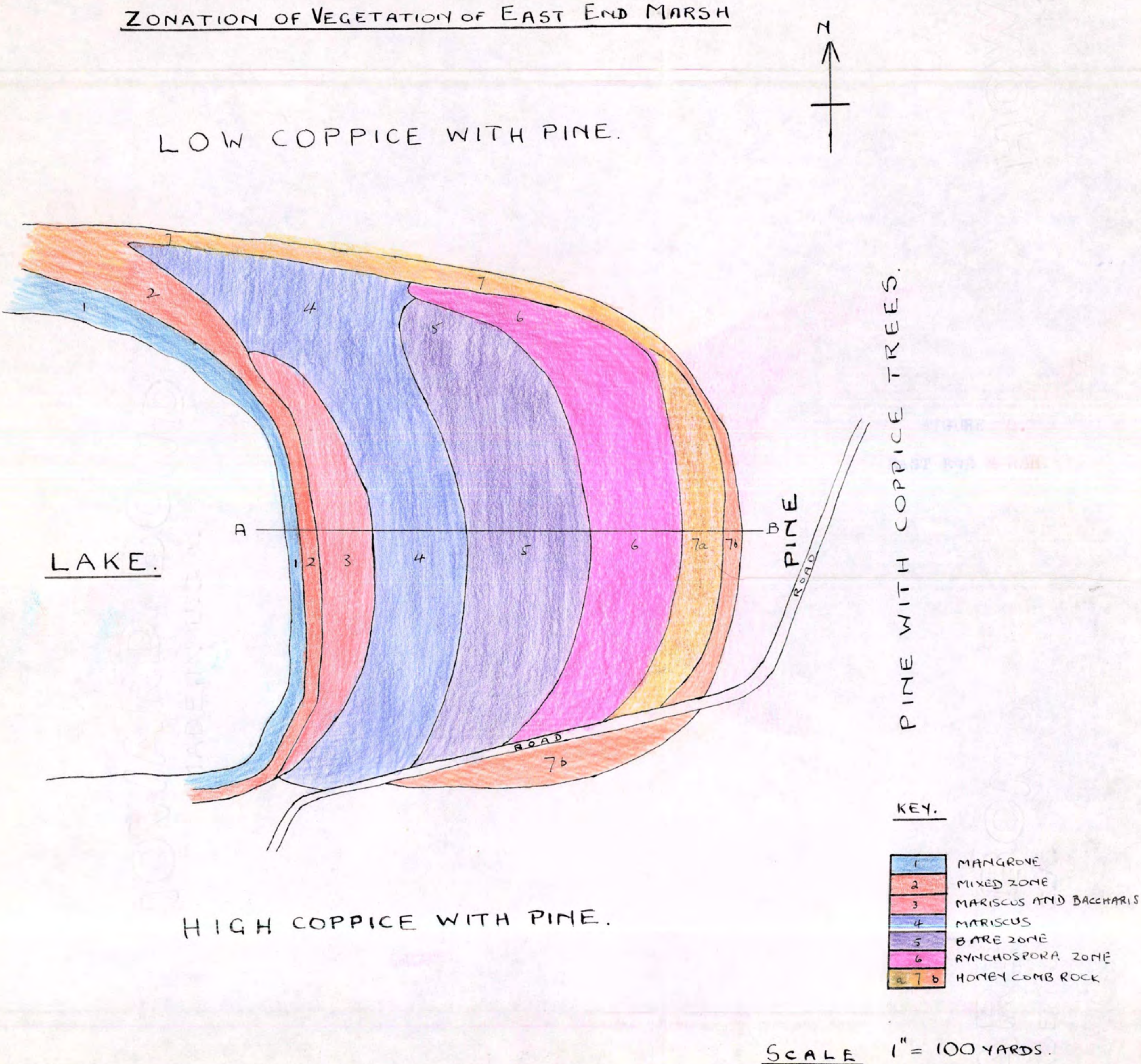

ZONATION OF VEGETATION OF EAST END MARSH
N
LOW COPPICE WITH PINE.
LAKE.
HIGH COPPICE WITH PINE.
PINE WITH COPPICE TREES.
PINE
ROAD
ROAD
A
B
1 2 3 4 5 6 7 7a 7b
KEY.
1 MANGROVE
2 MIXED ZONE
3 MARISCUS AND BACCHARIS
4 MARISCUS
5 BARE ZONE
6 RYNCHOSPORA ZONE
a 7 b HONEY COMB ROCK
SCALE 1" = 100 YARDS.

FIGURE 8.

EAST END MARSH.

It appears that really the soil is all predominantly marl but that in the regions of dense vegetation (zones 1 - 4) a considerable amount of humus has been added to the surface layers. This is supported by the fact that in zone 5, the bare zone, there was an isolated patch of comparatively luxuriant vegetation, which had a single specimen of Clusia in the centre. The surface layer of soil was quite black, lying on top of yellow marl. However, repeated attempts, without satisfactory apparatus, to discover yellow marl beneath ~~of~~ the humus in zones 1 - 4 feet met with no success.

As the zonation and the nature of the soil of this marsh was so unique the whole area received considerable attention and the theory was finally suggested that the whole area occupies what was formerly the original eastern end of the bed of the lake.

In support of this theory two sets of observations were made which proved to be very significant. A series of points was sighted in a straight line AB (see map) which was roughly taken to be continuous with the long median axis of the lake. A point at the lakeward end of the line was in the lake at the margin. At these points along this line a pole was thrust vertically into the soft marl until it reached rock. In this manner it was possible, with the aid of a metre rule, to find the depth of marl above bed rock at each point. It was found that at the edge of the lake there was a deposit of 6 feet of marl underlying 22 inches of water making a total of 8 feet

/in

in all. 20 yards from the margin of the lake the water level was found to be 7 inches below the surface, the soil being 7½ feet deep. As there had been no recent heavy rain and as undue evaporation was prevented by the tall, dense vegetation at this point it seemed logical to conclude that this water level was indentical with the lake-water-level. Under that assumption rock bottom was therefore approximately 7 feet below water level as compared with 8 feet at the margin of the lake. 100 yards from the lake the water level was 13 inches below soil level the soil being 7 feet deep. Accordingly the depth of mud below water level was calculated to be approximately 6 feet. At three of the remaining five points the water-level was found to be within a few inches of the surface of the soil. The soil here was not covered with dense vegetation as in the previous two stations and therefore the water level was very probably a few inches below lake-level. The depths of soil at these points were respectively 6 feet, 5½ feet, 4 feet, 20 inches and 0" - this last station having honey-combed rock at the surface which was completely exposed from this end of the transect eastwards to the Pine-zone. This data is det forth in the following table:

/Depths

Depths of soil and water in East End Marsh. TABLE I.

Station No.	Distance from lake.	Water level*	Depth of soil deposit.	Depth of rock below lake level.
1.	In lake 25 yards from shore	+22 ins.	6 ft.0 ins.	8 ft.
2.	20 yards.	-7 ins.	7 ft.6 ins.	7 ft.
3.	100 yards	-13 ins.	7 ft 0 ins.	6 ft.
4.	150 yards	Not observed	6 ft.0 ins.	6 ft.
5.	200 yards	-4 ins.	5 ft.6 ins.	$5\frac{1}{2}$ft.
6	250 yards	-2 ins.	4 ft 0 ins	4 ft.
7.	300 yards	-3 ins.	0 ft.20 ins.	$1\frac{1}{2}$ ft.
8.	320 yards	0 ins.	Nil.	Nil.

* + = above soil deposit

* - = below soil deposit.

Again, using the assumption that the level of water in the soil was approximately equal to the water level in the lake a section was constructed (Fig. 9 page 43). Examination of this section is alone fairly conclusive evidence in support of the assumption that this marsh occupies the eastern end of the original bed of the lake. Observations of depth of soil were made at only three points in a line at right angles to this transect to the south towards the road.

DEPTH OF LAKE.

In all, some 600 soundings of the lake wer e taken along 55 traverses across the lake. These were plotted on the most accurate map available which was provided by the Nassau Contracting Company and by this means the bathymetric chart of the lake was compiled and is seen on Fig. 10 page 44a .

/The

VERTICAL SECTION OF MARSH AT EAST END.

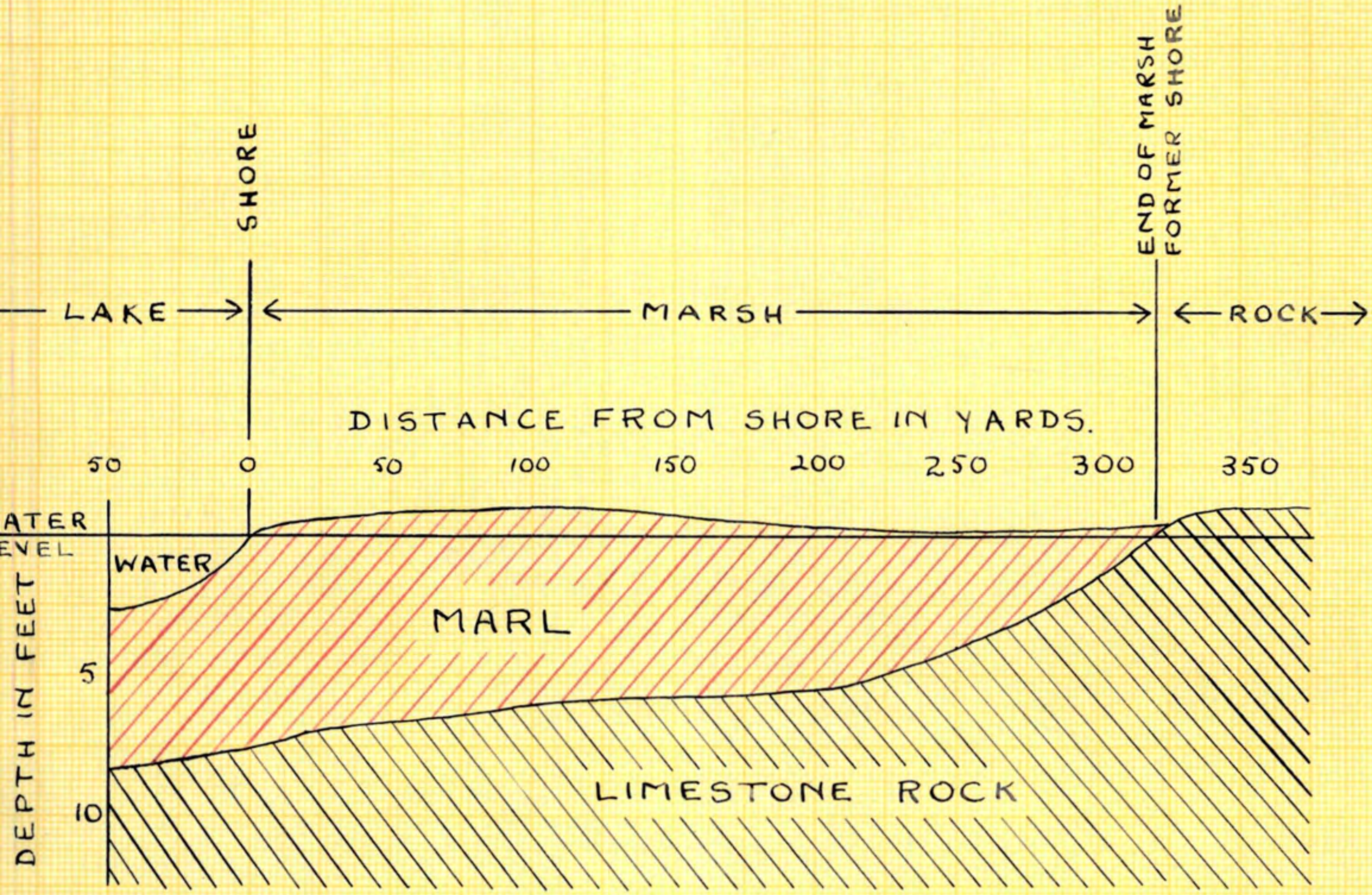


FIGURE 9.

VERTICAL SECTION EAST END MARSH.

The deepest sounding taken was $13\frac{1}{2}$ft. There are only two areas with depth greater than 12 ft. the one in the middle of the main body of the lake just to the east of Burnside Cay and the other in the middle of the North Arm. The greatest sounding taken in the South Arm was 10 ft. and towards the west end of this arm there is a considerable area deeper than 9 ft. The greatest extent of shallow water is found at the east end of the lake where there is a large area less than 9 ft. in depth. This area is covered on the bottom with a considerable amount of marl. At the east end of the north shore the manner on which shallow bottom swings out into the lake is clearly seen. It is on these banks that the majority of the Rhizophora grows.

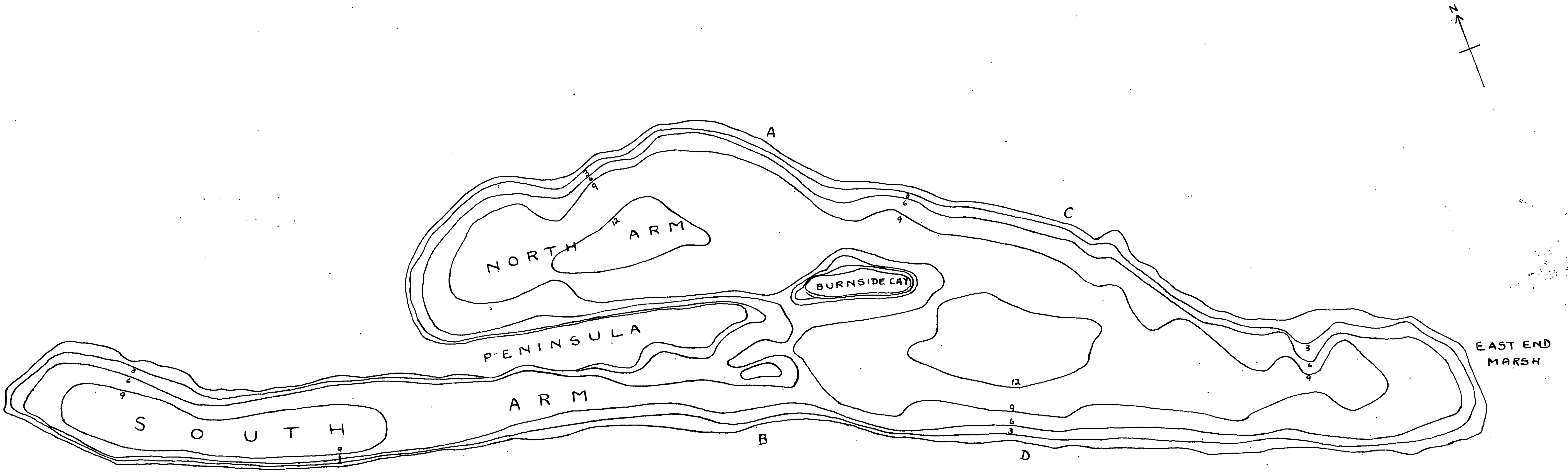
The Cay is seen to be, in effect, a continuation of the Peninsula to which it is connected by a strip of bottom for the most part shallower than 6 ft. To the WSW of Burnside Cay is a small island, not shown on the map because of its smallness, which is part of another peninsula, a branch of the large one and for the most part, submerged by less than 6 ft. of water.

Cross-sections of the lake have been drawn along the lines AB and CD and are to seen on Fig. 11 page. 45. The difference in slope on north and south sides is not marked here but it can be seen that the south bed slopes a little more steeply than the north side. This fact is seen more clearly in the South Arm.

/Depths

FIGURE 10.

BATHYMETRIC CHART OF LAKE CUNNINGHAM N.P. BAHAMAS.



SCALE: 1 inch = 600 feet

DEPTHS AT INTERVALS OF 3 FEET

Depths of soil in East End Marsh. Table 2.

Station No.	Distance from main transect.	Depth of Soil.
9.	150 yards	31 ins.
10.	175 yards	6 ins.
11.	180 yards	Nil (Rock).

An attempt was made to continue the main transect further into the lake but the usual practical difficulties attendant upon investigating depth of true bottom below false bottom from an unstable boat made it impossible.

A discussion of the possible origin of this marsh will be left until later in the thesis.

PHYSICAL AND CHEMICAL STUDIES.

Water level and Rainfall.

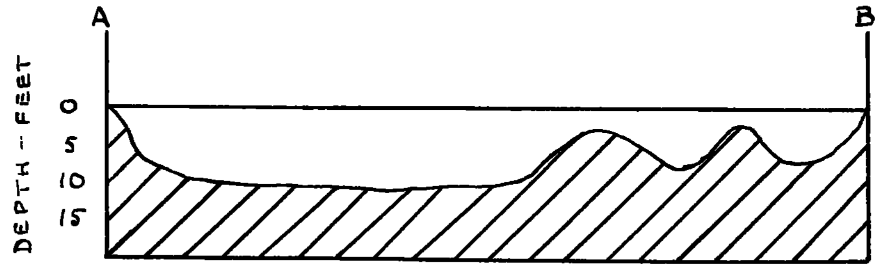
Rainfall and water-level records appear in Table 3 and these values are graphed in Fig. 12 page 47.

Rainfall and Water Level. TABLE 3.

Date 1940.	Water level	Average daily rainfall since preceding record.
April 1.	$-5\frac{3}{4}$	.014 ins.
May 4	$-5\frac{3}{4}$	.036 ins.
June 4	$-3\frac{1}{2}$	.066 ins.
June 29	-3 1/8	.173 ins.
August 9	-2	.081 ins.
Sept. 14	$+5\frac{3}{4}$	.211 ins.
Oct. 14	$-1\frac{3}{4}$	.385 ins.
Nov. 10	$-1\frac{1}{4}$	.025 ins.
Dec. 13	$-3\frac{1}{2}$	.006 ins.
1941.		
Jan. 21	-1	.170 ins.

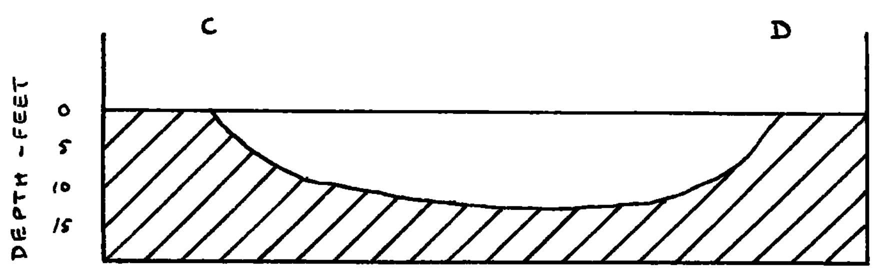
SHAPE OF LAKE BASIN.

11 A. CROSS SECTION FROM A-B (see Fig. 10)



HORIZONTAL SCALE: 1 cm. = 80 yards.

11 B. CROSS SECTION FROM C-D (see Fig. 10)



HORIZONTAL SCALE: 1 cm = 80 yards

FIGURE 11.

SHAPE OF LAKE BASIN.

April 6	$-0\frac{3}{4}$	.183 ins.
May 7	$-2\frac{1}{4}$	.170 ins.

The level of water in the lake varied between two extremes which were 11 ins. apart. Broadly speaking the lowest levels are recorded at the end of the dry season i.e. the months of April and May before the onset of the summer rains which begin before the end of May. From this lowest level there is a fairly uniform increase to a maximum at the end of the wet season when the level was highest in the month of September following a period when the average rainfall per day was 0.211 ins.

However, the beginning of the year 1941 was by no means typical as there was an abnormal rainfall there being 13.91 ins. from January 21st. to April 6th, an amount of precipitation 3 times the average rainfall for those months. As a result the level of the lake did not fall to the level recorded for April 1940 but remained 5 ins. above it.

The fact that heavy rainfall produces sudden large changes in water level is seen from the records for April 6th and April 8th. During this short period of two days the water level rose $2\frac{1}{2}$ ins. the total rainfall for these two days being 1.81. Similarly, the level rose by 2 ins. over a period of three days from April 28th to May 1st. and dropped $1\frac{1}{4}$ ins.in the next four days. Rainfall of 1.68 ins for May 7th to 9th was accompanied by a rise in level of $3\frac{1}{2}$ ins. This would indicate that seepage (not drainage - because of the porous nature of the rock) contributes substantially to the amount of water in the lake. The level therefore fluctuates a great deal with precipitation and evaporation.

/On

FIGURE 12.

MONTHLY RECORD OF WATER LEVEL AND RAINFALL

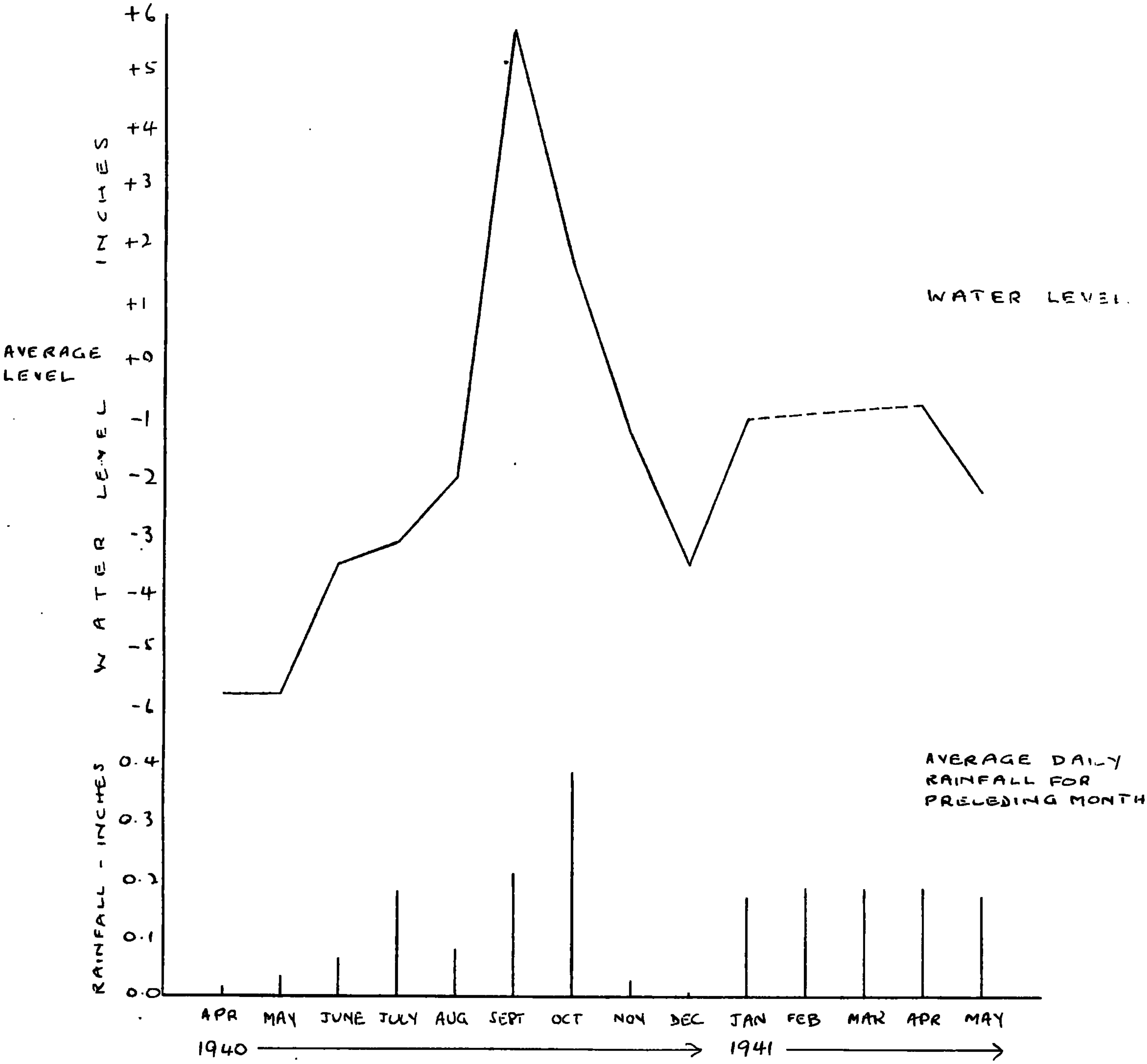


FIGURE 12.

WATER-LEVEL AND RAINFALL.

On several occasions records of water level were observed at regular intervals on the same day over aperiod of several hours. These observations showed that there was no suggestion of a rise and fall in the nature of tidal action. Therefore it must be assumed that the popular belief that this lake ebbs and flows with the tide is a fallacy.

2. Nature of Lake-Bed.

As has been described previously the lake lies in a hollow of land between Baillou Hills and Prospect Ridge. The whole of the bed-rock of this depression is limestone. It is considerably exposed around the margins of the lake particularly on the south shore, western end of both arms and the western end of the north shore. Here, wave action prevents any deposition of marl and weathers the exposed rock into smooth rounded surfaces known as "plate rock" (Shattuck 1905). However, at the east end the rock bordering the marsh on the east side, (which is postulated above as being the original east end of the lake) is "honey-comb" rock, weathered into innumerable small pockets with knife-like edges. This is characteristic of solution by rain and is most probably subsequent to the filling in of the lake at the east end to form the marsh now existing there.

The depth and nature of the true bottom of the lake is unknown except at the margins. In all other places it is covered by varying depths of marl. In colour this marl is a pale yellow or grey with a slight suggestion of redness in some localities. In texture it is exceedingly fine. When disturbed it emits a most disagreeable odour of hydrogen sulphide. The whole of the eastern shore of the lake is marl and wherever dredgings were

/taken

taken anywhere in the lake the dredge was always filled with this soft mud. Around the shores of the lake it is found nowhere except east end and north east corner where it is commonly 6 feet deep. The surface of this marl is by no means firm. In appearance it is very flocculent and remains half-suspended in the water and the merest agitation of the water causes it to rise in clouds to the top. The anchor of the boat, a large rock, when lowered gently into the mud disappears completely. The deposit is apparently flocculent in the top twelve inches at least. Further down, however, it is much firmer and a pole thrust through the whole 6 feet is removed only with difficulty.

Microscopically this deposit is not organized into any apparent crystalline form but appears as irregular grains each of which has at its centre a colony of the blue-green alga Aphanothece Castagnei (Breb) Rabenh. This is strikingly evident when a drop of hydrochloric acid is added to a sample of the marl on a microscope slide. The outer calcareous portion of the grains disappears and the algae can be seen distinctly. Furthermore, a sample of this marl, when exposed to light in a Petri dish turns distinctly green due to algal growth. This phenomenon is discussed later but it may be mentioned here that it seems that the algal colonies act as foci for the formation of the calcareous grains. With the increase in amount of marl accumulating around each colony its density becomes heavier than that of water and it therefore sinks but may be brought back temporarily into suspension by movement of the water.

COLOUR, LIGHT PENETRATION AND TURBIDITY.

The water is colourless. On occasion there may be the

/slightest

slightest suggestion of yellowness but only sufficient to cause a slight greenish tint with the blue colour produced by the reagents added in the Denigès test for phosphates. However, the lake usually has a decided green colour due to the reflection of blue from the sky coupled with the yellow colour of the false bottom.

Light penetrates to all depths of water above the false bottom but usually a Secchi disc can be seen only with difficulty in the deepest parts (greater than 10 feet). In August 1940 the Secchi disc was invisible at 10 feet and in September 1940 it was visible only down to 8 feet depth. This was due to turbidity caused by the disturbance of the marl by vigorous circulation of the water by strong winds. However, it may be stated that there is sufficient light at any point on the false bottom to allow plant growth.

DENSITY AND TEMPERATURES.

The S.G. of the water fluctuates between the limits of 1.0070 and 1.0090. The monthly variation of S.G. is set forth in Table 4, the temperature of the water when the density was observed also being given. These observations are graphed in Fig. 13 page 51.

An analysis of these figures shows that the S.G. increases gradually from October 1939 to February 1940 the temperature showing a corresponding decrease. From February to September there is a decrease accompanied by increase of temperature. Thereafter the first trend is repeated.

/In

FIGURE 13.

ACTUAL SPECIFIC GRAVITY AND TEMPERATURE AT WHICH S.G. RECORDED

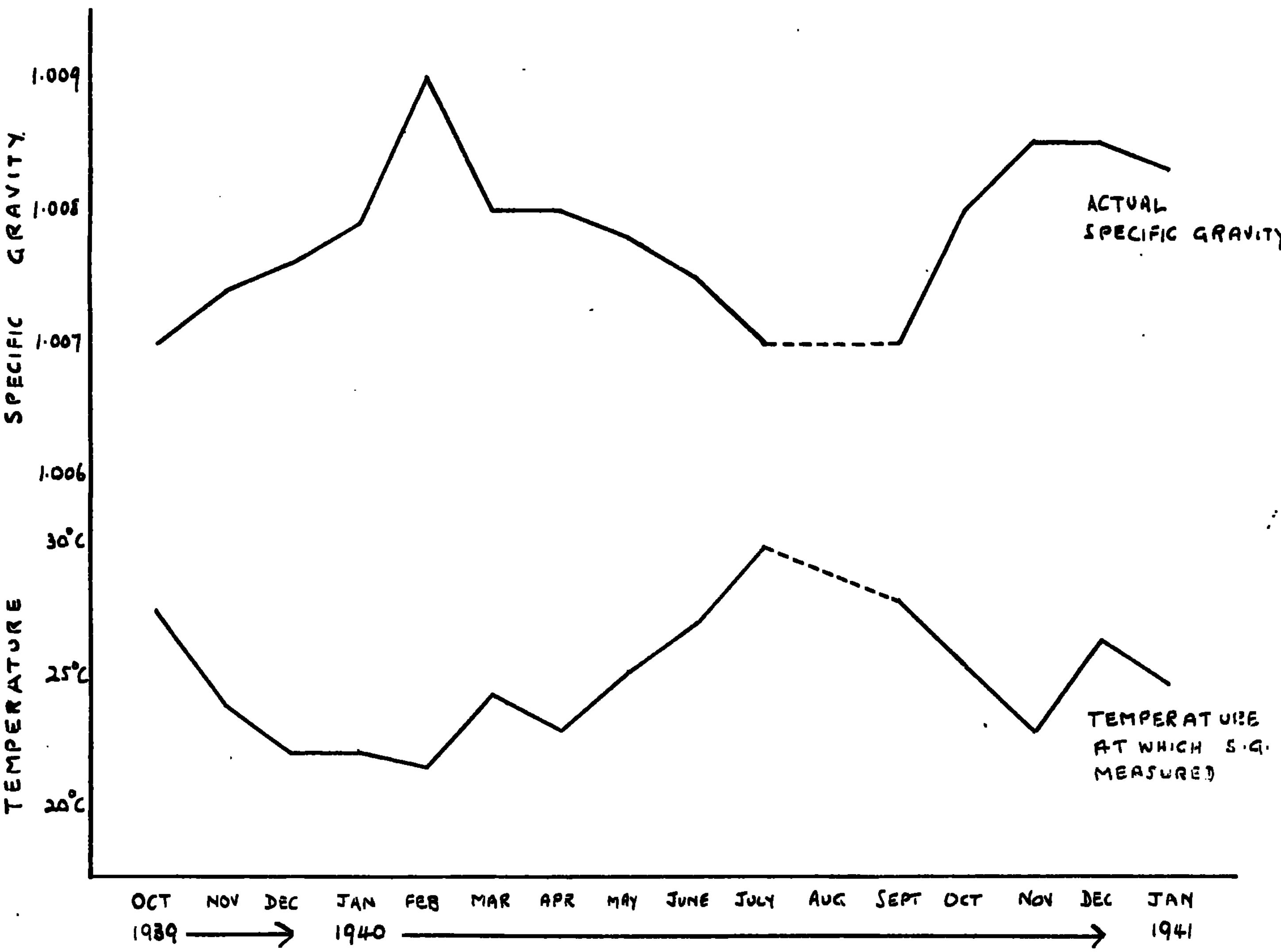


FIGURE 13.

ACTUAL S.G.

Specific Gravity

TABLE 4.

Date 1939.	Actual observed S.G.	Temperature of observation °C	S.G. correct to 25°C.
Oct. 28	1.0070	25.5	1.00767
Nov. 18	1.0074	24.0	1.00765
Dec. 8	1.0076	22.2	1 .00692
1940			
Jan. 9	1.0079	22.2	1.00722
Feb. 3	1.0090	21.6	1.00818
Mar. 2	1.0080	24.3	1.00782
April 1	1.0080	23.0	100751
May 4	1.0078	35.2	100788
June 4	1.0075	27.0	1.00803
June 29	1.0070	29.8	1.00842
Aug.	-	-	-
Sept. 14	1.0080	23.3	1.00808
Nov. 12	1.0085	22.9	1.00798
Dec. 13	1.0085	26.4	1.008[illegible]7
1941.			
Jan.21	1.0083	24.7	1.00822.

In the third column of Table 4 are given the values for the S.G. corrected for temperature differences using Birge's table for differences which is found in Welch's Limnology p.33. All S.Gs. are brought to a uniform temperature of 25°C. In Fig. 14 the density corrected to 25°C is graphed together with the total solid content of the water. The striking similarity of the two graphs is self-evident and shows that the density varies directly with total dissolved solids content as might well be expected.

The S.G. of the water corrected by the same method to 4°C is 1.011. Average sea-water at the same temperature has a S.G. of 1.025.

/Table

FIGURE 14.

SPECIFIC GRAVITY CORRECTED TO 25°C AND TOTAL SOLIDS CONTENT.

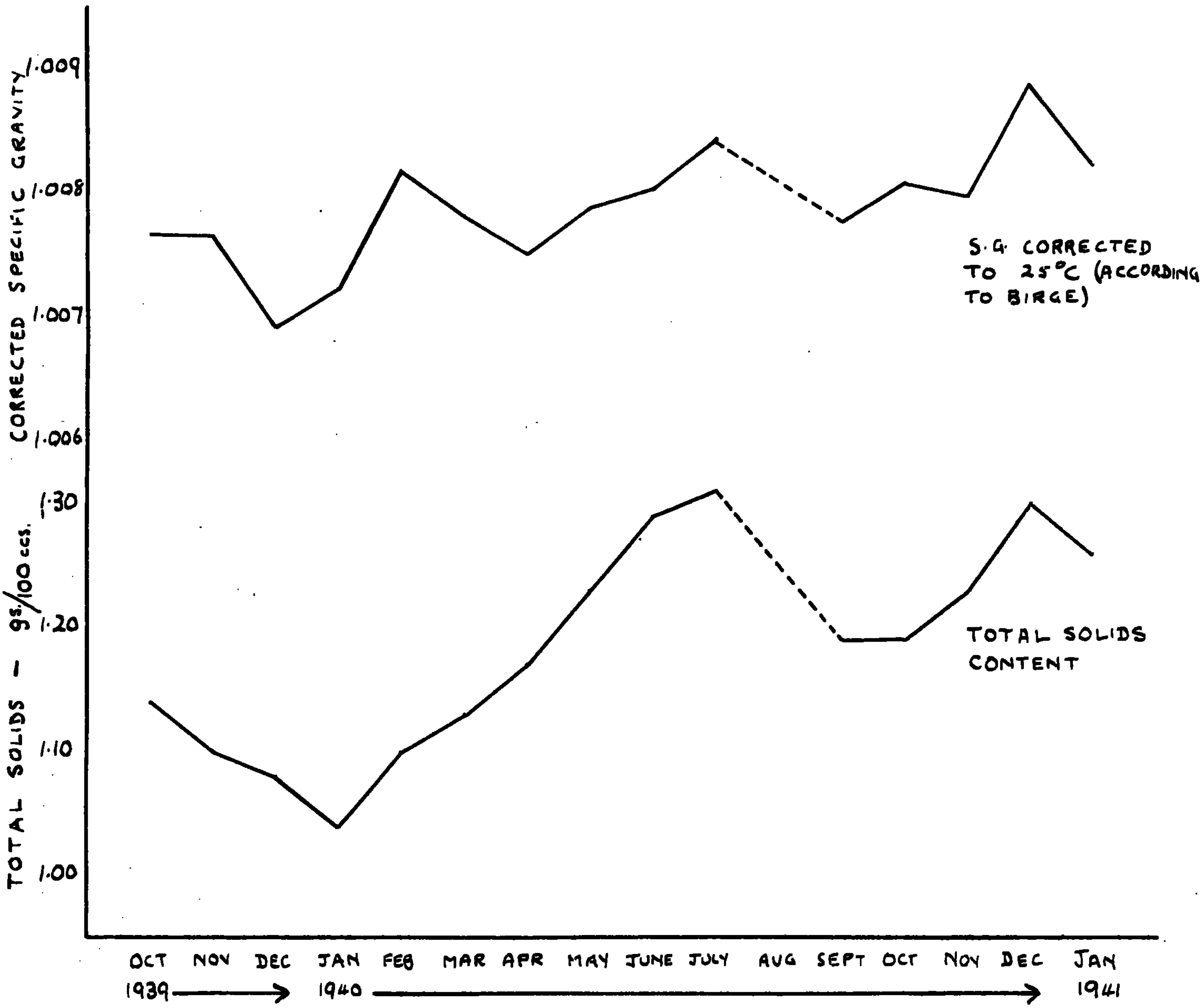


FIGURE 14.

CORRECTED S.G.

Table 5 gives air temperatures (shade), surface water temperatures and, in some instances, bottom temperatures at depths varying from $8\frac{1}{2}$ feet to 12 feet. These values are graphed on Fig. 15. page 57.

The surface temperature of the water varies from 20.6 °C in January 1941 to 31.2 °C in July 1940 (69.1 °F to 88.0 °F). The lake obviously belongs to the class "Tropical Lakes" in Whipple's classification and because of similarity of bottom and surface temperatures it is a 3rd. Order Lake in the same classification i.e. one so shallow that circulation is possible throughout the year. It might be suggested that such high summer temperatures are lethal in effect on organisms. The only observations made at this time were on plankton and so far from being lethal the increased temperature is accompanied by considerable increase in plankton population. No observations were made, however, at that time on any other of the plants or animals in the lake.

Air temperatures in the shade bear no apparent close agreement with water temperatures at the same time, being sometimes lower and sometimes highter.

The greatest difference observed was in October when the water temperatures was 25.3 °C: 2.6° below the temperature of the air at the same time. It should be noted however that these readings were made at 11.30 a.m. whereas observations were usually made at 4 - 5 p.m. The difference observed in May was also due to the same cause. Otherwise there was not a great deal of difference between the air and surface water temperatures.

Depth temperatures agree very closely with surface temperatures, differing by not more than 1.2°C. This indicates complete circulation

/of

Temperatures. TABLE 5.

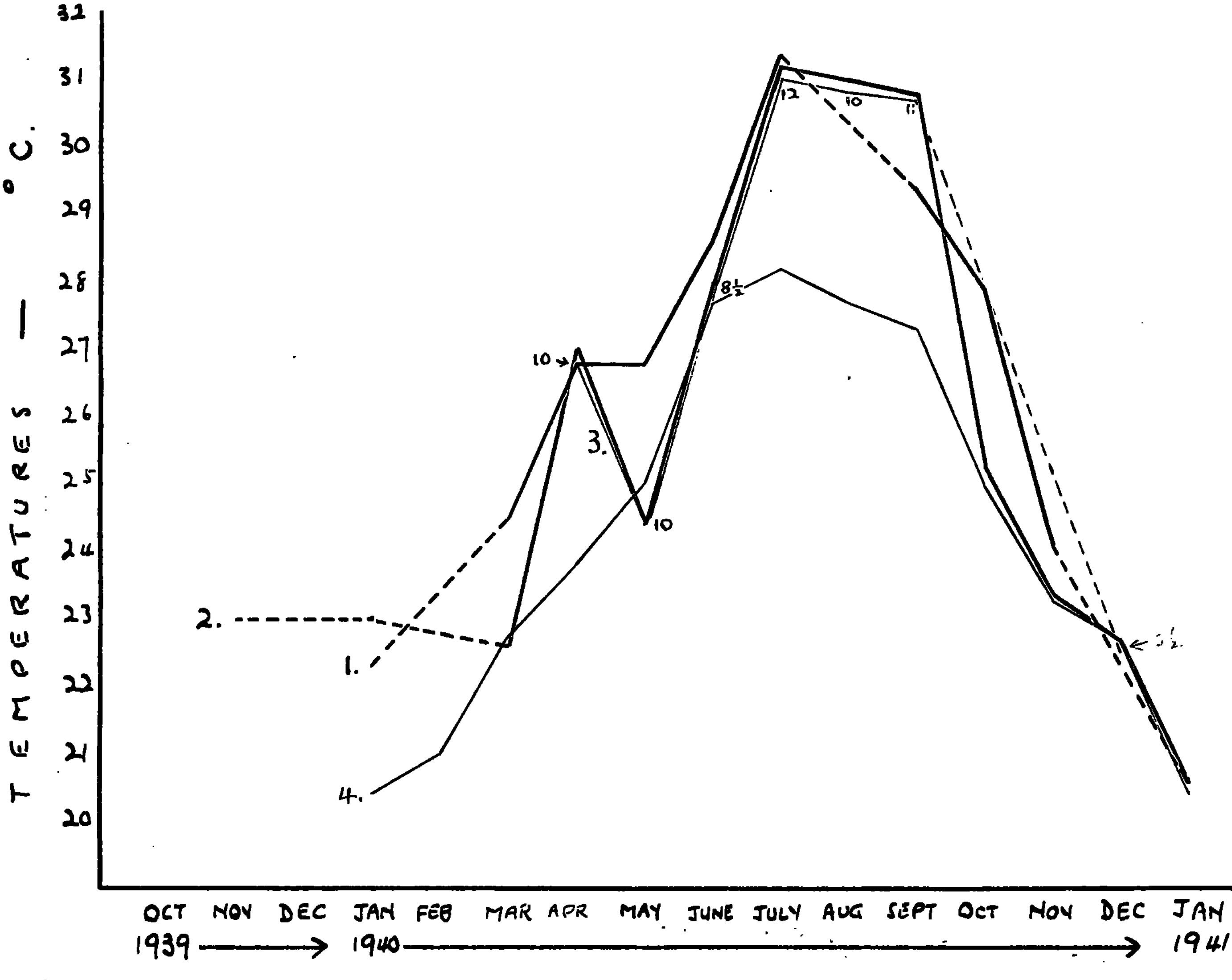
Date 1939	Air Temperatures °C	Surface Water Temp.	Bottom Water Temp. °C	Depth.
Nov. 18	-	23.0	-	-
Dec. 8	-	-	-	-
1940 Jan. 9	22.3	23.0	-	-
Feb. 3	-	-	-	-
Mar. 2	24.5	22.6	-	-
Apr. 1	26.8	27.0	26.8	10 ft.
May 4	26.8	24.4	24.4	10 ft.
June 4	28.6	28.0	28.0	8½ ft.
June 29	31.4	31.2	31.0	15 ft.
Aug. 9	2616	31.0	30.8	10 ft.
Sept. 14	29.4	30.8	70.7	11 ft.
Oct. 14	27.9	25.3	-	-
Nov. 12	24.1	23.4	-	0
Dec. 13	-	22.7	22.5	8½ ft.
1941. Jan. 21	20.6	20.6	-	-

of water above the false bottom. This may be attributed to shallowness and wind action both of which are factors contributing to complete circulation of water. That circulation is not complete in the false bottom of marl right down to bed rock is evidenced by the values shown in Table 6 of water and mud temperatures at the east end of the lake. The three values in column 2 were from one station while the two values in column 4 were from another the stations being only 5 feet apart.

FIGURE 15

TEMPERATURES: (1) AIR SHADE (2) SURFACE WATER (3) BOTTOM WATER.

(4) MID-TEMPERATURES FOR NASSAU.



LEGEND.

1. AIR SHADE TEMPERATURE
2. SURFACE WATER TEMPERATURE
3. BOTTOM WATER TEMPERATURE (NUMBERS INDICATE DEPTH IN FEET)
4. MID-MONTHLY TEMPERATURES FOR NASSAU

FIGURE 15.

TEMPERATURES.

Temperatures in False Bottom at East End. TABLE 6.

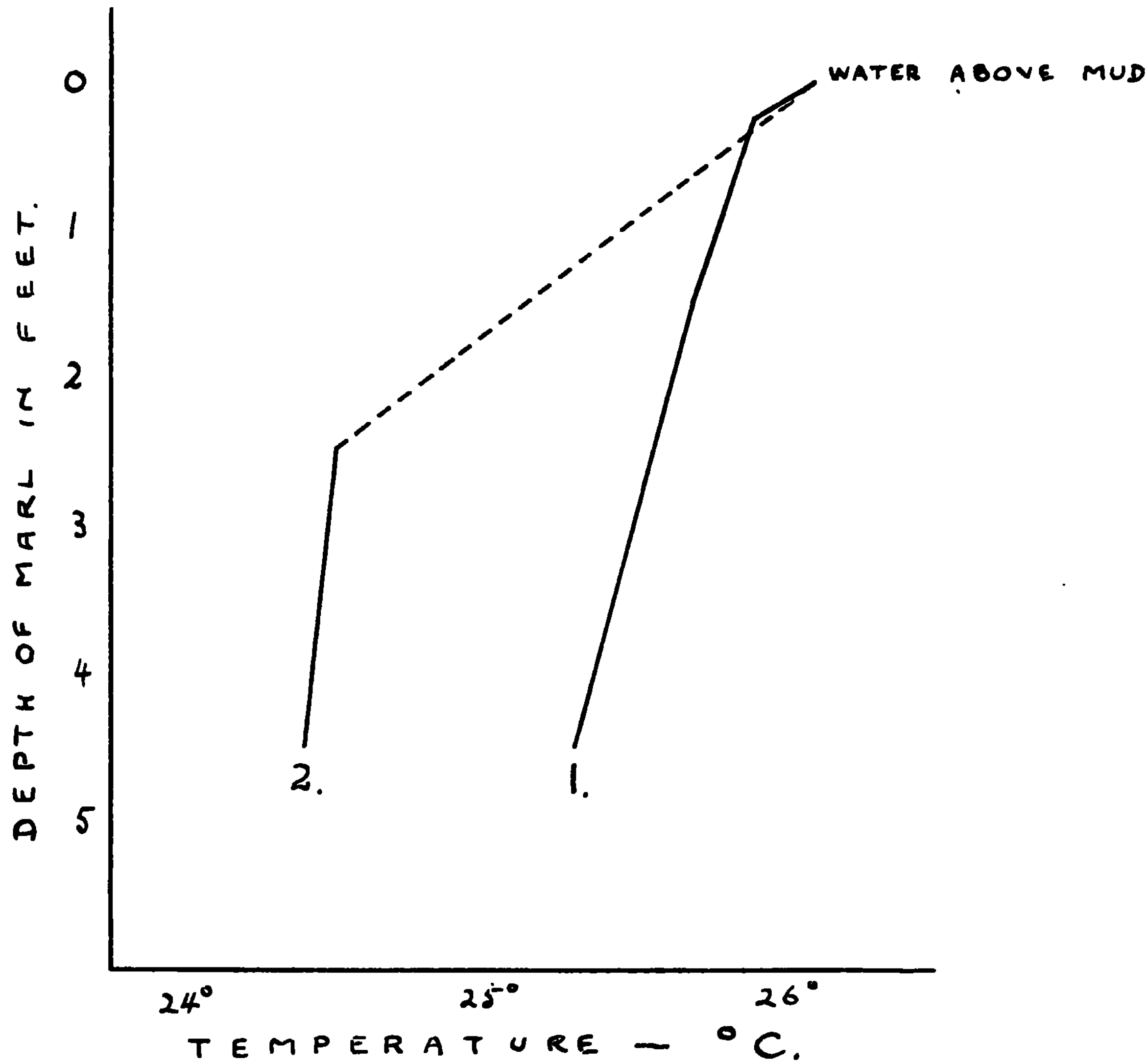
Station 1 Depth.	Temp. °C	Station 2 Depth.	Temp. °C
Water	26.2	Water	26.2
Mud 3 ins.	25.9	-	-
Mud 18 ins.	25.7	Mud 2 ft. 6 ins.	24.5
Mud 4 ft. 6 ins.	25.3	Mud 4 ft. 6 ins.	24.4

Fig. 16 page 59 shows this vertical distribution of temperature in the false bottom.

At this place the water was 2 feet deep and of uniform temperature. The figures indicate a drop of 0.3°C in the first 3 inches of mud and a further decrease of 0.6°C from top to bottom of the marl. The values at Station 2 indicate a total fall in temperature, from water surface to 4½ feet depth in the false bottom of 1.8°C. A comparison of the figures at both stations indicates a horizontal variation in the mud of as much as 0.9°C in a distance of 5 feet. A similar horizontal variation was observed by Welch in a Michigan Bog Lake (1939) and also by Birge, Juday and March (1928) in bottom deposits of Lake Mendota. Welch suggests that one important cause may be the differences in thermal conductivity of the false bottom materials in different places at the same level since these materials are not always homogeneous in character. The writer of this present paper has no evidence at this time which would justify any attempt at an explanation of the variations but it seems probable that another co-ntributory cause may be the different rates of organic decay, which is undoubtedly going on in this marl, with a consequent dis-similarity in production of heat.

FIGURE 16.

TEMPERATURE GRADIENT IN FALSE BOTTOM.



LEGEND.

1. ———— STATION 1.
2. ———— STATION 2.

FIGURE 16.

VERTICAL DISTRIBUTION OF TEMPERATURE IN FALSE BOTTOM.

HMDROGEN IN CONCENTRATION AND OXYGEN.

As mentioned previously the method for determining pH (hydrogen ion exponent) of the water was unsatisfactory and therefore no regular observations were made. Obsergations that were made at different times are given in Table 7.

HYDROGEN ION EXPONENT. TABLE 7.

Date	pH.
1940.	
April 1	8.4
May 4	8.5
June 4	8.6
Dec. 13	8.4
1941.	
Jan.21	8.5

From these 5 specimen results it is seen that the pH varies between the limits of 8.4 - 8.6. These values are distinctly on the alkaline side of neutrality.

In Table 8 are given amounts of dissolved oxygen expressed both as mgs/litre and as ccs/litre at N.T.P. These values are equal to values expressed as parts/million by weight and by volume respectively. Fig. 17 page 62 represents these values graphically.

Dissolved Oxygen. TABLE8.

Date 1940	Surface mgs/l	Surface ccs/l	Depth	Bottom mgs/l	Bottom ccs/l
Feb. 3	8.1	5.67	8 ft.	8.9	6.23
Mar. 2	8.9	6.23	-	-	-
April 1.	8.0	5.60	10 ft.	8.0	5.60
May 4	7.1	4.97	10 ft.	8.2	5.74
June 4	6.7	4.69	8½ ft.	6.5	4.55
June 29	6.7	4.69	12 ft.	6.6	4.62
Aug. 9	6.5	4.55	-	-	-
Sept. 14	6.9	4.83	11 ft.	7.2	5.04
Oct. 30	6.7	4.69	12 ft.	6.7	4.69
Nov. 12	8.0	5.60	9½ ft.	7.8	5.46
Dec. 13	7.3	5.11	8½ ft.	7.0	4.90
1941					
Jan. 21	8.3	5.81	-	-	-

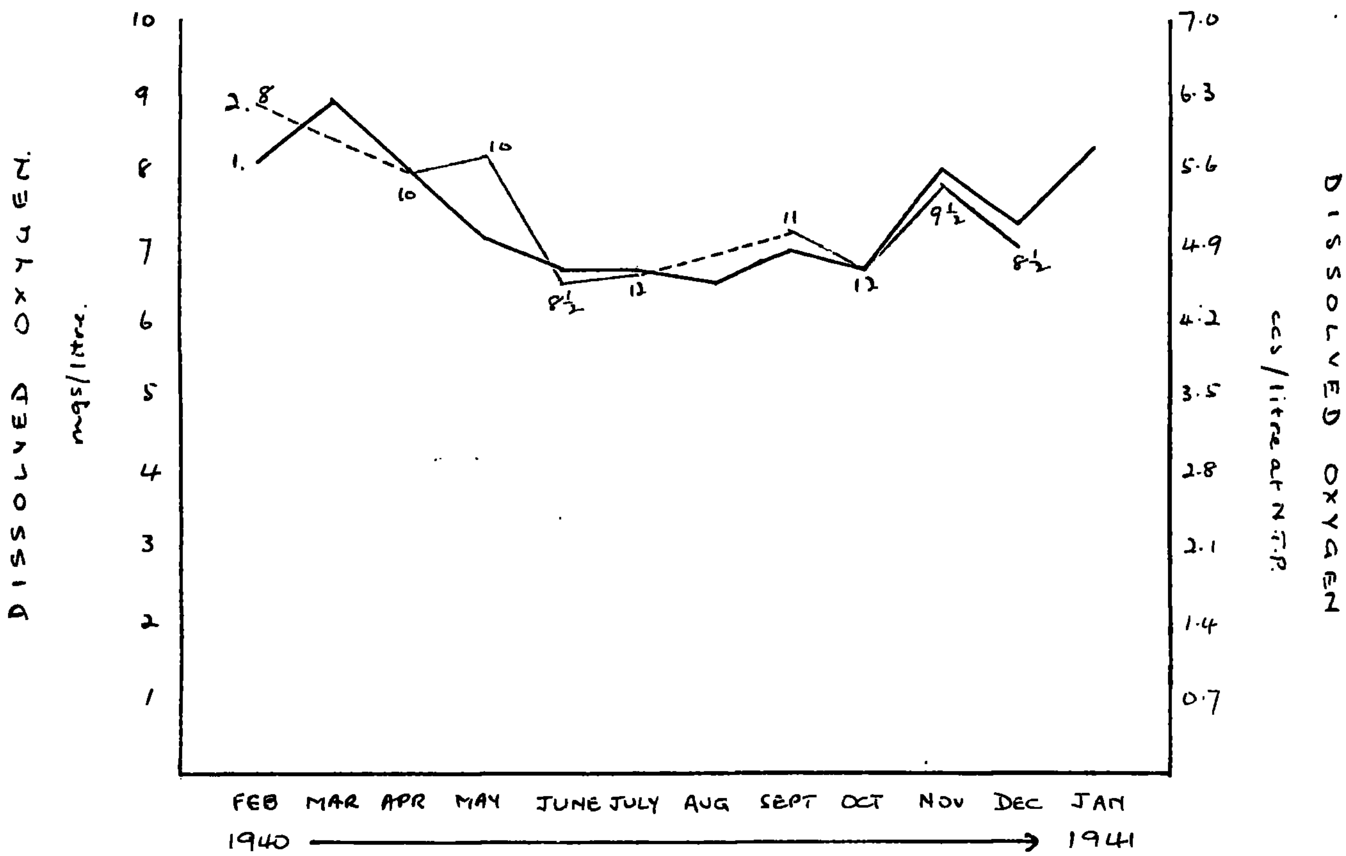
The amount of dissolved oxygen in the surface water was highest in March 1940 when the value was 8.9 mgs/litre (6.23 ccs) and is high generally in the winter months. The amount decreases in summer and the lowest recorded was 6.5 mgs/litre (4.55 ccs) in August 1940.

The amount in the bottom water differs very little from that in the surface water being slightly lower on four occasions, higher on three occasions and the same on three occasions.

OTHER GASES.

The amounts of dissolved (free) carbon dioxide are given in Table 9 expressed both as mgs/litre and as ccs/litre at

DISSOLVED OXYGEN.



LEGEND.

1. ———— SURFACE WATER.

2. ———— BOTTOM WATER.
NUMBERS INDICATE
DEPTH IN FEET.

FIGURE 17.

DISSOLVED OXYGEN.

N.T.P. These values are equivalent to parts/million expressed by weight and by volume respectively. Fig.18 page 64 represents these results graphically.

Free Carbon Dioxide

TABLE 9.

Date 1940	Surface mgs/l	Surface ccs/l	Depth	Bottom mgs/l	Bottom ccs/l
April 1	4.3	2.2	10 ft.	3.7	1.9
May 4	4.6	2.3	10 ft.	4.8	2.4
June 4	5.2	2.6	8½ ft.	6.1	3.5
June 29	4.9	2.5	12 ft.	4.9	2.5
Sept. 14	9.5	4.8	11 ft.	9.6	4.8
Oct. 14	9.0	4.5	12 ft.	8.8	4.4
Nov. 12	2.8	1.4	9½ ft.	3.2	1.6
Dec. 13	1.6	0.8	8½ ft.	2.4	1.2
1941.					
Jan. 21	11.0	5.5	-	-	-

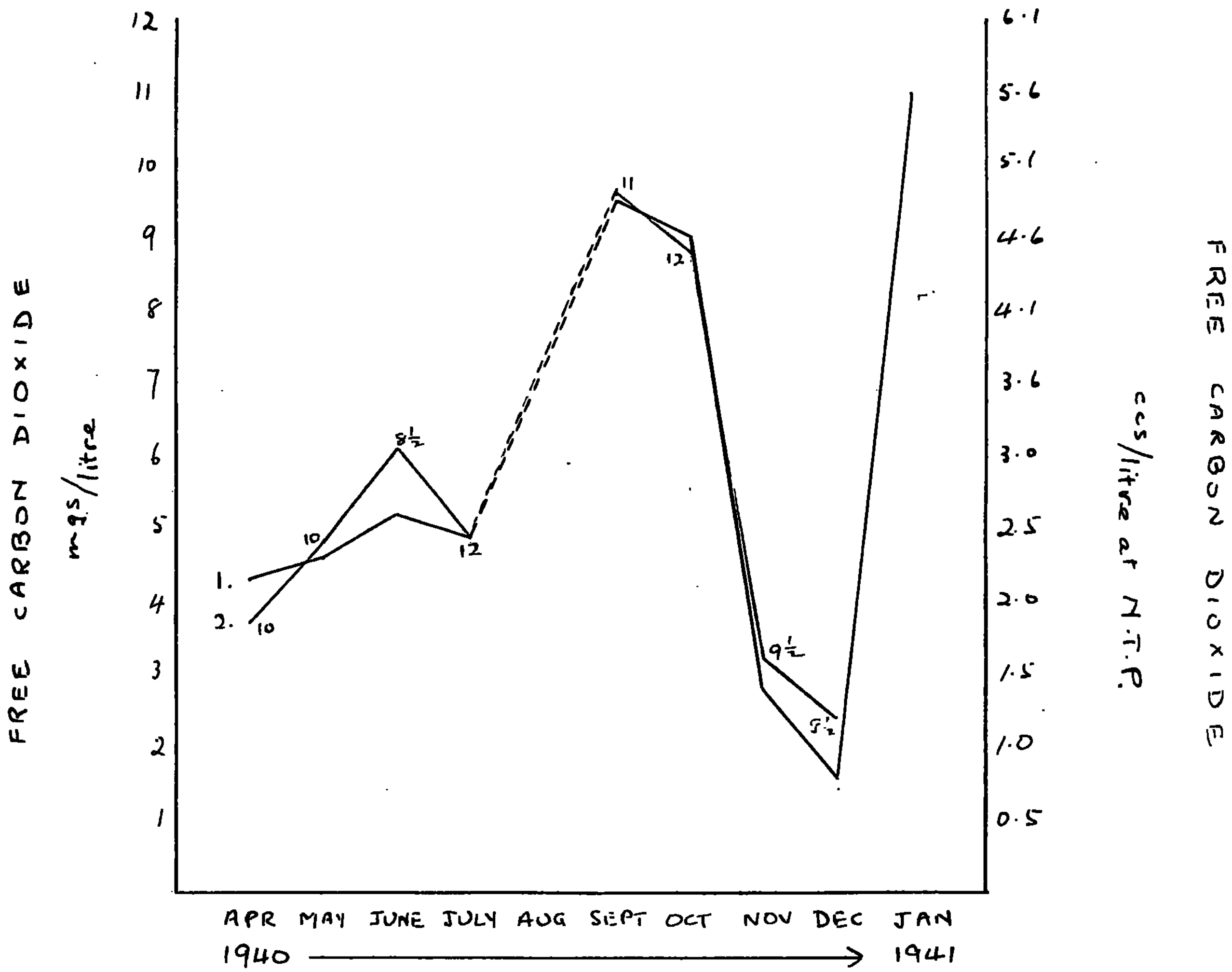
There is considerable variation in the amounts of free carbon dioxide found but as might be expected from the reaction of the water all the values are low. The lowest amount was observed in Dec. 1940 - 1.6 mgs/litre (0.8 ccs). Oddly enough the highest amount was recorded a month later in Jan. 1941 when there was 11 mgs/litre (5.5 ccs). But this appears to be an anamolous value. In Sept. and Oct. 1940 there was more than 9 mgs/litre (4.5 ccs). The free carbon dioxide in the bottom water never differed by a large amount from that in the surface water. On five occasions it was slightly higher, onee the same and twice slightly lower.

Tests for sulphuretted hydrogen in the water always gave results of less than 0.2 mgs/litre (0.13 ccs) but whenever the

/false

FIGURE 18.

FREE CARBON DIOXIDE.



LEGEND.

1. ———— SURFACE WATER

2. ———— BOTTOM WATER. NUMBERS INDICATE DEPTH IN FEET.

FIGURE 18.

FREE CARBON DIOXIDE.

false bottom of marl was disturbed to any great depth (1 foot or more) the odour of this gas was unmistakeable evidence of its presence. This is most probably associated with decay taking place and in the laboratory. A number of plants of Batophora and Chara were dredged up from the bottom of the lake and placed in a large jar full of lake water. This water was tested for hydrogen sulphide and found to contain 0.19 mgs/litre. Only three days later the smell of the gas became objectionable and a thin crust of sulphur was forming on the surface o f the water. The water was tested qualitatively with lead acetate and estimated quantitatively with iodine and found to contain 5.34 mgs/litre.

TOTAL SOLIDS.

Table 10 gives the results of analyses for total solids in gs/100 ccs and also in parts/million.FIG. 19 page 67 shows these results graphically together with average monthly temperatures as recorded at the Bahamas Government Meteorological Observatory, Soldier Road, New Providence.

Total Solids. TABLE 10.

Date	Total solids.	
1939	mgs/100 ccs	parts/million.
Oct. 28	1.14	11,400
Nov. 18	1.10	11,000
Dec. 8	1.08	10,800
1940 Jan. 9	1.04	10,400
Feb. 3	1.10	11,000
Mar. 2	1.13	11,300
Apr. 1	1.17	11,700
May 4	1.23	12,300

/June

	mgs/100 ccs.	parts/million
June 4	1.29	12,900
June 29	1.31	13,100
Aug.	-	-
Sept. 14	1.19	11,900
Oct. 14	1.19	11,900
Nov. 12	1.23	12,300
Dec. 13	1.30	13,000
1941		
Jan. 21	1.26	12,600

The total solids are seen to vary from 1.04 gs/100 ccs (10,400 parts/million) present in January 1940 to 1.31 gs/100 ccs (13,100 parts/million) present in July 1940. No analysis was made in August 1940. The general trend of the salinity shows, therefore, a gradual decrease through the winter months to a minimum in January followed by an increase to a maximum in July followed again by a decrease. That variation is directly associated with increase and decrease in average monthly temperatures is seen from Fig. 19.page 67.

There still remains to be explained however the anomolousy high values from October 1940 to January 1941. There is no obvious explanation of them as they show a distinct rise from October to December when one would expect a steady decrease as exhibited in the same months of the previous year. This abnormal increase is not paralleled by the temperature curve but examination of Fig. 14 page53. reveals a striking similarity between the corrected S.G. and the total solids content.

It is interesting to compare these values with the salinity of sea-water in Bahamian water. The average value is 36 °/oo but increasing in the shallowest parts of the Bahama Bank to

SALINITY : AVERAGE MONTHLY TEMPERATURES : CHLORIDES.

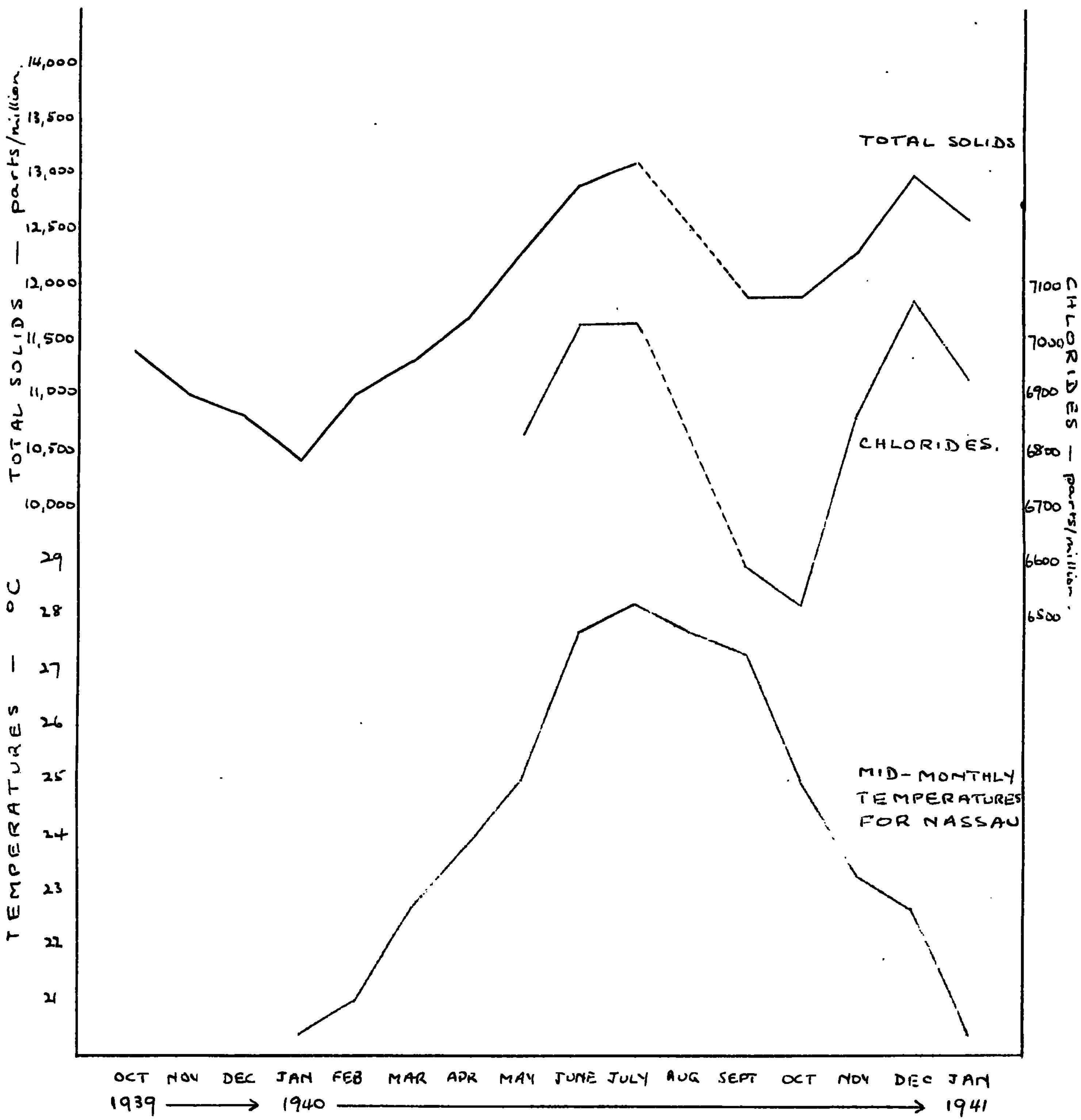


FIGURE 19.

SALINITY.

40 °/oo (see Smith 1940). Expressed in similar terms the salinity of this brackish water varies from 10 °/oo - 13°/oo i.e. approximately less than 1/3rd.

ALKALINITY

Regular observations were made only of total alkalinity or methyl orange alkalinity. These results are set forth in Table 11 and are expressed both as parts CO_3/million and as parts $CaCO_3$/million. They are illustrated graphically in Fig. 20 page69.

Total Alkalinity. TABLE 11.

Date	Total Alkalinity	
1939	parts CO_3/million	parts $CaCo_3$/million
Oct.	80	136
Nov.	82	139
Dec.	78	133
1940 Jan.	77	131
Feb.	88	150
Mar. to Aug.	No analyses	
Sept.	85	145
Oct.	84	143
Nov.	85	145
Dec.	89	151
1941 Jan.	90	153

The total alkalinity is therefore seen to be high varying from 1.3 parts $CaCO_3$/millioh (77 parts CO_3) to 153 parts $CaCO_3$/million (90 parts CO_3). There is not a sufficiency of results to obtain a clear picture of the manner of variation throughout the year but

FIGURE 20

TOTAL ALKALINITY OR CARBONATE

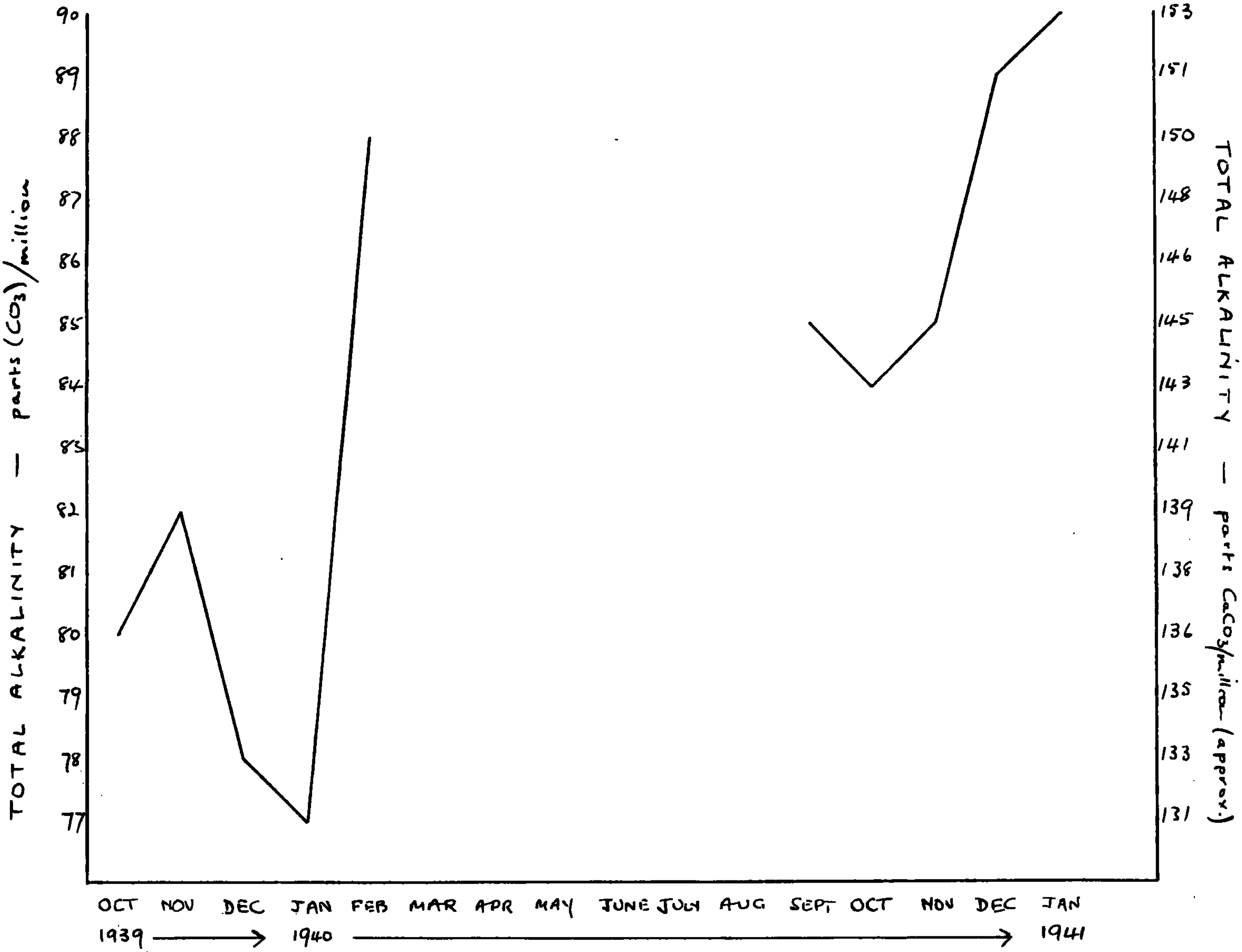


FIGURE 20.

TOTAL ALKALINITY.

there is some suggestion, evident from the graph, of a slight increase in alkalinity through the winter months.

The proportions of bound and half-bound carbon dioxide was computed from an analysis of the November 1940 sample which gave the following results.

TABLE 12.

Alkalinity analysis of November 1940 sample.

Titration total (methyl orange) alkalinity	143.0	p.p.m. $CaCO_3$
Titration caustic (phenolphthalein) alkalinity	11.7	p.p.m. $CaCO_3$
Hydroxide present	0.0	p.p.m.
Carboante present	33.4	p.p.m. $CaCO_3$
Bicarbonate present	109.6	p.p.m. $CaCO_3$
$[CO_3'']$	14.0	p.p.m. CO_2
$[HCO_3']$	145.9	p.p.m. CO_2
CO_2 present as carbonate	14.7	p.p.m. CO_2
CO_2 present as bicarbonate	96.4	p.p.m. CO_2
Bound carbon dioxide	62.9	p.p.m. CO_2
Half-bound carbon dioxide	48.3	p.p.m. CO_2
Free Carbon dioxide (from Table 9)	2.8.	p.p.m. CO_2
Total carbon dioxide present	113.9	p.plm. CO_2
%age bound	55.3%	
%age half-bound	42.3%	
%age free	2.5%	

The final result reveals that an insignificant part of the total carbon dioxide present is completely free. As for the rest the bound carbon dioxide is in excess of the half-bound carbon dioxide.

AMMONIA - FREE AND ALBUMINOID

Table 15 contains the results of ammonia analyses for the whole period. Albuminoid ammonia was estimated for only a part of that period values are expressed in parts NH_3/million.

Free Albuminoid Ammonia. TABLE 15.

Date 1939	Free ammonia mgs/litre	Albuminoid Ammonia mgs/litre
Oct. 28	.07	-
Nov. 14	.11	.59
Dec.8	.27	.61
1940 Jan.9	.32	.73
Feb. 3	.18	.70
Mar.2	.12	.74
Apr. 1	.15	.61
May 4	.10	.68
June 4	.07	
June 29	.08	
Aug.	-	
Sept.14	.05	
Oct. 14	.12	
Nov. 12	.09	
Dec. 13	.15	
1941 Jan. 21		

The amount of free ammonia varies from a minimum of 0.05 parts/million recorded in September 1940 to a maximum of 0.32 parts/million in January 1940. In general there is a decrease of free ammonia through the summer and an increase during the winter. On the whole the free ammonia present is not exceptionally high.

The albuminoid ammonia however is comparatively higher varying within the limits 0.59 - 0.74 parts/million during the few months it was estimated. A comparison of these values with the free ammonia content indicates the presence of organic matter of vegetable

/origin.

origin . The monthly variation of albuminoid ammonia shows similarity with the variation of free ammonia.

SULPHATE AND CHLORIDE.

Table 13 shows the values obtained by analysis for sulphate. These values are found to vary between the limits of 824 - 872 parts/million during the few months that the analyses were made.

Table 13 shows similar values for chloride content. These values are graphed in Fig. 19 page 67 together with total solids.

The chloride content varies between the limits 6520 - 7070 parts/million. Fig. 19 page 67 reveals in a striking manner the close similarity between the variation in total solids and in chloride content.

Sulphates and Chlorides. TABLE 13.

Date	Sulphates	Chlorides
1939.	mgs/litre	mgs/litre
Nov. 18	863	-
Dec. 8	839	-
1940		
Jan 9	872	-
Feb 3	824	-
Mar. 2	-	-
Apr. 1	-	-
May 4	-	6830
June 4	-	7030
June 29	-	7030
Aug.	-	-
Sept. 14	-	6590
Oct. 14	-	6520
Nov.12	825	6870

Dec. 13	-	7070
1941		
Jan. 21	-	6930

NITRATE PHOSPHATE AND SILICATE

Table 14 set forth the results of estimations of nitrate, phosphate and silicate radicles. Fig. 21 page 74 illustrates all these values in graphical form

Nitrates, Phosphates, Silicates. TABLE 14.

Date 1939	Nitrates mgs/litre	Phosphates mgs/litre	Silicates. mgs/litre.
Oct. 28	7.6	.6190	-
Nov. 18	7.5	.0050	2.5
Dec. 8	2.1	.0044	2.5
1940			
Jan. 9	-	.0038	0.5
Feb. 3	2.6	.0040	1.0
Mar. 2	-	.0035	2.0
Apr. 1	1.7	.0030	3.2
May 4	2.5	.0040	2.5
June 4	1.3	.0030	3.0
June 29	2.2	-	3.5
Aug.	-	-	-
Sept. 14	4.0	.0030	8.0
Oct. 18	3.3	.0100	6.0
Nov. 12	6.1	.0000	7.0
Dec. 13	4.4	.0000	6.0
1941			
Jan. 21	2.5	.0000	1.1

The amounts of nitrates present vary from 1.3 to 7.6 parts (NO_3)/million. The graph reveals that the nitrates are low through the

NITRATE (NO_3) : PHOSPHATE (P_2O_5) : SILICATE (SiO_2)

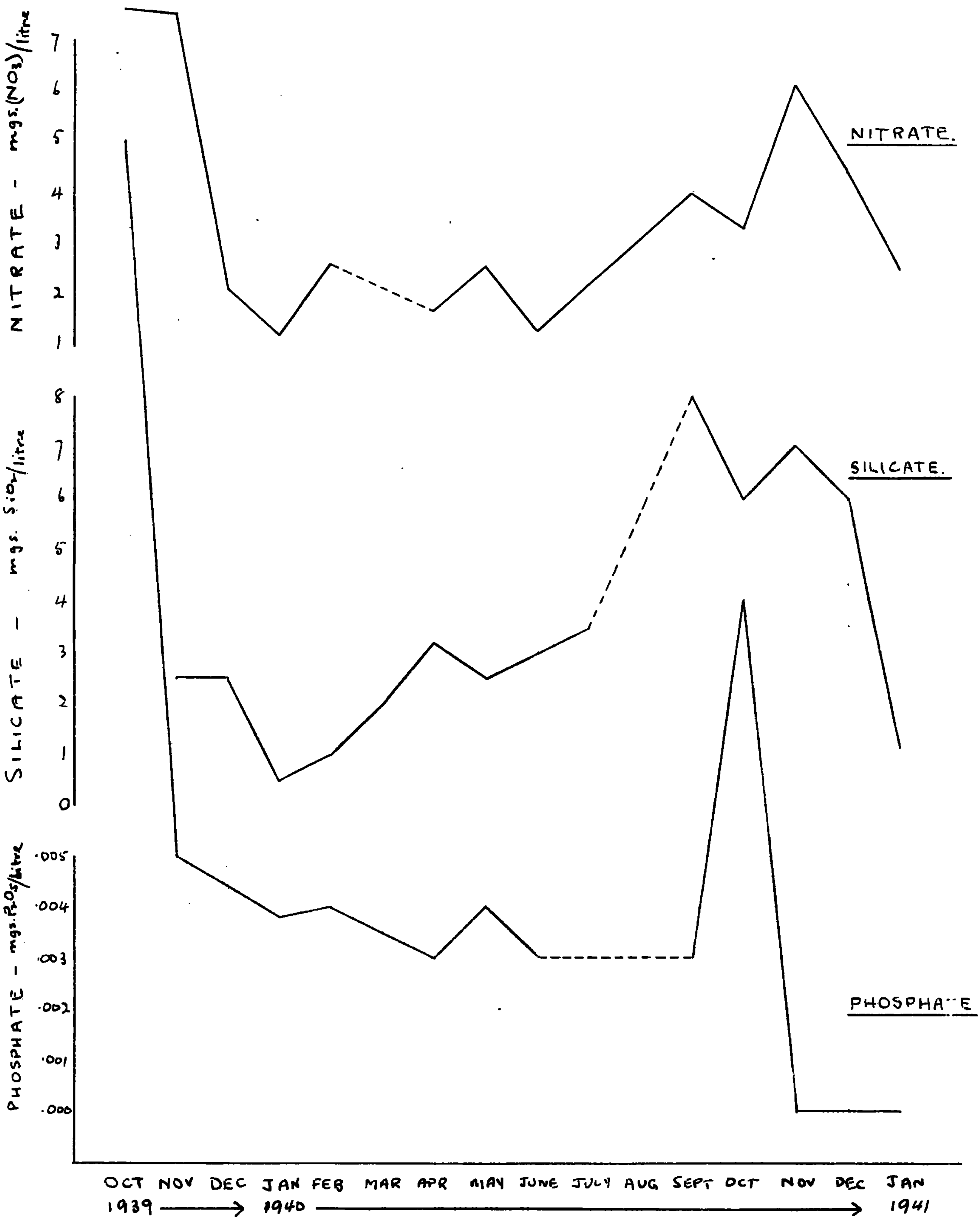


FIGURE 21

NITRATES: PHOSPHATES: SILICATES.

summer months generally and increasing rapidly in the "fall" of the year or at the beginning of the winter.

Phosphates have been present in exceedingly small quantities never being greater than 0.005 parts P_2O_5/million except for two isolated high values of 0.019 and 0.01 in the months of October of 1939 and 1940 respectively. During the winter of 1931 - 40 and throughout the summer of 1940 the phosphate content gradually diminished. The total absence of phosphate in the last three months of this period is surprising and cannot be compared with the gradual decline in the previous year.

Silica has shown a minimum of less than 1 part SiO_2/million in January 1940 and a maximum of 8 parts/million in September 1940. Values were higher in the summer months than in January and February and the peak was reached in the last four months of the year. There is thus not much similarity between the graphs for phosphate and for silicate.

METALLIC IONS.

Table 16 shows the results of analyses for calcium and magnesium.

Calcium and Magnesium — TABLE 16.

Date	Calcium mgs/litre	Magnesium mgs/litre
Nov. 18	168	412
Dec. 8	-	397
Jan.9	174	406
Feb.3	212	379
Mar. 2	174	-
April to Oct. no analyses taken.		
Nov. 12	191	469
Dec. 13	190	463

The calcium content varied between the limits 168 - 212 parts/million showing a minimum value in November 1939 and a maximum in February 1940.

During the same months the magnesium content varied from 379 parts/million to 469 parts/million. Two observations are worthy of mention. The first is the relative abundance of these two ions. By actual weight the magnesium content is approximately twice the calcium content. Expressed as milli-equivalents this ratio is even more pronounced. In November 1940 there were 39.1 and 9.5 milli-equivalents of magnesium and calcium pespectively the magnesium being thus about four times as abundant in solution as the calcium. The second point is that during the four months November 1939 - February 1940 the calcium and magnesium varied inversely with each other.

Only one analysis was made for iron and that is November 1939. The amount present was exceedingly small and can be described only approximately as being much less than 1 part/million.

In November 1940 a complete analysis of all the most important radicles was made and by finding their sum the amount of sodium and potassium present was found by subtraction from the total solids. It was found to be 3785 parts/million. By computation of all the most important ions in terms of milli-equivalents (which will shortly be described) the number of milli-equivalents of Na and K was calculated by equating the number of cations with that of anions. This was found to be 165 m.eqs/litre. By further calculation it was found that the difference of 3785 parts/million reckoned as being the amount of Na and K present corresponded to 164.6 m.egs/litre

/if

if calculated as being Na alone. Therefore allowing for error in analyses it may be concluded that the ion potassium if not entirely absent is present in exceedingly small amounts.

CORRELATION OF RESULTS OF ANALYSES.

In November 1940 a complete analysis was made for all the important ions and, as outlined above the amount of Na/K present was computed by subtraction from total solids. These values were expressed as mgs/litre (parts/million) and then converted to milli-equivalents/litre. From these values the amounts of important ions present were expressed as a %age of the total solids. These results are set down in Table 17 and a graphic representation of the final result is found in Fig. 22 page 79.

Analysis of November 1940 Sample. TABLE 17.

	Ion	mgs/litre	meqs/litre	%age of total ions
	(+ve)			
	Magnesium (Mg'')	469	39.1	9.1
CATIONS.	Calcium (Ca'')	191	9.5	2.2
	Sodium (Na') Potassium (K')	3785	164.6	38.7
	Total cations		213.2	50.0
	(-ve)			
	Sulphate (SO_4'')	825	17.2	4.0
ANIONS.	Carbonate (CO_3'')	14	0.5	0.1
	Bicarbonate (HCO_3')	146	2.4	0.6
	Chloride (Cl')	6870	193.5	45.3
	Total anions		213.6	50.0
	Total solids	12300	426.8	100.0

The most abundant salt is obviously sodium chloride, NaCl. There is also some magnesium chloride present and probably also a lesser amount of calcium chloride. There is a small amount of sodium carbonate or calcium carbenate and larger amounts of calcium and magnesium sulphates. The Ca/mg ratio is high. Another feature of interest is the high sulphate (SO_4'') content.

PROPORTION OF COMMON IONS.

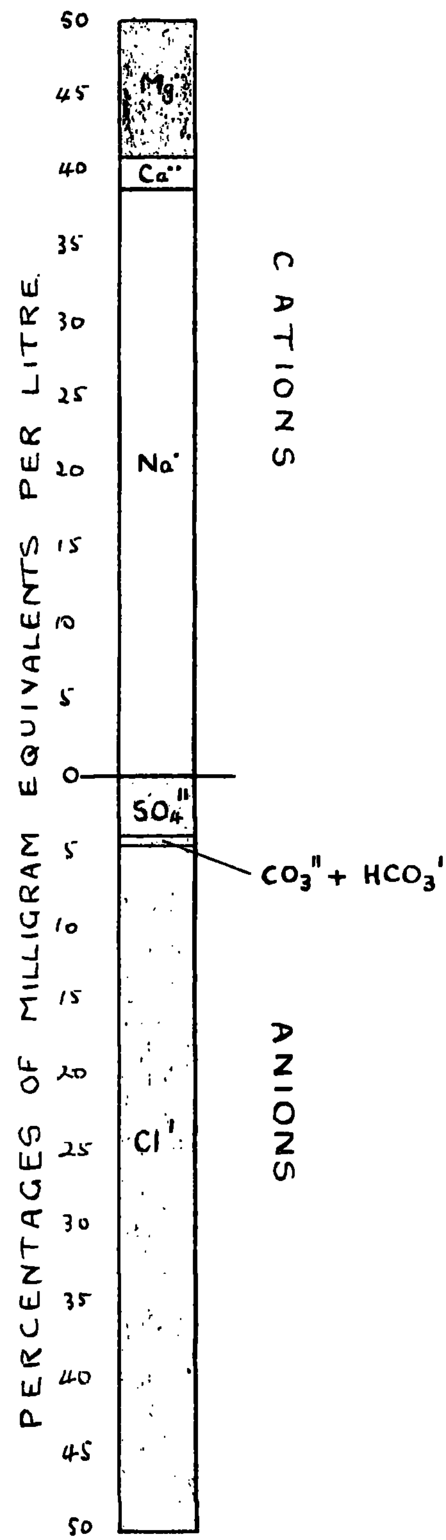


FIGURE 22.

PROPORTION OF COMMON IONS.

BIOLOGICAL EXAMINATION

PLANKTON.

Occurring in the plankton at one or other periods during the year or throughout the year were the following forms as shown in Table 18. The words in column 3 are purely relative to the total amount of plankton.

ZOOPLANKTONTS AND RELATIVE ABUNDANCE — Table 18

Group	Genera and Species	Occurrence	Months
Copepoda	Acartia tonsa	Abundant	All
	Laophonte sp.	Infrequent	All
	Nauplii	Abundant	All
Rotifera		Rare	Oct. - Nov.
Ostracoda		Common	May - Jan.
Hirudinea		Frequent	All
Mollusca Velegers		Common	All
Protozoa Vaginicola sp.		Abundant	Jan. - Aug.

PHYTOPLANKTONTS AND RELATIVE ABUNDANCE — Table 19

Group	Genera and species	Occurrence	Months
Myxophyceae	Aphanothece Castagnei	Very abundant	All
	Chroococcus minutus	Frequent	All
	Lyngbya Lagerheimii	Infrequent	June - March
	Spirulina subsalsa	Rare	Spasmodic
Bacillar-iophyceae	Coscinodiscus concinnus	Abundant	All
	Chaetocerous sp.	Abundant	All
	Cymbella sp.	Infrequent	All
	Navicula sp.	Infrequent	All
Chlorophyceae		Rare	

Similarly, the phytoplanktonts may be analysed as in Table 19.

TOTAL PLANKTON

Table 20 shows the numbers of all planktonts present per litre throughout the whole period and Fig. 23 page 83 shows the variation in total animals, total plants and combined total.

ANALYSIS OF DISTRIBUTION OF PLANKTON — Table 20

Individuals/litre. 1940 → 1941 →

	Genera	Mar.	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.
ZOOPLANKTON	Copepods	90	96	33	24	12	78	7	24	37	28	6	36
	Nauplii	19	10	16	23	11	7	1	5	5	3	3	6
	Velegers	-	-	23	7	4	12	0	6	6	3	1	14
	Ostracods	0	0	61	13	6	5	0	22	24	3	13	0
	Vaginicola	68	57	1239	52	7	25	0	0	0	0	6	22
	Rotifiers	0	0	0	0	0	0	0	21	4	0	0	0
	Total Animals	167	172	1373	122	41	127	8	78	76	37	29	78
PHYTOPLANKTON	Genera												
	Total Colonials	250	270	365	1023	612	5420	20	144	266	183	397	325
	Lyngbya	0	0	0	7	15	26	0	2	4	8	4	11
	Coscinodiscus	112	80	897	290	117	203	50	21	11	8	101	51
	Chaetoceros	0	0	200	805	317	1850	10	60	213	28	0	0
	Other diatoms	9	7	95	101	45	27	0	10	11	8	10	14
	Total Plants	382	328	1557	2104	1065	7415	80	237	505	235	512	401
ALL	Total Plankton	549	500	2930	2226	1106	7542	88	315	581	272	541	479

The plankton of the lake was very poor in all respects; in respect of number of species, in respect of number of genera and in respect of total number of individuals present at any one time. The highest total number of individuals of all species present reached a low maximum of less than 8000 per litre in August. This maximum when compared with the lakes of Michigan and Wisconsin is found to be barely more than the minimum recorded for some of the lakes considered to be poor in plankton. This maximum was followed immediately in September 1940 by the minimum number of planktonts recorded viz. 88 per litre. In eight months out of twelve for which counts were made the number of individuals per litre was about 500 or less. The greatest numbers occurred in the four summer months May - August 1940. In respect of total number of plankton there occurred a secondary maximum in May - June while the largest maximum occurred in August. The former is a combination of the zooplankton maximum and the secondary phytoplankton maximum. In the remaining months the population was fairly uniformly low with a decided minimum in September (immediately after the greatest maximum) and a secondary minimum in December.

When separated into plants and animals it is seen that the plankton is composed for the greater part of phytoplankton (see Fig.23 page 83). On no occasion did the zooplankton exceed or even equal the phytoplankton though in May a large increase in Vaginicola brought the animals total very nearly to that of the plants. Apart from this one occasion when the total animals exceeded 1000/litre the total was never as much as 200/litre and in seven months was less than 100/litre. Zooplankton, therefore showed only one maximum (in May) whereas phytoplankton exhibited two maxima - the main one in August and a subsidiary one in June.

FIGURE 23.

PLANKTON

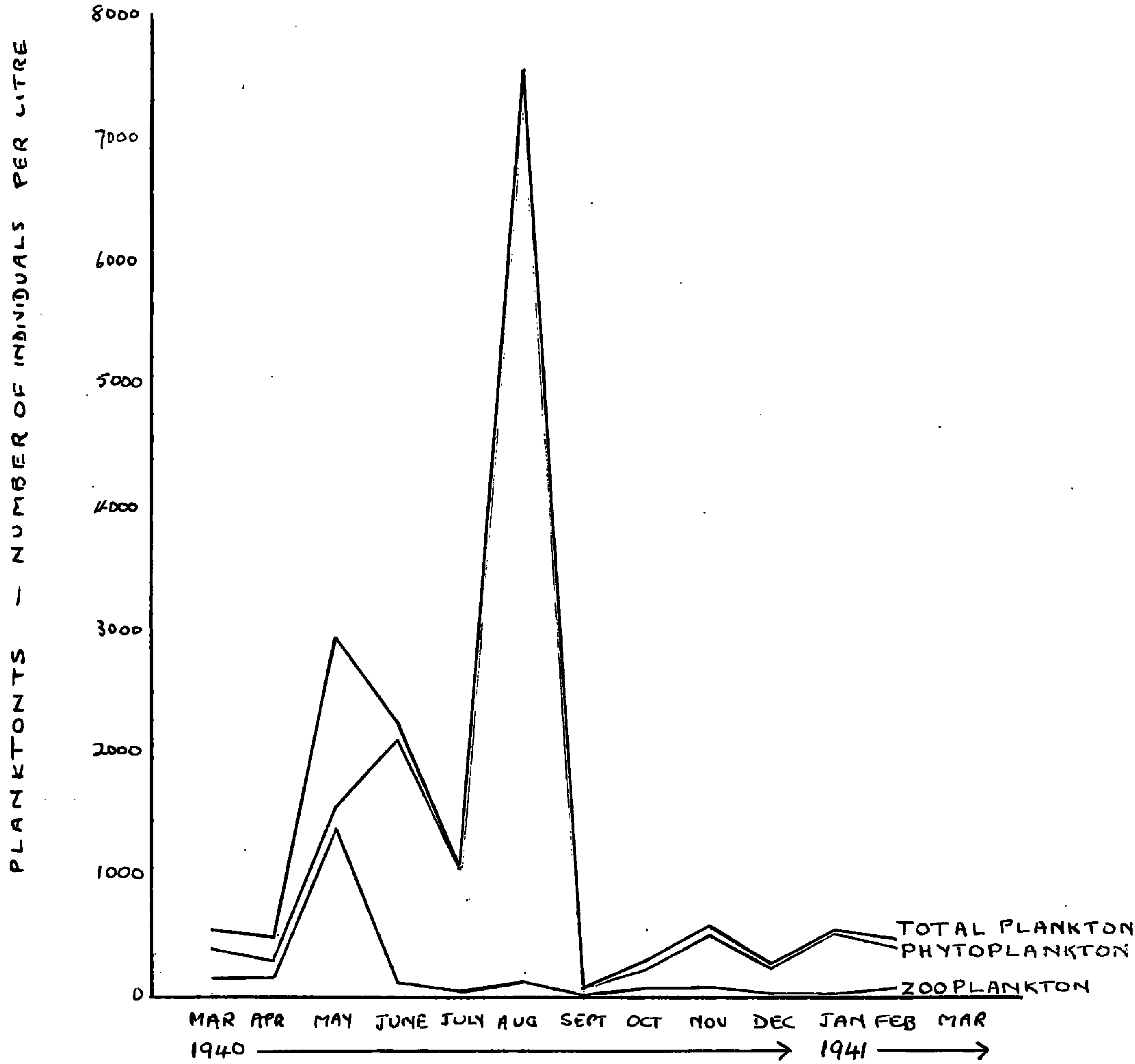


FIGURE 23.

TOTAL PLANKTON.

PHYTOPLANKTON.

The greatest part of the phytoplankton and of the total plankton was made up of Aphanothece Castagnei (Breb) Rabenh. The cells of this Myxophycean here ranged from 4-5 microms broad and up to 10 or more microns long. There were occasional other Myxophyceae which were counted with Anphanothece but formed an insignificant part of the total. This total reached a maximum of 5420/ litre in August and within a month fell to a very low minimum of 20/litre. The main maximum was preceded by a subsidiary maximum in June. Individuals of Aphanothece were commonly coated with a deposit of marl which quickly disappeared when attacked by acid. The action of a strong wind on the lake had the apparent effect of increasing the population of this alga considerably. This was due to the stirring up of marl whose particles, as described previously, all contain a colony. It was necessary, therefore, on occasion to repeat a plankton catch a few days later when the original had been taken after stormy weather. This alga can apparently stand a heavy coating of marl as samples of damp mud, when exposed to light in the laboratory, quickly assumed a distinctly green colour.

A species of the centric diatom, Coscinodiscus concinnus (W.Sm.), was the second most evident planktont due to its large size although in numbers it was less than Chaetoceros when that diatom was to be found in the plankton. Their average diameter was 200 microns. It is typically a marine genus found in northern waters. However, Grunow in his paper on the diatoms of Franz Josefs - Land states that a form which he synonymized with Co. concinnus W. Sm. has been found in Brazil and Hagelstein in his work on diatoms of Porto Rico states he has found the variety arafurensis of this species. There are many species of it in the seas around the Bahamas. Individuals of Coscinodiscus were always to be found in the plankton (See Fig.24 page 85a). There was one maximum in May of 887/litre. It did not fall to a minimum in September in common with all other planktonts but its minimum was delayed until December. This plant, together with Vaginicola was responsible for the subsidiary total plankton maximum in May. That the maxima of these two forms coincided is to be expected since the individuals of Vaginicola were epiphtic on the Coscinodiscus.

Although it was completely absent in the winter months January to April the small chain diatom Chaetoceros was more abundant than Coscinodiscus by virtue of sheer numbers but the individuals are so delicate and small (9 microns wide and up to 54 microns long) that they were not nearly so conspicuous. Furthermore, their long spine-like processes which were swollen at the base were numerous and varied from 102 microns to 143 microns in length. They seemed to spread out on the surface of the water in the counting cell and, by virtue of surface tension, prevented them from sinking. As a result, the process of counting, with these organisms present, had to be done at two different levels, - a most tedious process. Each chain of this diatom was made up of from 3 - 10 cells each about 6 microns in length. The numbers in Table 20, therefore, refer to chains and not single diatoms. These plants showed a unique periodicity having three distinct maxima. In common with Aphanotheca there was a main maximum in August and a subsidiary one in June but it showed yet a third in November after which it quickly disappeared to reappear again in May. As to this diatom, Dr. Ruth Patrick states that she can find no species to which these specimens exactly correspond. It is believed to be nearest to Chaetoceros perpusillus (Cl.) but may be a new species. On this point, however, Dr. Patrick has been unable, up to the present, to give a positive answer.

FIGURE 24.

DISTRIBUTION OF PHYTOPLANKTON. (1)

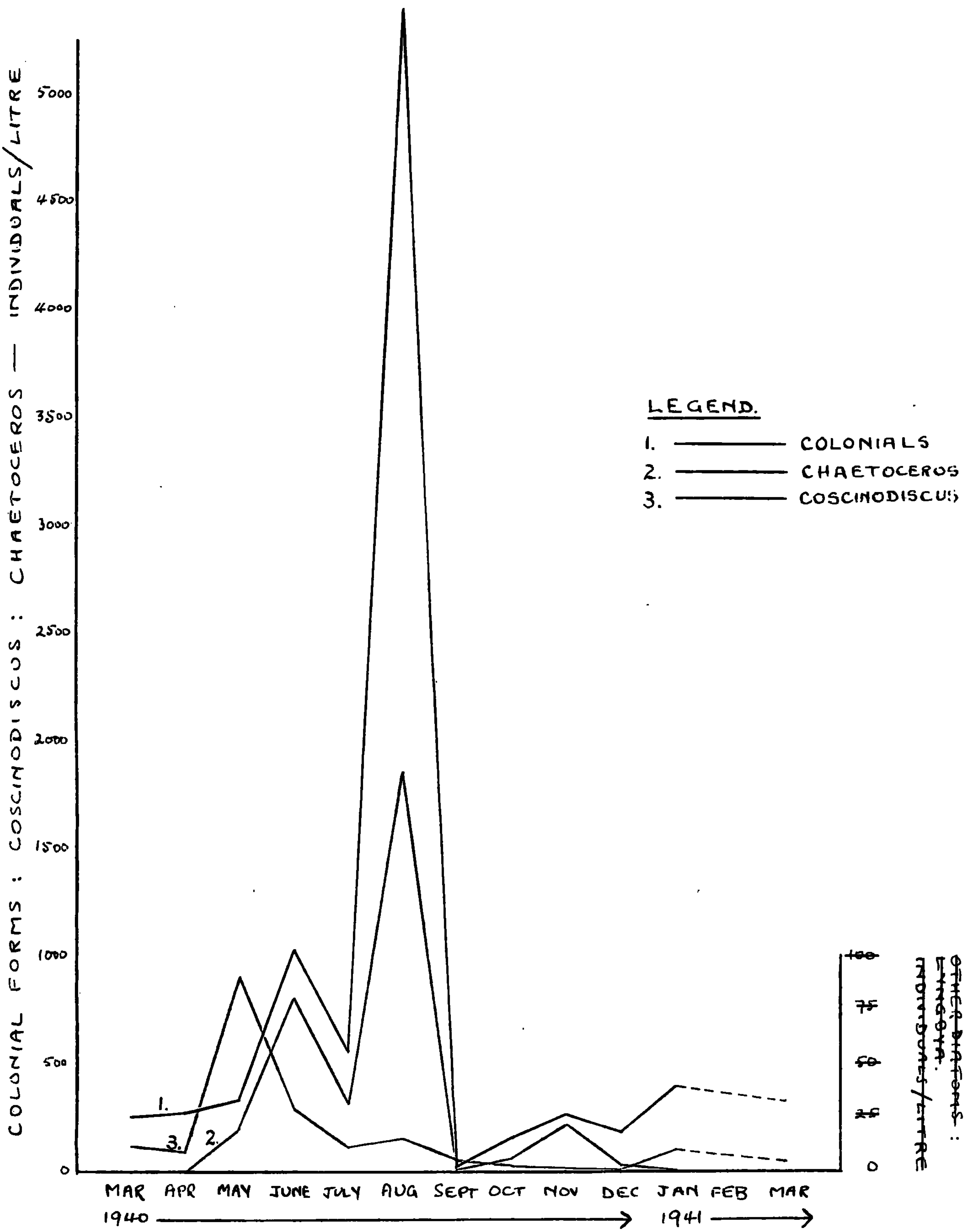


FIGURE 24.

DISTRIBUTION OF PHYTOPLANKTON (1)

The remaining diatom flora included species of Cymbella and Navicula. These were not nearly so abundant (see Fig.24a page 87) as the Coscinodiscus and Chaetoceros. It is most probable that they were not typically planktonic but rather were individuals which had become separated from Batophora where they were more abundant. In periodicity they showed a maximum from May - June but the maximum number present was only 100/litre.

Lyngbya Lagerheimii (Gom.) was the only filamentous planktont and at the best consisted of short fragments of filaments. It was by no means abundant and was completely absent in March and April. It reached the low maximum of 26 filaments/litre in August.

Also present occasionally in small numbers were Chroococcus minutus (Kutz.) Nag. and Spirulina subsalsa (Gom.) the latter less commonly than the former.

FIGURE 24a

DISTRIBUTION OF PHYTOPLANKTON (2)

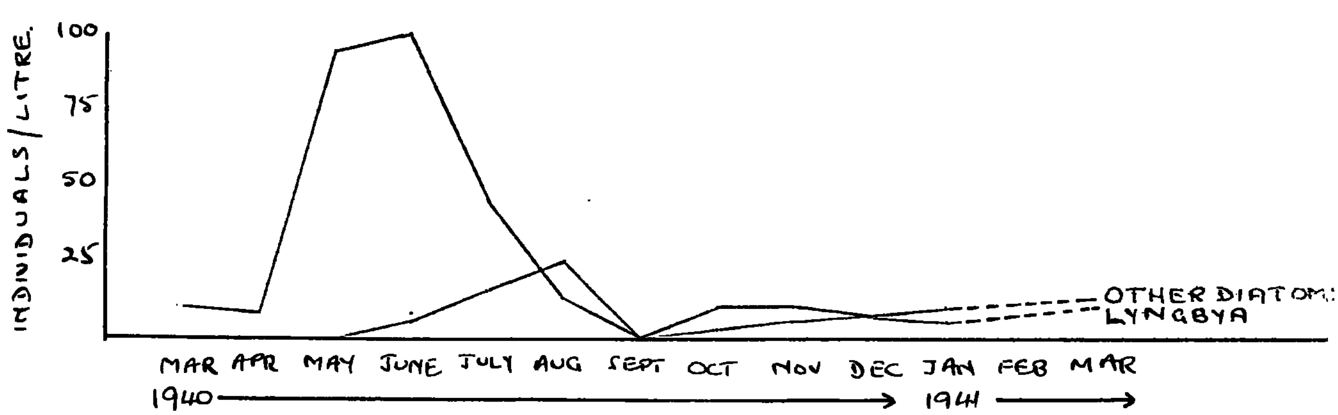


FIGURE 24a.

DISTRIBUTION OF PHYTOPLANKTON (2)

ZOOPLANKTON.

The chief Copepod was Acartia tonsa a form of wide distribution being found in the tropical Pacific, North Atlantic, California, Australia and is one of the commonest Copepods found at Wood's Hole in summer. The body is translucent to transparent with a faint greenish tinge though not very evident here. It can adapt itself to varying degrees of salinity and has even been found in fresh water. The periodicity of this and other animals is illustrated graphically on Fig. 26 page 90. It was never very abundant, ~~was~~ the number of adults never reaching 100/litre (see Table 20 page 81). The graph shows maximum occurrence at three periods the largest being March - April (109/litre). It showed two lesser maxima the one in August and the other in November. Neither adults nor nauplii completely disappeared from the plankton though they showed a low minimum of 8/litre in September and another of 9/litre in January.

Epiphytic on the diatom Coscinodiscus was the Infusorian Vaginicola, a ciliate Protozoan with a vasiform lorica without a valve and occurring in considerably varying numbers. It exhibited a large maximum of 1239/litre in May when the population of Coscinodiscus was also at a maximum. They were found on 262 individuals (less than 1 in 3) in numbers varying from 1 to 21. They disappeared completely from the plankton in September and did not reappear until January. Apart from this one occurrence of over 1000/litre they were not abundant.

A little Ostracod which has not been identified occurred in the months May - January. It reached its maximum abundance of 61/litre in the first month of its appearance. It was absent in September but reappeared in October and was present in small quantities in October - January when it disappeared again.

The only other zooplanktonts that were counted were the velegers or young stages of what were presumed to be the bivalve molluscs that are so abundant in the mud on the lake bottom. They

They exhibited no apparent periodicity their maximum abundance being 23/litre.

In addition there occurred other animals very infrequently. In October there appeared a Rotifer which disappeared equally suddenly before assuming large population and before opportunity was had to make any attempt at identification. There also occurred an occasional leech in the plankton catch.

DISTRIBUTION OF ZOOPLANKTON.

FIGURE 25.

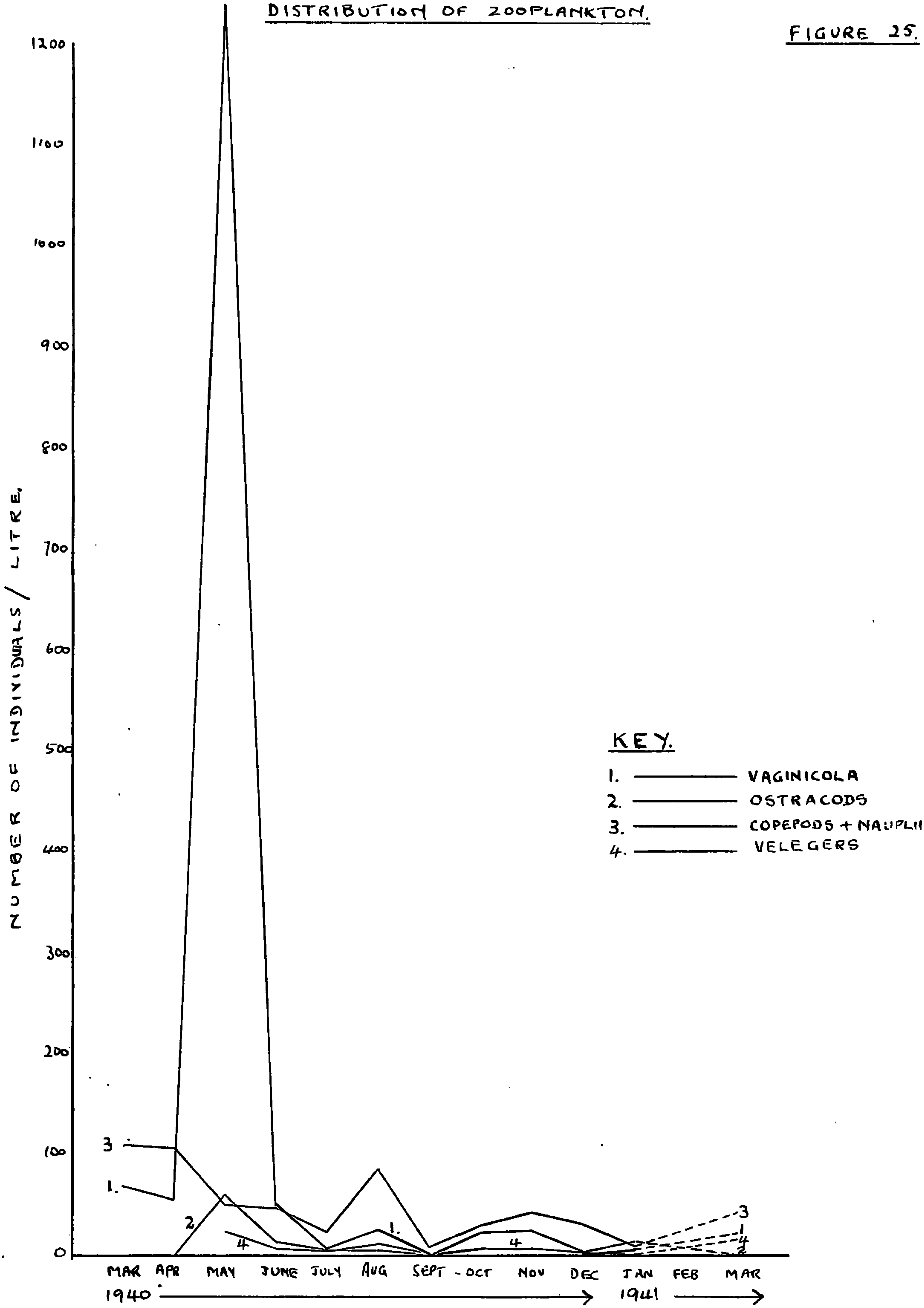


FIGURE 25.

DISTRIBUTION OF ZOOPLANKTON.

HIGHER ANIMALS

INSECTS

The insect fauna was perhaps the most varied fauna of the lake but even so there were few species to be found. Dragonflies were common and showed considerable range of colours. They were not naturally taken in the trap but occasional adults were caught on the wing and a lesser number of larvae were taken from the lake. Examination showed that they were probably species of Aeschna but certainly they belonged to the Aeschnidae. They were not identified. In all probability they fed on the abundant Dasyhelea to be mentioned now.

Table 21 gives an analysis of 18 sample localities in which the insect trap was set and emptied after a period of 24 hours. The depth of the water and the nature of the bottom are also given.

ANALYSIS OF INSECT CATCHES FOR 24-HOUR PERIODS. Table 21

Locality	Depth	Nature of bottom	Insects
1	1½ ft.	Batophora	20
2	1 ft.	Batophora	19
3	3 ft.	Batophora	16
4	2½ ft.	Batophora in shade of Rhizophora	15
5	2½ ft	Batophora in shade of Rhizophora	14
6	2 ft.	Batophora	10
7	1 ft.	Batophora	9
8	2 ft.	Batophora	9
9	1 ft.	Batophora	8
10	1½ ft.	Batophora, Burnside Cay	2
11	2 ft.	Batophora, Burnside Cay	2
12	4 ft.	Batophora and marl	1
13	1½ ft.	Batophora, Burnside Cay	1
14	2 ft.	Batophora, Burnside Cay.	1

ANALYSIS OF INSECT CATCHES FOR 24-HOUR PERIODS (Contd.) Table 21

Locality	Depth	Nature of bottom	Insects
15	4 ft.	Batophora and marl	0
16	4 ft.	Marl	0
17	10 ft.	Marl	0
18	10 ft.	Marl	0

Except for the two insects taken in Localities 13 and 14 the insects referred to belong to the genus Dasyhelea. It was not possible to refer them to a species but they are being sent to the London School of Tropical Medicine. There was a solitary specimen of Spaniotoma which was not referred to a species. In addition there was a solitary specimen of a minute beetle which has not been identified. They never appeared in the trap again.

An examination of Table 21 reveals that most favourable localities are those of shallow water 3 ft. or less in which the bottom is covered with a dense growth of Batophora. They are not found in deeper water nor yet over a pure marl bottom. A third factor may be the relative amount of shade offered by the larger marginal vegetation.

But localities 10, 11, 13 and 14 are located in shallow water off Burnside Cay, had dense growth of Batophora on the bottom and also afforded as much shade (and more in some cases) as the localities 1 - 9. But the insect population was low. The only explanation that can be given is that the Cay is surrounded by more than 200 yards of open water on all sides. Though this does not necessarily act as a barrier to the adult Dasyhelea yet the fact that the insect seems to feed on blood limits its population in this Cay because of the small number of animals on the island. This therefore may be yet a fourth factor in the distribution of this insect.

WATER-MITES

There occurred in the trap on three separate occasions in the same locality oh Burnside Cay in shallow water over a bottom densely covered with Batophora, a small number of water mites (Hydracarina). There were three distinct species but they were found in no other locality in the lake. They are being identified by Prof. J. S. Rogers.

CHAETOPODA.

Worms were represented by a mere half-dozen specimens of the Polychaete type. They appeared only rarely in mud samples that were being sieved for molluscs but they never appeared when the mud was being sieved especially for them. They were exceedingly brittle and up to 2 or 2.5 cms. long. The body was little more than 1 mm. wide at the swollen part at the anterior end. Their colour was blood red. It has been identified as Arenicola cristata (Simp).

MALACOSTRACA.

Higher crustaceans were represented by a few crabs whose habitat was actually in holes on land these being land crabs which occasionally wander into the sea or, alternatively, the lake. The majority of these crabs were small, about 1 inch across the carapace. In addition there was a fewer number of crabs of less size whose habitat was completely aquatic.

Occurring in the dense masses of Batophora were fairly numerous specimens of the Amphipod Hyalella sp. These creatures were very active and consequently difficult to catch. In length they were less than 1 cm.

MOLLUSCA.

A dredge drawn along the surface of the mud always brought up large quantities of delicate empty bivalve shells. Living bivalves were collected with the mud sampling apparatus (see Fig.7 page 30). When the mud was sieved there remained these small white or pinkish whte Lamellibranchs of maximum length 15 mms. and greatest width 10 mms. The shell was very delicate and the living animal was translucent. Large numbers of the shells, however, although tightly closed, were full of finely divided marl and smelled strongly of sulphuretted hydrogen when broken. They were identified as Donax variabilis (Say).

In addition there were found, chiefly on the bare surfaces of rocks or of submerged objects, numbers of the Gastropod Terebra concava vinosa Dall. The average length was 15 mms. but a few exceptionally large specimens were found. Another Gastropod found but rarely was the small exceedingly delicate Retusa perfenuis with a pure white shell.

Broken fragments of separate shells of a much larger Lamellibranch were also found but on no occasion was a living animal, nor yet a complete undamaged shell, found. From the fragments it was estimated that the shell may be as much as 18 cms. long when complete.

FISH.

The fish population of the lake was not abundant. There were no large fish such as might attract the angler. Indeed the largest was no more than 55 mms. long. The distribution of the fish was very limited.

Dr. C. L. Hubbs has identified two out of three species of these fish. Unfortunately the jar containing the most abundant of these species was broken and identification of it has not yet been received. Of the others one is Gambusia hubbsi, a new species found but once previously by Breder in Lake Forsythe in Andros. This fish has a characteristic spine on the anterior border of the ventral fin.

Its colour is shaded from steel-blue on the back to blue-grey laterally. Its average length is 30 mms. or slightly more. The other, according to Hubbs, is a new species of Cyprinodon. He describes it as being remarkably unlike the one species of the genus, C. baconi Breder, which has been named from the Bahamas. This species is 65 mms. in length.

Table 22 shows a record of a sample number of catches over 24-hour periods.

RECORD OF FISH CATCHES FOR 24-HOUR PERIODS — Table 22

Locality No.	Depth ft.	Locality	Gambusia	Unidentified Species.	Cyprinodon
1	3	East side of wharf. Rock, marl and Batophora	37	6179	0
2	10	Marl - in middle of lake.	0	3	1
3	2	Rock and Batophora	10	69	0
4	7	Marl	0	6 ‡	0
5	2	Sheltered side of promontory. Marl.	8	41	2
6	1	Dense Batophora. Sheltered bay.	41	81	28
7	2	Under old wharf. Rocks. Batophora in vicinity.	26	230	4
8	5	Over marl.	0	0	33
9	3	Near last locality. Over marl.	2	1	0
10	7½	Marl	1	1	5
11	4½	Marl	1	1	5
12	4½	Marl	16	14	2
13	5	Mangrove roots.	1	2	0
14	3	Very soft mud.	3	2	0
15	3	Marl. Considerable wave action.	0	1	0

‡ All very small - less than 15 mms.

The following observations may be made:

Fully-grown specimens of Cyprinodon were taken on only one occasion in 5 ft. of water - Locality 8. However, younger and smaller individuals were commoner in shallower water.

All the fish, therefore, excluding the adult forms of Cyprinodon were most abundant in shallow water (3 feet or less). This is significant in that it is the depth in which the most luxurious growths of Batophora are found and, as mentioned above, is also the depth in which the Dasyhelea larvae are most abundant.

Systematic examination of stomach contents was not made but the stomachs of the unidentified species were always crammed with Batophora. From this fact, and also from the data in Table 22 it would appear that the distribution of this alga plays an important part in the food chain of these fish either directly or indirectly. ON one occasion specimens of Gambusia were put into a tank with some small (10 mms. long) fish. Within three days at the most, the Gambusia were the only fish left. This species is apparently predacious.

Another factor influencing the distribution of all these fish is the amount of shelter afforded. The three most abundant catches were made in localities affording considerable shelter e.g. on the lee side of a wharf or promontory.

REPTILES.

Although no attempt was made to study them or identify them, mention should be made of the very abundant number of lizards running around the rocks and in the trees around the margins of the lake. Most of these are small but others have large bodies and are up to 12 ins. in length.

DISCUSSION

EVOLUTION OF THE LAKE.

The fact that the lake water contains such a large amount of total dissolved solids, and especially the high percentage of sodium chloride together with unusually high amounts of sulphate indicate some connection with the sea either at the present time or formerly. That there can be no appreciable influx of salt water from the sea is evidenced by the fact that there is no rise and fall of lake level comparable to tidal influence. What fluctuation in level does exist can be explained quite satisfactorily on the basis of evaporation and precipitation. It is true that there would be some lag in any effect that the tides might have if there was such connection, this being due to the resistance of the rock to the rate of movement of water through it. This lag in tidal ebb and flow might considerably reduce the actual rise and fall observed in the lake. It is even true that this resistance might possibly reduce tidal rise and fall to nil (it is not very appreciable even in the sea in any case). And it is possible that such tidal effect might be reduced to nil without actually preventing some mixing and passage of water. But if this is so, then there remains to be explained the seasonal difference in lake level. Any fall in lake level during the dry season should, if there were any connection with the sea at all, be compensated by an inflowing of sea water. Similarly, seasonal rise should be counteracted by a seepage of water out through the bottom of the lake. Neither of these compensations actually occurs and the results show that throughout the period of recording lake levels there was a total variation of nearly a foot which would not have occurred had there been even a slight connection with the sea. Therefore for these reasons it has been concluded that whatever connections there may have been in time past there is no such connection now and any such connection that may have once existed has been sealed by some means or other.

In this connection there may be mentioned together, popular belief and also the remark "ebbs and flows" that appears on the lake on U. S. Hydrographic Chart No.1377 originally published in 1893. On communicating with the U. S. Hydrographic Office about the authority it was learned that the statement had been taken from British Admiralty Chart No.1489 which was compiled prior to 1881. A letter was despatched to the Admiralty but no reply has been received as yet. It is quite possible that, not being particularly interested in such inland lakes from the point of view of shipping, the compilers of these original surveys simply accepted popular belief as fact. This belief may have been founded on the fact that such ebb and flow does exist in other bodies of water e.g. ocean-holes. But on the other hand it may have been founded on the fact that ebb and flow did actually take place either then, 60 years ago, or within living memory at that time. That this is possible, and that changes may be so comparatively rapid, is witnessed by the fact that a peninsula at the west end of New Providence is known as Lyford Cay (pronounced as "key". Cay is the Lucayan Indian word for island) and it was, as late as 1830, actually an island, boats being able to pass where there is now land 10 feet above sea level. Assuming then that such connection with the sea did exist the presence of salt water in the lake may be satisfactorily explained. But what it does not explain is the manner in which the bed of the lake came to be formed in the first place.

Baillou Hills and Prospect Ridge are both accepted by geologists as being, in effect, fossilized sand dunes. There must have been a time, therefore, when the sea covered all the land up to the north side of Prospect Ridge and this ridge was the coastline.

Similarly, at some time previous what is now Baillou Hills must have been sand dunes on the north coast of the island (this dune formation takes place only on the north of New Providence because of its position relative to the direction of prevailing winds). In the light of what is known about coral activity in the sea at the present time, resulting in the formation of a reef parallel with the sea coast and about a quarter to one mile from it, it seems logical to suppose that such a reef then existed about half a mile from the coast in the line now occupied by Prospect Ridge. At that time therefore, what is now the bed of Lake Cunningham, was then the bed of the sea within the reef. This theory is further supported by the existance of a line of swamps occupying the valley between Baillou Hills and Prospect Ridge and extending for some miles east from Lake Cunningham which is the westernmost and the largest of these bodies of water. The next biggest is a fairly extensive but shallower pond less than two miles south of Nassau (Fig.1 page 13). This state of affairs was followed by uplift, evidences of which have already been discussed, thus lifting the reef out of the water. The reef was probably above water already - witness, the present reef. At the same time the area of sea between the coast and the reef (now Prospect Ridge) was drained to a certain extent but perhaps not completely. It now formed an arm of the sea almost cut off by the elevated reef. This arm was drained to the sea through a gap in this elevated ridge in the region of what is now Chippingham (Fig.1 page 13). The process of dune-formation was then recommenced on the new coastline. This dune is now fossilized and is now Prospect Ridge. At the same time another process was being repeated i.e. that of reef-building still further to the north. Subsequent further uplift partially drained the sea between this new reef and the new coast, lifted the new reef out of water, established yet another new coastline still further to the north and also further emptied the

the valley between Baillou Hills and Prospect Ridge reducing it to a string of lakes and swamps. Finally a new reef was formed. This is ~~xx~~ roughly the condition at the present day. Going north from Baillou Hills, which are postulated as being the original coastline, one finds the following alternation of dune and valley:

1. The valley occupied by Lake Cunningham and other bodies of water and swamps, this being originally that part of the sea lying between the coast and the reef,

2. Prospect Ridge, originally the reef, and later the sea coast where the penultimate dune-formation occurred,

3. Low-lying land occupied by swamps and areas of standing water, formerly that part of the sea between the coast and the reef prior to the last uplift,

4. The present coast, formerly a reef before the last uplift and now the scene of dune-formation, though these are still very young and low,

5. That part of the sea now between coast and reef and

6. The present reef now above sea level in many places.

Lake Cunningham, therefore, before the last uplift, was more extensive and, depending on the height of that uplift may have been drained through the gap in Prospect Ridge in the region of Chippingham. Subsequent to the last uplift it may for some time, perhaps until quite recently (i.e. early part of last century) have retained communication with the sea by seepage of water through the porous limestone rock. But it is now quite completely sealed off from the sea. In further support of this suggested process of evolution is the fact, to be discussed later, that many animals and plant forms, now in the lake are distinctly marine.

One further change has taken place and that is the filling in, by marl, of the eastern end of the lake to form what is now

East End Marsh. It would appear that this process is destined to play considerable part in the future evolution of the lake and therefore before considering this matter, it would be well to turn to the precipitation of calcium carbonate.

CALCIUM CARBONATE PRECIPITATION.

The problem of the precipitation of calcium carbonate precipitation has received considerable attention. Murray (1895), Tilden (1897), Wesenburg Lund (1901), Pollock (1919) and Kindle (1927) all made some contribution to the problem and suggested variously the activities of blue-green algae in both the formation of concretions and the formation of finely-divided marl. The Myxophyceae, to which were attributed such a rôle, included various species of Schizothrix, Lyngbya, Dicothrix, Rivularia, Gleocapsa, Tolypothrix, Phormidium and Centrosphaeria. Drew (1914), Kellerman and Smith (1914) and Bavendamm (1932) when investigating such precipitation in the sea on the west coast of Andros attributed a considerable rôle to bacteria and ammonifying bacteria. Smith (1940) on the other hand, regards the bacterial hypothesis as unnecessary and suggests that purely physico-chemical conditions are the cause.

In this particular lake there is considerable precipitation of calcium carbonate. It has been found distinctly surrounding colonies of the blue-green alga, Aphanothece Castagnei. Furthermore, the precipitated marl, when examined, is found to contain this alga in its particles and, when exposed to light, will develop a green colour due to the growth of this alga.

On the basis of these observations it seems logical to deduce that this alga is responsible for the precipitation. This is believed to be true. But at the same time it does not seem logical to argue that this alga is the only contributory cause. This is to carry an otherwise logical deduction beyond the point where it ceases to be logical. Nor is it believed to be necessary to adopt an extreme point of view and deny any such rôle to living organisms altogether. It is always possible, and indeed in the majority of cases is so, that there is more than any one single cause of any one observed phenomenon such as this.

The problem revolves around the existence, in solutions containing calcium and/pr magnesium which are in contact with air, of the following equilibria:-

$$H_2O + CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons H^{\cdot} + HCO_3{}' \rightleftharpoons H^{\cdot} + H^{\cdot} + CO_3{}'' \quad \ldots\ldots\ldots\ldots \quad 1$$

$$CO_3{}'' + CO_2 + H_2O \rightleftharpoons 2HCO_3{}' \quad \ldots\ldots\ldots\ldots \quad 2$$

In (2) the Ca and/or Mg ions have been omitted to avoid cumbersome equations. In any case they are not necessary to explain the changes.

In this water the pH is high, the bound $CO_2$is high and the free CO2 is low. In addition there is ample opportunity for the water to dissolve salts of calcium and magnesium from the rocks of the lake shore where wave action is considerable.

Although the amount of plankton is not great yet the population, expecially that of Aphanothece, increases considerably in the summer months particularly August. The demands of these algae for carbon dioxide for photosynthesis is considerable and the amount of isolation increases this process. As a result the equilibrium of both these equations is displaced to the left with an increase in $[CO_3{}'']$and, theoretically, an increase in pH. (Although the observations of pH taken in three summer months of 1940 show this theoretical increase they cannot be relied upon for reasons discussed previously). As a result of this increase in the concentration of $(CO_3)''$ ions the ionic products $[Ca^{\cdot\cdot}] \times [CO_3{}'']$ and $[Mg^{\cdot\cdot}] \times [CO_3{}'']$ are increased. But the solubility product of $MgCO_3$, though not exceptionally high, is greater than that of $CaCO_3$ and as a result, the solubility product of $CaCO_3$

though not exceptionally high, is greater than that of $CaCO_3$ and as a result, the solubility product of $CaCO_3$ is exceeded and this compound is precipitated. It is natural to suppose that this precipitation will take place in the immediate vicinity of the removal of this CO_2 i.e. near and around the algal colonies. As a result they become coated with finely divided calcium carbonate. With the advance of this process due to the continued removal of CO_2 this deposit becomes thicker and eventually so heavy as to cause the whole particle viz. algal colony + precipitated $CaCO_3$, to sink to the bottom of the lake where, as has been proved earlier in this paper, the alga does not necessarily cease active photosynthesis and so the process is continued, at any rate by the surface layers, in the marl.

With the death and decay of the algae, free CO_2 is once again liberated in the water (see Fig.18 page 64) and the equilibria are displaced to the right thus decreasing the ionic products $[Ca^{\cdot\cdot}] \times [CO_3'']$ and $[Mg^{\cdot\cdot}] \times [CO_3'']$ and so permitting further solution of these salts. This may take place from the precipitated marl on the bottom but the majority is most likely to occur from the rocks on the shore where wave action increases solution. According to this, perhaps the greater part, but at any rate some part, of the marl already precipitated is not brought back into solution and so there is a progressive accumulation of this deposit on the bottom of the lake.

As stated, $CaCO_3$ is the first to be precipitated, its solubility product being lower than that of $MgCO_3$. This removes many of the $(CO_3)''$ ions and so prevents the solubility product of $MgCO_3$ from being exceeded and this compound remains in solution. But if there is unusual photosynthetic activity then $[CO_3'']$ is so far increased as to cause the ionic product of the magnesium and carbonate ions to exceed the solubility of this compound and this salt is also precipitated. But this happens but rarely and is believed to explain the small amount of magnesium in the marl (see Table 23) and also the high Mg/Ca ratio in the lake water (see Table 16 page 75).

CHEMICAL ANALYSIS OF SWAMP MARL. (from Shattuck 1905) Table 23

By acid digestion (HCl S.G. 1.115)

Constituent		Percentage
Potash	(K_2O)	0.306
Soda	(Na_2O)	2.120
Lime	(CaO)	47.500
Magnesia	(MgO)	2.850
Iron and Aluminium	(Fe,Al)	Trace
Nitrogen	(N)	0.054
Phosphorus pentoxide	(P_2O_5)	0.123
Sulphur trioxide	(SO_3)	0.370
Chlorine	(Cl)	2.970
Silica	(SiO_2)	3.220
Carbon dioxide	(CO_2)	40.480
Total		99.993

But, in addition to all this, it must also be realized that the high insolation at this time of the year increases, not only photosynthesis, but also evaporation. This evaporation causes a direct increase in $[CO_3'']$ and at the same time causes the evasion of a considerable amount of free carbon dioxide to the air due to a lowering of its solubility with increase in temperature. This adds to the decrease in CO_2 caused by photosynthesis and produces the same shift of equilibria and the same chain of events. In late summer temperatures fall and the amount of CO_2 in the water is less than its solubility at this lower temperature and it is once more taken into solution at the surface. There is also a production of CO_2 in decay. This causes a displacement to the right and the water is free to dissolve more $CaCO_3$.

The writer therefore adopts an attitude between the two extremes mentioned before, not for the sake of agreeing with both sides, but because it seems most logical to attribute a share in this process to both causes and scientifically illogical for either extreme to deny a share in the process to the other cause.

One question remains to be explained. Why is this calcium carbonate found precipitated on the Aphanothece and not on the other phytoplanktonts? The most satisfactory explanation of this seems to be that since each colony is an aggregate of individual cells in a small space the demand for, and absorption of, CO_2 in the immediate vicinity of the colony is much greater than in the vicinity of any other of the algal planktonts. As a result, the amount of CO_2 absorbed by the other plants is not sufficient to set the chain of events in motion through to the ultimate conclusion. It is admitted, however, that this explanation denies the existence of such a thing as circulation of the water which would cause an even distribution of the concentration of all ions.

FUTURE DEVELOPMENT OF THE LAKE.

As to the future of the lake, one thing is obvious above all others, and that is the progressive deposition of marl and the consequent filling in of the lake leading to its ultimate annihilation. This is evidenced by filling in of the lake already at the east end for almost a quarter of a mile i.e. about 1/12th. of its original length.

The following explanation is given to account for the fact that this filling in has taken place from the east end and the northeast corner. Prevalent winds are Trade Winds and their commonest direction is due east. The east end of the lake is therefore sheltered by the marginal belt of mangrove etc. and the water is always still at the extreme east end. Consequently, the $CaCO_3$ settles whereas in the rest of the lake circulation of water always keeps a large amount of the marl in suspension. But this does not explain why there should be a greater amount of marl at the east end. It is thought that the prevalent east winds blow straight down the lake from west to east and so cause a drift of surface water in a westerly direction. This carries with it suspended marl which is not deposited due to continual movement of water. A compensatory bottom current of water, also carrying suspended marl with it, occurs from west to east. On reaching the extreme east end the movement of water ceases due to the shelter afforded by the vegetation and the marl is deposited and accumulates.

Furthermore, as the amount of marl at the east end increases there will be a gradual movement westward of the mangrove zone (Fig.8 page 39) and this will be accompanied by an increase in the amount of humus. Consequently, the other zones of vegetation will join in the general encroachment on the lake. The lake will therefore diminish gradually being filled in from the east end where it will be replaced by marsh.

About 12 months ago, with the intention of establishing an aquatic club, the vegetation was cleared (burned and cut) off the greater part of the marsh thereby making its zonation rather indistinct. As a result, the east end is a little more exposed than usual but at the same time the Aquatic Club developed too much water in the wrong place and the marsh is much wetter than formerly. What effect this may have on the vegetation remains to be seen though it appears for the most part that the zones are beginning to reappear in their former state.

As the lake bottom is sealed and as there is no outflow there seems no reason to suppose that the lake will become any less brackish than it is now.

COMPARISON WITH OTHER LAKES.

General observations were made on other lakes in the Colony during visits to them but in addition samples of water were taken from a lake 7 miles into the interior of Andros Island. Analysis showed it to contain only 356 parts/million total solids i.e. about 0.03 of the salinity of Cunningham. It falls therefore into the group of Bahamian Freshwater Lakes. Its S.G. was 1.005 at 21.7°C or 1.0027 corrected to 0°C. The (Cl)' content (83p.p.m) was comparatively high for freshwater lakes but only about 1/9th of that in Cunningham. Silicate (7 p.p.m.) was present in the same amount and total alkalinity (34.7mgs.CO_3/litre) was also comparatively high but less than ½ that of Cunningham. No extensive biological examination was made. The marginal flora included Avicennia nitida as well as the Common Mangrove and at the east margin there was a deposit of marl. The native guide described the presence of distinctly common types of usual size but no examination could be made in the absence of a boat.

Breder gives an analysis of water from Lake Killarney on New Providence which agrees very closely with similar date for Cunningham except that the total solids were only 7551 p.p.m. as compared with 10,000 to 13,000 p.p.m. The proportion of ions was approximately the same with the exception that the Ca/Mg ratio was nearly equal to unity. The precentage of Cl as chlorides was higher, being 58.08%. (It is not quite clear how all this amount could be in combination with cations since its %age exceeds 50%).

Cunningham then seems to be a half-way stage between the freshwater types and the salt-pans since these are said (Shattuck 1905) to be, in salinity, equal to or greater than the sea.

Explanation of these extremes may be simply that, in lakes at altitudes higher than sea level and which are not sealed rain falls and tends to lie, as an upper stratum, on top of salt water. It is a known fact (authority - Public Water Works Department) that, underlying the main rock formations in New Providence is salt water. As rain seeps through it does not mix with the saline water but rests on top and can therefore be pumped for city purposes. Most of these freshwater lakes are at considerable distances from the sea.

The possible explanation of the "Salt-pan" type is that these are on low lying land near the sea and likely to be inundated by such features as tidal waves accompanying hurricanes. After the sea has receded evaporation concentrates this water and may even lead to the precipitation of salt. Repetition of these processes (flooding and subsequent evaporation) causes a further increase in the salinity.

The lakes of the Bahamas, then, show a fairly extensive range in salinity from fairly fresh through brackish to very salt.

But in one respect all the lakes that have been seen have agreed in one respect, namely, there is evidence of $CaCO_3$ deposition in all. This is not surprising in view of the fact that the rocks are wholly limestone and remarks made about $CaCO_3$ precipitation in Cunningham may be applied to all lakes in general. The amount of this precipitation varies and is taken to be an in--dication of the age of the lake. It cannot be a precise in-dication as the relative proportions and absolute amounts of other dissolved salts must inevitably have some effect on the solubility product of $CaCO_3$ in these different waters. But it seems evident that, unless there is further uplift or subsidence of the land, the precipitation will convert all the lakes into marl swamps. In only one type of body of water (the ocean-hole) may this process never take place, depending on the size of the connection with the sea. In these cases $CaCO_3$ precipitation may take place but the ebb and flow of the water may keep the connection with the sea scoured out and so prevent, or at any rate delay for some considerable time, the filling in of these ocean-holes.

GENERAL PRODUCTIVITY.

This is manifestly low. In this respect it compares with all other marl lakes that appear to have been studied. Various possible explanations have been put forward in one place or another the majority attributing the major rôle to calcium. It is certain that the abundance of calcium in the soil of these islands gives rise to serious lack of chlorophyll in many plants the condition being known as "calcium chlorosis". This commonly leads to the death of plants suffering in this manner. As to how far the abundance of Ca is an inhibitory factor in this lake or the exact mechanism of the part it plays, there is not sufficient data to postulate any views on the matter.

A limiting factor in the matter of large aquatic vegetation may be the low concentration of iron which is an important constituent of chlorophyll.

The amounts of the important ions, silicate, phosphate and nitrate may be significant in this respect. The fact that the minimum for silicates (Fig.21 page 74) preceded by some four months the Coscinodiscus maximum (Fig.24 page 85a) and by some seven months the Chaetoceros maximum (Fig.24 page 85a) would indicate that the concentration of silicates does not act as a limiting factor in the productivity with respect to diatoms. It was unfortunate that because of absence from the Colony no analysis for silicate was possible during August but there was the anticipated maximum in

September after the disappearance of the Chaetoceros.

Similarly, the fact that although the $[NO_3]$ (Fig.21 page 74) decreases in summer and shows increase in winter beginning in September after the death of the plankton, the store of nitrates is never reduced to exceedingly low quantities, would indicate that $[NO_3]$ is not a limiting factor.

The P_2O_5 is very low and may possibly act as a limiting factor. Even after the decay of the plankton in September the amount of phosphate did not assume any appreciable quantity being only 0.019 mgs./litre in October 1939 and 0.010 mgs./litre in October 1940 (Fig.21 page 74). The disappearance of phosphate in November 1940 to January 1941 is anomalous. The paucity of macrophytic and phytoplankton population may be referred to to explain the general poorness of fauna, these plants being the starting point of so many food chains. This explanation does not appear to be sufficient in respect of the fish population. In this connection further reference must be made to the rôle of calcium in the metabolism of the lake.

ROLE OF CALCIUM.

The role of calcium in the process of photosynthesis has already been discussed at some length.

The fact that fish of marine type are said to occur in the freshwater lake examined at Andros together with the established fact that such fish do live in other fresh and brackish lakes on the west of Andros (Breder 1934) would suggest that there is no reason why this particular lake should not support a fauna of the larger marine species of fish. In this connection Breder suggests that the Ca may compensate for the lower concentration of NaCl in such waters. As a result marine species are able to tolerate water of salinity lower than that of sea water provided that the Ca is high. A simple experiment in support of this was performed in the laboratory. Specimens of Gambusia manni were removed from a tank of lake water where they had been for 24 hours after being taken from the lake, and placed in a tank of water from the city supply. They immediately went to the bottom and appeared to be considerably excited. They assumed a position at the bottom at an angle of about 30° with the horizontal and by rapid movement made desperate attempts to rise. These were in vain as their tails remained on the bottom. They were soon tired with this exertion and rested on the bottom. They remained there for about 24 hours and then seemed to become acclimatized and swam about freely in the water. These same specimens are in the same tank still, three months later. The city supply of water is very hard and apparently the Ca was sufficient to compensate for the less concentration of other salts especially NaCl.

In the light of this theory, as propounded by Breder, there seems to be no apparent reason why larger fish should not be able to exist in this lake. Certainly, there is an abundance of small fish for food although admittedly a dearth of plants other than Batophora.

The writer was requested by Sir Harry Oakes and other residents on the lake to investigate the possibility of stocking the lake with game fish. However, this was outside the scope of the present work but such experiments in stocking will shortly be commenced probably under the guidance of Prof. W.J.K.Harkness of Toronto University.

RELATIONSHIPS OF THE LAKE.

The organisms in the lake may be divided into three groups:

1. Those which are typically marine forms,

2. Those which are typically marine but which can stand considerable variation in salinity and

3. Those which are typically brackish water forms.

The presence of the individuals of Groups 1 and 2 may be explained on the hypothesis of the evolution of the lake from the sea by uplift, drainage and dune formation. Where the organisms of Group 3 originated is not known nor is there any evidence as yet to postulate any theories. Some few may be endemic but this subject cannot be discussed fully until such time as identifications are complete and can be examined and compared.

SUMMARY.

1. The macrophytic vegetation consists of a narrow marginal belt in which Rhizophora Mangle is predominant. Vegetation is markedly zoned at East End Marsh. Submerged flora is poor and consists almost entirely of the alga Batophora.

2. There is active deposition of marl associated with the Myxophycean Aphanothece Castagnei. This process has filled in the bed of the lake at the east end to form East End Marsh.

3. A bathymetric chart has been compiled showing the lake to have a maximum depth of $13\frac{1}{2}$ ft. above the false bottom of marl.

4. Temperature records reveal that the lake is a Tropical 3rd Order Lake according to Welch's classification.

5. The oxygen content of the water is fairly high due to ease of solution from the atmosphere. It is never a limiting factor.

6. The hydrogen ion concentration of the lake is low, the free carbon dioxide concentration is low and the percentage of bound carbon dioxide is slightly in excess of the half-bound.

7. The salinity is high (over 10,000 p.p.m.) with a large amount of sodium chloride and comparatively large amounts of the sulphate ion.

8. The magnesium concentration is more than three times the concentration of calcium expressed in terms of milligram-equivalents.

9. Albuminoid ammonia is in excess of free ammonia and suggests the presence of organic matter of vegetable origin.

10. Nitrate, phosphate and silicate decrease in summer and increase in winter. Phosphates disappear completely in the winter of 1940/1.

11. A graphical representation is given of the important ions expressed as percentages (of milligram-equivalents) of the total solids.

12. Phytoplankton is poor consisting of diatoms and blue-green algae. One of the diatoms may be a new species.

13. Zooplankton is more varied in species but poorer in actual numbers. Most important are a Copepod and a ciliate Protozoan.

14. Insect fauna was restricted to one species of Dasyhelea and a variety of Dragon-flies.

15. Molluscs were present in comparatively large abundance but there were few species.

16. The fish were restricted to three species of small size inhabiting shallower water. A new species of Cyprinodon was found. Batophora figures largely in the food chain.

17. Other animals included three species of Hydracarina, one species of Polychaetae, one species of Hyalella and a few crabs.

18. A theory of the evolution of the lake from the sea is propounded and evidence ~~ax~~ in favour of it discussed.

19. The phenomenon of calcium carbonate precipitation is discussed and the opinion suggested that it is partly due to photosynthetic activity and partly a result of evaporation.

20. The future history of the lake will end with its extinction by filling in with marl.

21. Lakes of the Bahamas include a wide ragge from very salt to fairly fresh. Calcium carbonate precipitation is a feature of all and the extent to which it has taken place may be an approximate guide as to its age and maturity.

22. The general productivity of the lake is poor in common with other marl lakes though while the high calcium concentration may explain much of this it does not account for the poorness of the fish fauna.

23. In the section dealing with methods an account is given of a new type of plankton trap which can take a representative sample of plankton from all depths of a lake in one haul.

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