B. Berichte und Sammelreferate.

The Biological Work of the Scottish Lake Survey.

By **D. J. Scourfield** (Leytonstone).

By way of an introduction to this short sketch of the biological work accomplished by the Scottish Lake Survey a few words about the Survey itself will probably be useful. It is especially to be noted that the fundamental aim of the Lake Survey was the sounding of the Scottish fresh-water „lochs“ and the preparation of bathymetrical charts of the same, while the physical and biological observations were always considered as subsidiary to this.

The systematic bathymetrical survey of the Scottish lakes was definitely commenced by Sir John Murray and Mr. Fred. P. Pullar in 1897. From 1897 to 1900 a number of important lakes in the Forth and Tay basins were sounded, and the results were published in the *Geographical Journal* for 1900 and 1901 (Vol. XV, pp. 309—352 and Vol. XVII, pp. 273—295). Then the work was interrupted for a year owing to the death of Mr. F. P. Pullar who lost his life while most courageously endeavouring to save others in a lamentable ice-accident on Airthrey Loch in the early part of 1901. Mr. F. P. Pullar's father, Mr. Laurence Pullar, however, conceived the idea of perpetuating his son's memory by placing a fund in the hands of trustees in order that the work which his son had helped to originate might be carried to a conclusion, and thus in 1902 a fresh start was made under the immediate supervision of Sir John Murray and with an increased staff. From that time to the latter part of 1906, when the field-work of the Lake Survey, as regards actual soundings, was brought to an end, considerably more than 500 lakes (562 actually) were surveyed. The reports on these, accompanied by beautiful bathymetrical maps, have been published in a long series of papers under the general title „Bathymetrical Survey of the Fresh-water Lochs of Scotland“ in the *Geographical Journal* from 1903 to the present date and there are still some more to follow.

From the very commencement of the survey some attention was given to the collection of physical and biological data, and records of temperature were made and collections of plankton taken almost without exception from all the lakes visited. In addition to this, during 1903 and 1904 special measures were adopted to obtain continuous physical and biological observations from a single

typical Scottish lake, and for this purpose a portion of the Lake Survey staff was stationed for a time at Fort Augustus on Loch Ness, one of the lakes in the line of the Caledonian Canal.

As already pointed out, however, the primary object of the Lake Survey was not so much to carry out exhaustive researches upon the physical and biological problems presented by lakes as to sound as many lakes as possible with a view to the preparation of bathymetrical maps. Consequently the physical and to a still larger extent the biological results obtained have been of a somewhat disconnected character although taken altogether they form a very solid contribution to the knowledge of inland waters. It is, of course, the object of the present paper to attempt to show that this statement is justified so far as the biology is concerned, but it may be remarked in passing that students of limnology are also greatly indebted to the Scottish Lake Survey for a large amount of additional information concerning those peculiar oscillations of the water of lakes known as „seiches“ and particularly for the discovery of the so-called „internal seiche“ or „temperature seiche“ which may affect the water at some considerable depth below the surface (in the neighbourhood of the „Sprungschicht“ in fact) without being recognisable at the surface.¹⁾

Coming now to the essential subject matter of this paper, namely, the biological work of the Scottish Lake Survey, it will be convenient to consider it under the following heads: (1) Collection and examination of material, (2) Some results arising from the enumeration of the species in the collections, (3) The special investigation of Loch Ness, (4) The comparisons of Scottish with Danish and Swiss lakes, (5) The work on Tardigrada and Bdelloid Rotifera, and (C) Miscellaneous results.

Collection and examination of material.

The great majority of the collections made by the Lake Survey consisted of plankton only and the material preserved from most of the lakes was confined to a single sample taken when the soundings were being made. Much more extensive collections, including collections from the littoral and abyssal regions, were of course made in a number of important lakes, such as Lochs Ness, Morar, Rannoch, Earn, etc., especially in the first named. As a rule the collecting was done by means of ordinary qualitative nets of fine silk gauze, but a few

¹⁾ See the article by Dr. Collet in this „Revue“ (p. 193) and also the following papers: Chrystal, Prof. G., On the Hydrodynamical Theory of Seiches. Trans. Roy. Soc. Edin. Vol. XLI, p. 599, 1905.

Chrystal, Prof. G., and Wedderburn, E. M., Calculation of the Periods and Nodes of Lochs Earn and Treig. Ibidem, p. 823.

Chrystal, Prof. G., and Murray, James, An Investigation of the Seiches of Loch Earn by the Scottish Lake Survey. Ibidem, Vol. XLV, p. 361, 1906.

Watson, E. R., Movements of the Waters of Loch Ness as indicated by Temperature Observations. Geographical Journal, Vol. XXIV, p. 430, 1904.

Wedderburn, E. M., Seiches observed in Loch Ness. Ibidem, p. 441.

Wedderburn, E. M., The Temperature of the Fresh-water Lochs of Scotland. Trans. Roy. Soc. Edin. Vol. XLV, p. 407, 1907.

Wedderburn, E. M., An Experimental Investigation of the Temperature Changes occurring in Fresh-water Lochs. Proc. Roy. Soc. Edin. Vol. XXVII, p. 2, 1907.

Wedderburn, E. M., Notes on the Temperature of the Water in Loch Ness. Geog. Journ. Vol. XXXI, p. 51, 1908.

Wedderburn, E. M., Notes on the Seiches of Loch Ness. Ibidem, p. 56.

quantitative collections were made both with Apstein's net and a pump. A considerable number of special methods of collecting were tried at various times, especially in Loch Ness, without, however, leading to any striking results.

Commonly the collections could not be examined on the spot, at least not in any detail, and it was therefore necessary to look through a large amount of preserved material before any definite results as to the general character of the Scottish plankton and the distribution of particular species could be obtained. This laborious work was carried out almost entirely by Mr. James Murray during the winter months when bathymetrical work was not in progress. For certain groups of organisms in particular localities assistance was given by various specialists such as Dr. E. Penard for the abyssal Rhizopods of Loch Ness, Messrs W. and G. S. West and Dr. H. Bachmann for Phytoplankton, Messrs C. F. Rousselet and D. Bryce for the Rotifera, Mr. C. H. Martin for Oligochaeta and Turbellaria, and the present writer for Entomostraca. It will, however, be readily understood, that the amount of attention given to the different groups was very unequal and that in particular some classes of animals (Infusoria for example) have been very inadequately studied.

Some results arising from the enumeration of the species in the collections.

Altogether rather more than 700 species have been so far enumerated in the collections made by the Lake Survey, including about 450 Invertebrates and nearly 200 Protophytes, the remainder being higher aquatic plants belonging to the Phanerogamia, Characeae, etc. The groups most abundantly represented are the Rotifera (about 180 species), Crustacea (about 80 species), Protozoa (about 90 species), Tardigrada (about 30 species) and among the plants the Chlorophyceae (more than 140 species). Twentynine of these species have been described as new, namely, 13 Tardigrada, 1 Oligochaete, 11 Rotifera, 1 Flagellate, 1 Desmid and two other Algae, and there are still some undetermined species which may prove to be new upon further investigation. Naturally a much larger number, about 50, although not new, were additions to the previously known fauna and flora of the British Isles.

Among the new records are a number which perhaps deserve special notice as they still further strengthen the evidence for a close connection between the fauna and flora of Scotland on the one hand and Scandinavia (and other Arctic and sub-Arctic countries) on the other. The chief of these are the Cladoceran *Ophryoxus gracilis*, the Hydrachnid *Huitfeldtia rectipes* and the Tardigrada *Echiniscus spitsbergensis*, *E. wendti*, *Macrobiotus annulatus*, *Diphyscon spitzbergense* and *D. scoticum*. The distribution, so far as known, of the first-named is Scotland (Lochs Ness and Lochy and the Caledonian Canal), Scandinavia, Finland and North America, of the second Orkney and Norway, and of the Tardigrades Scotland and the Arctic regions only.

The tabulation of the species found in the plankton¹⁾ has brought out several points of considerable interest. In the first place the number of forms that may occur in the plankton, not only in all the lakes taken together, but in many of them individually, is found to be very large. Many of these must no

¹⁾ Owing to the comparatively small number of collections from the littoral and abyssal regions of the lakes, it is impossible to deal with these in a general way.

doubt be considered simply as casuals and it is very probable that their presence in the Scottish plankton is directly connected with the very narrow form of the great majority of the lakes, combined with the heavy rainfall and the tempestuous weather often experienced. But some are very probably to be considered as true plankton species so far as Scotland is concerned although only known elsewhere from the littoral region or from bogs. I am inclined to class a few of the Rhizopods and Heliozoa in this category, more particularly *Clathru-
lina elegans* the pretty perforated capsules of which are quite a feature of the plankton of many Scottish lakes. However this may be, one fact stands out very clearly and that is that, after making all allowances for forms casually introduced, a remarkable number of species of Desmids occur in the plankton of very many of the Scottish lakes, especially those of the north and north-west and of the western Islands (Hebrides). This peculiarity, which is so different to what might have been anticipated from the plankton studies made on the Continent, was first pointed out by Messrs W. and G. S. West (20), but the collections made by the Lake Survey have furnished ample confirmation of the fact. Between 40 and 50 species of Desmids appear to be genuine members of the plankton of Scottish lakes, being either only found in the pelagic region or more abundant there than in any other situation. It is now known, however, from the further researches of Messrs W. and G. S. West, that this peculiarity is shared to a great extent with the lakes of the extreme west of Ireland and North Wales and some of the lakes of the English Lake District. On the Continent the only known plankton approaching the Scottish in the variety of its Desmids is the Scandinavian, notwithstanding the fact that very exceptionally in other countries also a lake may be found to possess a rich Desmid plankton flora, e. g. the Schönenbodensee in Switzerland. A point of great interest in connection with the Scottish plankton Desmids is that many of them are only known in Europe from the north-western coast-districts (west of Scotland, Ireland, Wales and Scandinavia) while they occur again in the eastern parts of the United States and in Nova Scotia. The significance of these facts about the comparative abundance, variety and special character of the plankton Desmids of the Scottish lakes has not yet been finally settled although a number of suggestions have been made such as presence of humic acid, absence of lime, excessive rainfall, and the antiquity of the geological formations in which the lakes occur. Not one of these alone, however, seems to account for all the facts.

Apart from the Desmids the association of true plankton organisms occurring in the Scottish lakes seems not to be markedly different from that commonly found in European lakes. There are, to be sure, many differences in detail more especially in relation to the comparative abundance of particular forms. Thus Bachmann (1) points out that certain Diatoms of the genera *Cyclotella* and *Fragilaria* are quite unimportant in the Scottish lakes although very abundant in Switzerland, while conversely certain species of *Tabellaria* and *Rhizosolenia* have exactly the opposite relative abundance in the two countries. The plankton Crustacea may perhaps be looked upon as forming a somewhat peculiar association owing, on the one hand, to the common occurrence of a number of forms which may be considered as Arctic (or at least as Arctic and alpine) such as *Bosmina obtusirostris*, *Diaptomus laticeps*, *D. wierzejskii*, *D. laciniatus*, *Holopedium gibberum*, and *Bythotrephes longimanus*, and on the other hand to the absence of some common European

species such as *Diaptomus graciloides*, *Cyclops oithonoides*, *C. leuckarti*, *Daphnia cucullata*, *Bosmina longirostris* and *B. coregoni*. The last four it is true occur in Scotland but their absence from the plankton of Scottish lakes in general is well established.

Another result of the tabulation of the species in the collections has been that a very considerable number of facts connected with the distribution of certain species has been obtained. In the main these facts are, at least for the present, only of local interest, but a few may be noted here. For instance, *Bosmina obtusirostris*, although perhaps only quite absent from some small lowland areas, is certainly rarer in the east and „Lowlands“, while *B. longirostris* practically only occurs in the last-named districts. Again, while *Diaptomus gracilis* occurs everywhere except in the Shetland Islands and North Uist, *D. wierzejskii* is confined to the Shetland Islands, the Outer Hebrides and the northernmost counties — Sutherland, Caithness and Ross. The other two plankton species of *Diaptomus*, namely, *D. laticeps* and *D. laciniatus* have a much wider range than *D. wierzejskii* being found almost co-extensive with the „Highland“ and northern regions including the western isles, though curiously enough they scarcely ever occur in the same lake. These results confirm and extend Dr. T. Scott's earlier observations on the Crustacea of the Inland Waters of Scotland. A considerable number of the plankton Desmids also show a limitation to the Highland, northern and western districts and even to small parts of these.

The special investigation of Loch Ness.

As already mentioned an attempt was made to investigate the biology of Loch Ness in a more systematic way than was possible with any of the other lakes visited by the Lake Survey, and a large number of collections were made not only from the open water, but also from the margins and the bottom.

The lake itself is in most respects typical of the larger Scottish lakes, being long, narrow, and deep with precipitous shores. The extreme length is a little over 24 miles with a maximum breadth of less than 2 miles and a mean breadth of less than one mile. The greatest depth is 754 feet, the mean depth 433 feet, and the total volume of water is calculated to exceed 260 000 million cubic feet. The water, although quite clear, appears of a yellowish brown colour when seen in considerable quantities thus betraying the presence of much humic acid derived from the peat-bogs of the surrounding moors. Owing to this the lake never presents the wonderful blue colour so noticeable in the majority of the lakes of Switzerland and Upper Italy for example, but always appears somewhat dark, as indeed do all or nearly all the Scottish lakes.

The plankton was found to be excessively small in quantity and apparently not to vary very much in this respect during the year. A series of vertical hauls with Apstein's small quantitative net were made by the writer on one day in the early part of August 1903, approximately along the middle of the lake, and although no less than five distinct hauls were made at each station from a depth of 150 feet, only the following quantities¹⁾ of plankton were obtained:

¹⁾ Measured after being allowed to settle in a 5 cc. graduated cylinder for 24 hours.

Station I (near Fort Augustus)	0,35 cc.
" II (" Invermoriston, 5 miles beyond St ⁿ I) . . .	0,25 cc.
" III (" Foyers, 5 miles beyond St ⁿ II)	0,30 cc.
" IV (beyond Urquhart Castle, 7 miles beyond St ⁿ III)	0,35 cc.

or on the average about 0,30 cc. for each set of five hauls, i. e. about 0,06 cc. for each haul of 150 feet. Such a figure as this for the middle of summer is, so far as I know, almost without parallel.

Besides being invariably very small in amount the plankton of Loch Ness is not quite so rich in species as that of many other Scottish lakes. This is more particularly the case with the phytoplankton although even here no less than 16 species of Desmids have been recorded. It is impossible in this paper to refer to each of the different groups represented in the plankton but as illustrating a very common association of Scottish plankton organisms the Crustacea may be specially mentioned. In the summer the normal elements of this association are *Daphnia hyalina* (galeata), *Bosmina obtusirostris*, *Bythotrephes longimanus* (s. str.), *Leptodora kindtii*, *Diaptomus gracilis*, *D. laticeps* and *Cyclops strenuus*. With these may be associated at various times and in varying numbers *Polyphemus pediculus*, *Diaphanosoma brachyurum* and even *Sida crystallina* not to speak of quite casual occurrences of more littoral species. Only once has *Holopedium gibberum* been taken in Loch Ness and it cannot therefore be considered as belonging to the fauna of the lake. In the winter the forms present are *D. hyalina*, *B. obtusirostris*, *D. gracilis*, *D. laticeps* and *C. strenuus*. Capsules of *Clathruina elegans* either empty or with encysted animals¹⁾ are practically a constant feature in the plankton of Loch Ness and at certain seasons a considerable number of large red *Chironomus* larvæ occur having apparently risen from the bottom.

The evidence regarding the distribution and movements of the plankton in Loch Ness is not very extensive mainly owing to the difficulty of working with such excessively small quantities of material. From the figures already given, however, it seems evident that the horizontal distribution may be considered as fairly uniform so far as the total is concerned although the numbers of individuals of different species present in widely separated parts of the lake may certainly vary considerably. For example, at Stations III and IV the number of *Daphnias* present in the plankton was several times greater than at Stations I and II. The vertical distribution appears to be very similar to that of the majority of deep lakes, namely, a concentration of the mass of the plankton in a layer which commences, in the day time, a few metres below the surface and extends to a depth of 50 or perhaps even 100 metres, after which, to the bottom, there is very little if any living plankton. At night there is nearly always a marked movement of various elements into the surface layers of the water.

The littoral region of Loch Ness, when it can be said to exist at all, is for the most part very narrow and stony and if it were not for two or three shallow sheltered bays there would not be much to record from this part of the lake. Luckily, however, in the favourable spots alluded to, there has been

¹⁾ Living examples of *C. elegans* in the plankton have hitherto only been seen in Loch Lochy where the majority of the examples had the pseudopodia fully extended.

found a pretty abundant fauna and flora constituting in fact the majority of the species known to be living in the lake. Very few mollusca occur, only five species in all having been noted. But the Crustacea are fairly well represented by some 40 species including the rare *Ilyocryptus agilis* and the characteristically northern form *Ophryoxus gracilis* which was found by the writer in Inchnacardoch Bay in 1903, this being the first time it had been seen in any part of Europe south of Norway, Sweden and Finland. More than 20 species of Tardigrada and nearly 150 species of Rotifera have also been taken, several being new. The evidence of two seasons showed that these littoral Rotifers in Loch Ness had a well-marked maximum development in the winter, culminating in February. Many forms were only present in the winter while others were then much more abundant than during the rest of the year.

Although the actual littoral region in Loch Ness is as a rule very narrow, it was ascertained that quite a number of littoral species could be found down to a depth of several hundred feet. In fact a depth of about 300 feet may perhaps be taken as the boundary between the littoral (using the term in its widest sense) and the abyssal regions in this lake, and curiously enough this depth approximates very closely to the extreme depth at which living plankton occurs in any measurable quantity. Whether this connection is accidental or not is uncertain, but the great depth to which a fairly abundant association of littoral species occurs is no doubt largely dependent upon the very steep slopes of the sides of the lake.

To the abyssal region of Loch Ness (300—754 feet) a large amount of attention was given in the hope that something striking perhaps would be discovered. But the principal fact which emerges is that there appears to be practically nothing peculiar living in the great depths of Loch Ness. All the species found (with the possible exception of a few Rhizopods) have been littoral types without evident signs of modification. Not a single specimen of the so-called „fauna relicta“ (*Mysis relicta* etc.) has been obtained (and this is true of all the Scottish lakes examined) although many workers searched diligently with various appliances and Dr. Wesenberg-Lund used the very same apparatus with which he secured these forms in the Danish lakes. It seems quite certain therefore that these forms at any rate do not exist in Loch Ness and possibly not in Scotland, although *Mysis relicta* has, as is well known, been found in several Irish lakes. The constantly occurring larger species in the abyssal region of Loch Ness are a mollusc (*Pisidium pusillum*) three Entomostraca (*Cyclops viridis*, *Candona candida*, *Cypria ophthalmica*) two Oligochaeta (*Stylodrilus gabreteae*, and an undetermined species which, however, is also found, as well as *Stylodrilus* in the littoral region), a Turbellarian *Automolus (Monotus) morgiensis* and *Chironomus* larvæ. Very rarely, a few other species of Mollusca, Crustacea etc., may be taken at great depths, but they cannot be considered as forming part of the normal abyssal association. Of the smaller forms several ectoparasitic Infusoria are pretty constantly present on one or other of the species already mentioned, but the most numerously represented group is undoubtedly the Rhizopoda. Dr. Penard (14, 15) of Geneva has recorded a large number of species from depths exceeding 300 feet in Loch Ness and a few of these he considers to be peculiar to the abyssal region of great lakes. But the evidence for this is not very strong as has been pointed out by Mr. James Murray (7). There seem to be no abyssal Rotifers in Loch Ness although a fair number of

species have been found at depths from 250 to 300 feet. Only on one occasion was a single species of Rotifer found below this, namely, *Proales daphnicola*, parasitic upon a worm at 500 feet.

It may be interesting to note that a very similar association of animals to that found in Loch Ness at depths exceeding 300 feet was also found in Loch Earn at about 200 feet and in St. Mary's Loch at 100 feet.

Comparisons of Scottish with Danish and Swiss Lakes.

Two extremely interesting pieces of work connected with the Lake Survey were the comparative studies made by Dr. Wesenberg-Lund and Dr. Bachmann upon the Scottish and Danish and Scottish and Swiss lakes respectively.

In the very suggestive paper (17) giving the general results of his impressions upon the Scottish and Danish lakes, Dr. Wesenberg-Lund deals first of all with the great contrast in nearly all particulars in the physical conditions of the lakes of the two countries. In Denmark, owing to the very moderate rainfall, the comparative flatness of the country and the friable nature of the soil, very little water passes through the lakes. The lakes themselves are, for the most part, small, usually rather shallow, roundish in contour and with a broad littoral region. Nearly every winter they are frozen over, while in the summer they often attain a surface temperature of 23° C. The colour of the water in April is usually bright blue, but becomes yellowish green in May and so continues until the ice is formed. In Scotland, at least in the mountainous parts, where the majority of the lakes are situated, the rainfall is many times greater than in Denmark, as much as seven times in the Western Highlands, and the amount of water passing through the lakes is very considerable. In outline nearly all the Scottish lakes are long and narrow and they are usually very deep, one of them, Loch Morar, actually just exceeding 1000 feet. The shores are usually steep and precipitous and there is as a rule but a very narrow littoral region or even none. The larger lakes are never frozen over in winter but on the other hand their summer temperature never exceeds 18° C., being usually much less. The water is nearly always yellowish brown in colour, doubtless due to the fact that it contains much humic acid derived from the extensive bogs through which it drains on its way to the lakes.

Dr. Wesenberg-Lund then considers the organisms in relation to the very different physical conditions prevailing in Denmark and Scotland pointing out the salient differences in the animal and vegetable life of each of the three main regions of the lakes.

In Denmark, and the Danish lakes it may be mentioned in passing are very similar in most respects to those of the great central European plain, the broad littoral region is almost always marked by distinct zones of aquatic vegetation succeeding one another in regular order and corresponding to the gradual deepening of the water. These marginal belts of the higher plants harbour a very rich fauna and micro-flora in the warmer months, but when they die down in the winter the organisms also to a large extent disappear. The narrow littoral region of the typical Scottish lakes on the other hand rarely exhibits distinct zones of vegetation and the animal life of this region is very poor, only approaching the richness of the Danish fauna in small shallow bays. Especially noticeable is the extreme poverty both in species and individuals of

the littoral Mollusca of the Scottish lakes a fact to be attributed perhaps to the absence of lime and the presence of much humic acid in the water. The blue-green algae too which are such an important element in the littoral region of the Danish lakes, often covering the stones and depositing on them a layer of greyish lime, are almost non-existent in the corresponding region in Scotland.

The pelagic regions of the lakes of the two countries are not perhaps in such sharp contrast as the littoral regions, but there are still many points of difference. The quantity of plankton is certainly very much less in Scotland than in Denmark although the total number of different species present is probably quite as large. The colour and transparency of the water in the Danish lakes goes through a regular series of changes during the year owing to alterations in the quantity and nature of the plankton organisms, but this is certainly not the case in Scotland where it very rarely happens that either the colour of the water or its transparency is altered to any appreciable degree by the development of particular organisms. As regards the organisms themselves the Cyanophyceae play a very much less important part in Scotland than in Denmark, while conversely the Desmids, as has already been pointed out, are remarkably well represented in the plankton of the Scottish lakes and but feebly so in the Danish in common with nearly all central European lakes. Again the contrast in the plankton Crustacea is particularly interesting, Scotland showing in this respect a distinctly Arctic and Alpine character, while Denmark once more betrays its close affinity with the central European plain. Other contrasts are to be found in the seasonal variations of form of many plankton organisms which are well-marked in Denmark but practically unknown in Scotland (doubtless correlated with the much more equable temperature of the Scottish lakes) and in the diurnal vertical movements of the plankton which are very small in amount in the former country, but take place on a much more extensive scale in the latter.

The abyssal regions of the Scottish and Danish lakes have not been sufficiently studied to permit of very important generalisations. Dr. Wesenberg-Lund is of opinion that, in spite of their comparative shallowness, some of the Danish lakes do exhibit a region, lying below a depth of 30—35 feet, which possesses a fauna somewhat similar to the abyssal fauna of the Swiss lakes. The abyssal region of the larger Scottish lakes on the other hand, although more truly abyssal in its physical characteristics, being situated at depths from five to ten or more times as great as the corresponding region in the Danish lakes, does not appear to possess a fauna showing any specially modified forms. The „fauna relicta“ also seems to be absent although represented by several species in the Danish lakes.

In the concluding section of his paper, Dr. Wesenberg-Lund deals with the influence of the organic life upon the lakes themselves and their surroundings, showing how in the Danish lakes thick deposits of various kinds are being formed by the rapid growth and decay of plants and animals — the vegetation of the littoral zone being transformed into peat, the blue-green Algae, the Characeae, the Potamogetons and the Molluscs producing layers of lime, and the bottom organisms, by their digestive action upon the rain of plankton falling upon them, producing peculiar deposits known as „gytjes“ differing in character according to the predominating element in the plankton (Diatom-gytje, Cyanophycea-gytje, Chitin-gytje, etc.).

Now in Scotland all these processes are very much reduced in intensity or even stopped altogether, and it seems certain that the deposits of organic origin derived from the littoral and pelagic regions in the Scottish lakes are very small. The organic matter which does occur on the bottom is mostly of a peaty nature washed down from the surrounding bogs.

Dr. Bachmann's comparison of the Scottish and Swiss lakes (1), although confined to the phytoplankton, has nevertheless yielded some very valuable results. He enumerates about 100 species from eight Scottish lakes visited by him and a few additional forms from specimens of plankton which he received from three other lakes. From the Swiss lakes on the other hand he records about 150 species and varieties, but it should be mentioned that these resulted from a much larger number of gatherings than in the case of the Scottish lakes. Dr. Bachmann was struck at once by the number of Desmids regularly present in the Scottish plankton in spite of the fact that the lakes visited by him are by no means so rich in this respect as many others farther to the north and west. In Switzerland it appears to be quite exceptional to find even a single species of Desmid occurring in the plankton, at least in the larger lakes. In one of the smaller lakes however (Rotsee), as many as five species have been recorded and in a still smaller lake (Schönenbodensee) no less than 19 species, a number comparable with all but the richest of the Scottish lakes. In a discussion of the meaning of these facts and of the various views advanced by previous writers, Dr. Bachmann comes to the conclusion that the existence of numerous Desmids in the plankton cannot be connected with the geological age of the rocks in which the lakes occur, nor with the absence of lime, but depends rather upon the presence of certain substances in the water derived from the peat moors which favour the growth of the Desmids and he adds that it is most desirable that exact chemical investigations should be made of lakes exhibiting a rich Desmid flora in widely separated regions.

After the Desmids the most important contrast in the phytoplankton of the Scottish and Swiss lakes is to be found in the Diatoms. The genera *Cymatopleura*, *Cyclotella* and *Fragilaria* are very poorly represented in the Scottish lakes whereas in Switzerland they form most important constituents of the plankton. On the other hand *Tabellaria* and *Rhizosolenia* attain to a much greater development in the former than in the latter country and it is noteworthy that *T. flocculosa*, which is considered by Schröter as a bottom form, is undoubtedly a true plankton organism in the Scottish lakes. But from his observations on the Scottish plankton *Tabellariae*, Dr. Bachmann comes to the conclusion that *T. flocculosa* and *T. fenestrata* are connected by an unbroken series of intermediate forms and that they really only represent extremes of one species. He also considers that the evidence is distinctly in favour of the view held by several previous writers, that *Asterionella formosa* and *A. gracillima* are only varieties of one and the same species.

With regard to the blue-green Algae Dr. Bachmann's comparison of the Scottish and Swiss lakes shows that the two countries are practically similar so far as general abundance goes, but that the characteristic dominant species in the former are *Gomphosphaeria Naegeliana* (*Coelosphaerium Kuetzingianum* of W. and G. S. West's papers) and *Anabaena Lemmermanni*, and in the latter *Clathrocystis aeruginosa* and *Anabaena flos aquae*. The *Peridineeae* and *Flagellatae* appear to exhibit a very close similarity in both countries, but Dr. Bachmann considers that the passive plankton *Flagellates* are much

more often seen in Scotland than in Switzerland. The altogether remarkable range of variation shown by *Ceratium hirundinella* is practically the same in both Scotland and Switzerland and it cannot be correlated either with seasonal changes in the organism or with peculiarities in the different lakes.

In a very interesting section Dr. Bachmann deals with the Epiphytes of the plankton. The colonies of *Gomphosphaeria Naegeliana*, especially those from Loch Earn, were found to harbour quite a number of minute organisms. The gelatinous layer surrounding the colonies can usually be seen to exhibit, even without preparation, numbers of fine radiating lines and by staining with gentian-violet it is found that these lines are formed of innumerable rod-shaped bacteria. In the interior of the colonies also two other kinds of bacteria are found massed together in nests. As these bacteria seem to be constantly present in *G. Naegeliana* and are not found in any of the other phytoplankton, it seems reasonable to suppose that we have here a case of symbiosis and Dr. Bachmann further believes that there is good ground for supposing that these particular bacteria are connected with the assimilation of nitrogen. Besides the three kinds of bacteria no less than six other organisms were found epiphytic upon *G. Naegeliana* from Lochs Earn and Lochy, namely, *Chlamydomonas inhaerens*, *C. stipitata* (a new species), *Hyalobryon lauterborni* var. *mucicola*, *Dinobryon caliciformis* (a new species), *Diplo-sigiopsis elegans* (also a new species) and *Stylochrysalis aurea*. Other points briefly touched upon in this important paper are the character of the plankton in relation to climatic and other conditions and the vertical distribution and periodicity of the phytoplankton.

In looking over these two papers by Dr.'s Wesenberg-Lund and Bachmann, one cannot help feeling that they suggest the exceptional importance to the proper development of limnological knowledge of comparative studies in widely separated countries by one and the same specialist. There seems no doubt that more and more of this kind of work will have to be done in the future and much credit is due to Sir John Murray for having originated and rendered possible such work in connection with the Scottish Lake Survey.

The work on Tardigrada and Bdelloid Rotifera.

The excellent contributions of Mr. James Murray to the systematic knowledge of the Tardigrada (9, 11, 12) and Bdelloid Rotifera (8, 10, 13) together form such an important item in the general results of the Scottish Lake Survey that it is necessary to refer to them in some detail, although the animals themselves are probably of very little importance in connection with the biology of lakes.

The Tardigrada are, as is now recognised, typically inhabitants of mosses, although a few of them occur pretty constantly in the mud of ponds and lakes when no moss is present. Even these forms, however, are also commonly found in mosses. So far as they occur in lakes, they are exclusively littoral forms being most abundant in the strip of shore between the highest and lowest levels of the water. In the Scottish lakes they have also been found at considerable depths (about 300 feet in Loch Ness for example) but as they share this in common with many other littoral forms they cannot for this reason be considered as entering the truly abyssal region. No less than 30 species have

been found by Mr. James Murray in the Scottish lakes, out of a total of 41 recorded from all situations in that country, 13 of them being new. Three of these appear to be characteristic of lake margins having been found nowhere else. The genus *Echiniscus* is represented by nine species, *Macrobiotus* by fourteen, *Diphascon* by six, and *Milnesium* by one.

Many interesting observations in connection with the structure, development, moulting, eggs, habits, etc., of Tardigrades are recorded by Mr. Murray. For instance *Macrobiotus annulatus* was observed to carry about its old skin, containing the eggs, like a sack on its back, sometimes until the latter were hatched. Another species, *M. hastatus*, although laying its eggs free from its moulted skin, nevertheless seems to select empty shells of certain Cladocera (*Alonella nana*) in which to deposit them three at a time. In *M. zetlandicus* living young have been seen within the body, but this was probably an accident as even in this species, in common with all other Tardigrada, it is usual for the eggs to be deposited before hatching.

Particularly interesting are Mr. Murray's remarks on the peculiar „simplex“ forms of many species of *Macrobiotus* and on the „encystment“ of others. The two phenomena may be connected but there are difficulties in harmonising all the facts. In the „simplex“ forms the masticatory apparatus is very much reduced in complexity and may even be absent, notwithstanding the fact that the stomach may be full of food. Probably the reduction is only of a temporary nature and Mr. Murray inclines to the view that in general it is connected with the process of moulting although this cannot be true in the cases observed by Richters of „simplex“ forms in the egg.

In the encystment process, followed very carefully by Mr. Murray in *Macrobiotus dispar*, both an outer (apparently a true skin with stumps of legs) and an inner (ovoid) case are formed and within the latter the limbs, claws, teeth, pharynx, etc., gradually become obliterated so that in about a week little more than a dark amorphous mass is to be seen. The eye-spots however persist and the characteristic fat-cells in the blood are still recognisable. After remaining in this condition for a time, a new growth of the lost parts takes place and the animal emerges from the cyst with all its organs complete. The emergence takes place by the animal crawling out backwards from the cyst, the end of which opens like a lid. This remarkable process of degeneration and renewal of important organs seems to be comparable with what takes place in certain Acarina (Tyroglyphidae) and thus gives additional support to the now commonly accepted idea that a real affinity exists between the Tardigrada and the Acarina.

The distribution of all the known species of Scottish Tardigrada, both within Scotland itself and as regards other countries, is also touched upon by Mr. Murray and although it is premature to draw any very general conclusions the evidence points to a very distinct Arctic element in the Scottish Tardigrade fauna.

The special work on the Bdelloid Rotifera undertaken by Mr. Murray proved equally fertile with that on the Tardigrada. From the collections made during the course of the Lake Survey, including collections from all situations, some sixteen new species have been described belonging to the genera *Philodina* and *Callidina*. This very notable addition to the knowledge of these forms has confirmed and extended the views of Milne, Bryce and other workers as to the modifications necessary in the conception of the two genera and of

the grouping of the species within each genus, and it now seems that we are on the high road to a more natural classification of these, to the systematist, exceedingly troublesome creatures.

But more important than the new species of *Philodina* and *Callidina* has been the discovery of a form differing so much from the previously known Bdelloids that it forms the type of a new family of equal value with the *Philodinadae* and *Adinetadae*. It has been named by Mr. Murray *Microdina paradoxa* and the family, of which it is as yet the only known representative, the *Microdinadae*. It resembles a *Philodina* in general form but it has no corona and the jaws are intermediate between the typical Bdelloid arrangement and that found in *Melicerta*, with, however, some resemblances to certain families of *Ploima*. In feeding, a biting action is continually repeated, the jaws being protruded as in many *Notommatadae*, but they need not be merely snapped and withdrawn for they can seize such an object as a filament of *Spirogyra* and chew it for a long time while still half out of the mouth. *Microdina paradoxa* has been found at the margins of many Scottish lakes, both large and small, and occasionally in running water. It is of „tireless activity“ creeping unceasingly over the stems of algae and mosses, feeding all the time.

Miscellaneous Results.

In addition to the results referred to in the foregoing sections, the work of the Lake Survey necessarily brought to light a very large number of miscellaneous facts of which it is very difficult at present to give a connected account. Many of these are incidentally noticed in Mr. Murray's notes appended to the bathymetrical reports (5), others occur scattered through the various papers mentioned in the Bibliography, and others are still unpublished. It will only be possible here to briefly refer to a few of these results in the hope that although disconnected they may possibly contain some suggestions of value.

In illustration of the rapidity with which certain plankton forms may be transported from one lake to another and then succeed in establishing themselves may be cited the case of an artificial lake or reservoir several miles in length which came under the observation of the Lake Survey staff. The reservoir in question was constructed many miles away from any natural lake but after only a few months it was found to contain many of the commoner plankton species in abundance.

The marked peculiarities of certain lakes is a subject of much interest, as the full investigation of such cases will undoubtedly lead to important generalisations. Several such lakes came under the notice of the Lake Survey but a reference to only one of these, Loch Morar, must suffice. This lake, the deepest in the British Isles, has never yielded a single specimen of *Daphnia* although some form of *D. hyalina* is to be found in the great majority of the other large Scottish lakes. This absence of *Daphnia* in Loch Morar was remarked upon by Dr. T. Scott as long ago as 1892. Loch Morar is further characterised by the presence of the typical *Bosmina longispina* all the year round, most of the other lakes exhibiting some form of *B. obtusirostris*. Still more characteristic perhaps is the occurrence in abundance of a variety of the *Desmid Xanthidium subhastiferum* (var. *Murrayi*) which has never been found anywhere else and there is this further peculiarity about this variety that

it may occur as a semi-cell attached to another semi-cell of the typical form! It appears almost as if we had here a case of direct action of the environment upon the organism, especially when it is remembered that Cushman observed that quite dissimilar semi-cells may be produced by various Desmids under peculiar pathological conditions. (*Rhodora*, Vol VI, p. 234, 1904.)

The phenomenon of „Wasserblüte“, at least in the original significance of the term, is apparently not a very common occurrence in the larger Scottish lakes and in the largest lakes is probably unknown. In lakes of smaller and moderate size, however, *Gomphosphaeria Naegeliana*, *Anabaena Lemmermanni*, etc., and even *Ceratium hirundinella* may produce at times some amount of discoloration of the water by their abundance and accumulation near the surface. The most curious fact noticed in this connection was that a few lakes, including some of considerable size, e. g. Loch Earn and St. Mary's Loch, „flowered“ in mid-winter while remaining clear in the summer.

In a couple of short papers, one on *Oligochaeta* (2) and the other on *Turbellaria* (3) Mr. C. H. Martin has put on record some interesting facts arising from his study of these forms in the Scottish lakes. From Loch Tay he was fortunate enough to obtain sexually mature specimens, and cocoons containing embryos, of *Stylodrilus gabreteae* and he was thus enabled to give a description of the genital organs of this form in their perfect condition. Previous to this there had apparently been no account of the anatomy of the sexual organs in the mature form of any species of the genus. From Loch Lomond he obtained a new species of *Stylaria*, described under the name of *S. Lomondi*, which superficially resembles *S. lacustris* but has a shorter proboscis, possesses eyes, and exhibits a characteristic arrangement of the chaetae.

Mr. Martin's notes on *Turbellaria* (3) deal chiefly with three species — *Polycystis goettei*, *Microstoma lineare* and *Automolus (Monotus) morgiensis*. A pretty full account of the first-named is given, which differs in some important points from the original description of Bresslau, and the systematic position and alleged fertilisation of immature ova in the germarium of the last-named, which is the commonest Turbellarian in the deep waters of the Scottish lakes, are discussed. But the most generally interesting statements are those in connection with *Microstoma lineare*. Mr. Martin has found that the nematocysts occurring in the skin of this species are derived from the *Hydra* upon which it feeds and he believes that all true nematocysts found in *Rhabdocoels* are obtained in a similar way. Conclusive evidence in favour of this view is given in a separate paper (4). This important result may be compared with what has been recorded within the last few years by Grosvenor, Cuénot, etc., concerning the derivation of the nematocysts of *Aeolids* from their coelenterate prey.

In conclusion attention must be called to a very instructive and profusely illustrated paper (18) by Mr. George West on the higher aquatic flora of some Scottish lakes. This, together with the same author's notes on the aquatic flora of the Ness area (19) will give those interested an excellent idea of the characteristics of the littoral vegetation of the Scottish lakes and the important influence of the geological history of the country, the climate, the composition of the water and the character of the bottom upon the plant associations now existing.

Bibliography.

- 1) **Bachmann, H.**, Vergleichende Studien über das Phytoplankton von Seen Schottlands und der Schweiz. Archiv f. Hydrobiologie und Planktonkunde. Bd. III, 1907.
- 2) **Martin, C. H.**, Notes on the some Oligochaets found on the Scottish Loch Survey. Proceedings of the Royal Society of Edinburgh. Vol. XXVIII, pp. 21—27, 1907.
- 3) **Martin, C. H.**, Notes on some Turbellaria from Scottish Lochs. Ibidem, pp. 28—34.
- 4) **Martin, C. H.**, The Nematocysts of Turbellaria. Quarterly Journ. Micro. Science. Vol. LII, pp. 261—277, 1908.
- 5) **Murray, James**, A Series of Short Notes appended to the Bathymetrical Reports of the Lake Survey published in the Geographical Journal as follows:
 - Biology of the Lochs of the Tay Basin. Vol. XXIII, pp. 55—61, 1904.
 - Notes on the Biology of the Lochs in the Assynt District. Vol. XXIII, pp. 471—473, 1904.
 - Notes on the Biology of Loch Morar. Vol. XXIV, pp. 77—79, 1904.
 - Biology of Loch Ness. Vol. XXIV, pp. 442—443, 1904.
 - Notes on the Biology of the Lochs in the Shiel District. Vol. XXV, pp. 285—6, 1905.
 - Notes on the Biology of the Lochs of the Conon Basin. Vol. XXVI, pp. 68—9, 1905.
 - Notes on the Biology of the Lochs of the Shin Basin. Vol. XXVI, p. 534, 1905.
 - Notes on the Biology of the Lochs of North Sutherlandshire. Vol. XXVII, pp. 164—5, 1906.
 - Notes on the Biology of the Lochs of the Beaully Basin. Vol. XXVII, p. 585, 1906.
 - Notes on the Biology of the Lochs in the Lochy District. Vol. XXVIII, pp. 614—5, 1906.
 - Notes on the Biology of the Lochs of the Ness Basin. Vol. XXXI, pp. 64—7, 1908.
- 6) **Murray, James**, On the distribution of the Pelagic Organisms in Scottish Lakes. Proceedings of the Royal Physical Society of Edinburgh. Vol. XVI, pp. 51—62, 1905.
- 7) **Murray, James**, The Rhizopods and Heliozoa of Loch Ness. Proc. Royal Society of Edinburgh. Vol. XXV, pp. 609—615, 1905.
- 8) **Murray, James**, On a new Family and twelve new Species of Rotifera of the Order Bdelloida collected by the Lake Survey. Trans. Roy. Soc. Edinburgh. Vol. XLI, pp. 367—386, 1905.
- 9) **Murray, James**, The Tardigrada of the Scottish Lochs. Trans. Roy. Soc. Edinburgh. Vol. XLI, pp. 677—698, 1905.
- 10) **Murray, James**, The Rotifera of the Scottish Lochs. Trans. Roy. Soc. Edinburgh. Vol. XLV, pp. 151—191, 1906.
- 11) **Murray, James**, Scottish Tardigrada collected by the Lake Survey. Trans. Roy. Soc. Edin. Vol. XLV, pp. 641—668, 1907.
- 12) **Murray, James**, Encystment of Tardigrada. Trans. Roy. Soc. Edin. Vol. XLV, pp. 837—854, 1907.
- 13) **Murray, James**, Scottish Rotifers collected by the Lake Survey (Supplement). Trans. Roy. Soc. Edin. Vol. XLVI, pp. 189—201, 1908.
- 14) **Penard, E.**, Sur les Sarcodines du Loch Ness. Proc. Roy. Soc. Edinburgh. Vol. XXV, pp. 593—608, 1905.
- 15) **Penard, E.**, Les Sarcodines des grands Lacs. Genève, 1905.
- 16) **Soar, C. D.**, Note on the Occurrence of living Hydrachnid Larvae in the Stomach of a Trout. Journal Quekett Microscopical Club. Vol. VIII, pp. 463—4, 1903.
- 17) **Wesenberg-Lund, C.**, A Comparative study of the Lakes of Scotland and Denmark. Proc. Roy. Soc. Edinburgh. Vol. XXV, pp. 401—448, 1905.

- 18) **West, George**, A comparative study of the dominant Phanerogamic and Higher Cryptogamic Flora of Aquatic Habit in three Lake Areas in Scotland. *Proc. Roy. Soc. Edinburgh*. Vol. XXV, pp. 967—1023, 55 plates, 1905.
- 19) **West, George**, Notes on the Aquatic Flora of the Ness Area. *Geographical Journal*. Vol. XXXI, pp. 67—72, 1908.
- 20) **West, W., and G. S.**, Scottish Freshwater Plankton, No. 1. *Journal Linnean Society (Botany)*. Vol. XXXV, pp. 519—556, 1903.
- 21) **West, W., and G. S.**, A further Contribution to the Freshwater Plankton of the Scottish Lochs. *Trans. Roy. Soc. Edinburgh*. Vol. XLI, pp. 477—518, 1905.
- 22) **Williamson, W.**, Hydrachnidae collected by the Lake Survey. *Proc. Roy. Soc. Edinburgh*. Vol. XXVII, pp. 302—7, 1907.

Note. A paper by Mr. James Murray on the biology of the Scottish lakes, including a census of the species, will probably be published this year. For the use of Mr. Murray's MS. in the preparation of the present paper, the writer is indebted to Sir John Murray.