Astacus fluviatilis.
Squilla.
Porcellana rugosa.
—— *longicornis.*
Galathea.
Pagurus tibicen.
—— elegans.
—— Bernhardus.
Clibinarus.
Trichia.
Gelasimus.
Cyclograpsus.
Libinia.
Menætheus.
Stenorhynchus.
Mithrax.
Trapezia pectinata.
—— ferruginea.
Pilumnus.
Melia tessellata.
Carpelodes rugipes.
Actinurus setifer.
Xantho Lamarckii.
Actæa obesa.
Thia ?
Liomera.
Pirimella ?
Thalamita.
Achelous.
Euriphia.
Thalassina.
Carcinocystus, n. g.

III. "On a Secular Variation in the Rainfall in connexion with the Secular Variation in amount of Sun-spots." By CHARLES MELDRUM, M.A., Director of the Mauritius Observatory. Communicated by B. STEWART, F.R.S., Professor of Natural Philosophy, Owens College, Manchester.

(Abstract.)

In this paper the author sums up the principal results obtained by his investigations as follows :—

(1.) Taking for the individual years of maximum and minimum sun-spot those given in par. 4*, it is found that the rainfall in the maxima exceeds the rainfall in the minima years in each country or district, and therefore in all taken collectively, the mean annual excess for Great Britain being 1·94, for the continent of Europe 3·64, for America 5·17, for India 8·98, and for Australia 6·23 inches, which gives a mean excess of 5·19 inches. In Great Britain the rainfall in seven of the nine years of maximum sun-spot exceeds the rainfall in the corresponding seven out of nine years of minimum sun-spot; on the continent of Europe six out of seven maxima years are similarly favourable; in America five out of six are favourable, in India four out of six, and in Australia two out of three.

A comparison of the mean rainfall of all the stations taken collectively gives an average annual excess of 7·01 inches in favour of the years of maximum sun-spot, and seven of the nine maxima years are favourable.

(2.) It is thus seen that the excess is not owing to abnormal and casual heavy falls in one or two years of maximum sun-spot, but that it

* Namely :—Years of maximum sun-spot, 1729, 1739, 1750, 1761, 1770, 1778, 1789, 1804, 1817, 1829, 1837, 1848, 1860, 1871; years of minimum sun-spot, 1733, 1743, 1756, 1766, 1776, 1785, 1798, 1811, 1824, 1834, 1843, 1856, 1867.

is evidently the result of law; for the years of most sun-spots are the rainiest years *generally* in every part of the world the rainfall of which has been obtained for a sufficient number of years.

(3.) By taking three-year maxima and minima periods, and comparing their rainfall, it is found that an increase of rain from the minimum to the next maximum period, and from the maximum to the next minimum period, is the general rule, with a few local exceptions, almost all of which disappear when means of all the observations are taken. Thus we find that 95·7 per cent. of the three-year maxima and minima periods are favourable in Great Britain, 75·0 on the continent of Europe, 88·8 in America, 88·2 in India, and 87·5 in Australia, &c., giving a favourable mean percentage of 87·0.

(4.) Taking the annual mean rainfall of the five districts collectively, the percentage of favourable maxima and minima periods is 91·3, showing that there is scarcely any exception to the law of increase of rain in the years of maximum, and decrease of rain in the years of minimum sun-spot. This fluctuation is well seen in the Tables containing the annual mean rainfall of the *globe* (that is, of all the stations), the rainfall of each of the triennial periods being given separately. Of the nine wettest and the nine driest years 77·8 per cent. are within two years of the epochs of maximum and minimum sun-spot.

(5.) A large majority of the entire sun-spot periods are also favourable. This is shown by taking the annual rainfall at the same stations for each period, placing the rainfall in the years of minimum sun-spot at the beginning and end, and the rainfall in the years of maximum sun-spot in the middle of the period, and observing whether the rainfall first increases and then decreases. Of the number of entire sun-spot periods, 78·6 per cent. are completely favourable, and some others partially favourable, making the favourable percentage still greater.

(6.) When the years of greatest and least rainfall occur within two years of the years of most and least sun-spot respectively, they are considered favourable, and unfavourable when they fall beyond these limits. From this point of view, we have for Great Britain 72·2 per cent. of the wettest and driest years favourable, for the continent of Europe 57·1, for America 66·7, for India 83·3, and for Australia also 83·3, giving a mean percentage of 72·5. The mean rainfall of all the stations (globe) gives a favourable percentage of 77·8.

(7.) With respect to the rivers, the results, as might be expected, are similar. The depths in the maxima exceed the depths in the minima sun-spot years by an annual average of 16·2 inches (Austrian); and of thirteen maxima years, compared with thirteen minima years, there are only three in which the excess is not in favour of the former. As to the maxima and minima triennial periods 79·4 per cent. of them are favourable, the rivers, as a rule, rising and falling with the amount of sun-spot. Of the thirteen entire sun-spot periods 77 per

cent. are favourable. Of the fifteen years in which the depths were greatest 60 per cent. were within two years of maxima sun-spot years, and 61·5 per cent. of the years in which the depths were least were within two years of minima sun-spot years. The latter percentages, although favourable, are less so than those for the rainfall, owing to obvious causes.

(8.) All the above results have been obtained by strictly adhering to the adopted years of maximum and minimum sun-spot, and by taking the absolutely wettest and driest years, however little the rainfall in them might differ from that of other wet and dry years in their neighbourhood. It is clear that this was subjecting the hypothesis to a severe test; for there is some doubt as to the positions of the years of maximum and minimum sun-spot, especially in the earlier periods of observation; and, assuming a connexion between rainfall and sun-spots, it might well happen that the absolutely wettest and driest years would not always, or even often, fall within two years of the epochs of maximum and minimum sun-spot. The results, therefore, may be considered highly favourable; but they become still more so if, in a few cases, the epochs of maxima and minima be altered to the extent of *one* year, and if, for the absolutely wettest and driest years, almost equally wet and dry years be occasionally substituted. A slight alteration of this kind would, for instance, raise the percentage of favourable maxima and minima periods on the continent of Europe from 75 to 100, and make *all* the wettest and driest years favourable. Similar results would be obtained for the other districts of observation.

(9.) The ratios of the maximum and minimum rainfall to the mean rainfall (especially the latter ratio) are nearly the same for each part of the globe; and this points to the sun as the main agent in producing rainfall variation. The ratios of the maximum and minimum river-depths to the mean depth are almost the same as those for the rainfall.

(10.) The years of maximum and minimum sun-spot are characterized by great rainfall and river oscillations, a circumstance which also points to the sun as the disturbing cause *.

(11.) As the mean duration of the sun-spot period is 11·1 years, while the interval from the minimum to the maximum is about 3·7 years, and from the maximum to the minimum about 7·4 years, the durations of the rainfall and river cycles, and the intervals between their epochs of minima and maxima and maxima and minima, should approach those for the sun-spot cycle, supposing that the three cycles are connected by a common cause. Now this is found to be generally the case. The intervals between the consecutive wettest and between the consecutive driest years for Great Britain are 11·3 and 10·8 years respectively, while the interval from the driest to the wettest years is 3·9, and from the wettest to the driest years 6·8 years. For the continent of Europe

* The greatest river-fluctuations occur in minima years.

the mean duration of the period is 11 years; but the intervals are less favourable, being 5·3 years from the driest to the wettest, and 5·2 from the wettest to the driest. The results for America are nearly the same. In India the mean duration of the period is 10·8 years, the mean interval from the driest to the wettest years 4·5, and from the wettest to the driest 5·8 years. For Australia we get a mean period of 10·7 years, with an interval of 4·7 from the driest to the wettest years, and of 5·5 from the wettest to the driest years. The means of the five results are as follows:—Duration of period = 11 years; interval from driest to wettest years = 4·8 years; interval from wettest to driest years = 5·8 years.

The mean rainfall of the globe (all the stations) gives the following results:—Mean duration of period = 10·6 years; mean interval from driest to wettest years = 4·9 years; mean interval from wettest to driest years = 6 years.

For the river-depths the mean duration of the period is 11 years; the mean interval from minimum to maximum 3·8, and from maximum to minimum 6·8 years.

(12.) The results just given are of course only approximations. They were, however, considered so favourable as to encourage a closer examination; so that whenever I procured a portion (at least) of the Kew values of the sun-spot area, and of Wolf's relative numbers, I compared the former with the rainfall from 1832 to 1867, and the latter with the rainfall and river-depths for the longest possible periods, and on the whole obtained very favourable results.

(13.) Supposing (as Mr. J. Allan Broun does) that any connexion that may subsist between sun-spots and rainfall may be approximately represented by the equation $\Delta R = f \Delta A$, it is found that the values of f for Great Britain, the continent of Europe, America, India, and Australia from 1832 to 1867 are all favourable, except for America, where it is slightly unfavourable.

(14.) There are, apparently, some discrepancies between the Kew values and those of Wolf for the period 1832–67. For when, in place of ΔA (difference of sun-spot area from the mean) we take Δr (difference of Wolf's relative numbers from the mean), we obtain favourable values of f for *all* the five districts.

(15.) A comparison of Wolf's relative numbers with the rainfall of each country for the longest possible periods also gives very favourable results. The agreement of ΔR and δ with Δr, in regard to the signs (+) and (−), is remarkable, especially for the period 1842 to 1872, during which the rainfall of a portion of the southern hemisphere is represented. The values of f in the equation $\Delta R = f \Delta r$ are favourable for each country, and (taking all the stations) they are also favourable for each of the seven sub-periods, except the one 1832–41. The whole period of 77 years gives for the rainfall of the globe $\Delta R = + \cdot 05745 \Delta r$; and

from this equation we obtain a mean annual difference of 5·03 inches in favour of the years of maximum sun-spot.

(16.) A similar comparison of Δr with Δ D (differences of river-depths from the mean) also gives favourable results. The 116 years of river-depths (1756 to 1871) compared with the relative numbers of sun-spots for the same years give the equations $\Delta \mathrm{D} = + 0{\cdot}17322\ \Delta r$ and $\Delta \mathrm{D} = + 0{\cdot}12266\ \Delta r$. According to these equations the depth in the years of most sun-spot should exceed the depth in the years of least sun-spot by an annual average of 12·69 inches. For all, except three, of the 11 sub-periods into which the 116 years are divided the values of f are favourable, and they would no doubt be found favourable as far back as the observations of river-depths extend (1728), if we had the sun-spot numbers for those years.

(17.) Sun-spot, rainfall, and river curves laid down from the Tables have, notwithstanding some exceptions, a general resemblance, which cannot, I think, be ascribed to chance. The resemblance, as might be expected, is greatest in the case of the rainfall curve for the globe. Here, with the exception of two or three years in the period 1765 to 1776, for which there are only three stations, and of three years in the period 1832 to 1841, the resemblance is very strong.

(18.) Of the seven entire sun-spot periods of rainfall for the globe, the mean values of six can be compared with the mean values of Wolf's relative numbers by placing the maxima years near the middle and the minima years at the beginning and end of each period, so as to have nearly all the maxima years in one horizontal line, and the minima years in other horizontal lines. This is done in one of the Tables. The river-depths for the same six periods are similarly arranged in another Table. Then, applying Bessel's formula, we get three equations, the second terms of which enable us to lay down three curves showing the general progression of sun-spot, rainfall, and river-depths. The modification of these curves by the third terms of the equations is shown by dotted curves. In a similar way we obtain three other equations and curves for five sun-spot periods, in which the minima years of sun-spot are placed near the middle and the maxima years at the commencement and end. The resemblance of the curves to one another is very striking.

(19.) According to the terms containing θ and $2\,\theta$ in the first three equations the three cycles have nearly the same lengths. The rainfall maximum occurs 4·8 months *after* the sun-spot maximum, and the river maximum 9·6 months after the rainfall maximum. According to the second three equations the rainfall minimum occurs 10·8 months *after* the sun-spot minimum, and the river minimum 3·6 months *after* the rainfall minimum. The mean range of rainfall variation is 6·19 inches, and of river-depth variation 16·73 inches. The intervals from the minima to the maxima epochs are in every case less than those from

the maxima to the minima epochs, and the ratios of the former to the latter intervals are nearly the same for all the three cycles.

(20.) These results will be somewhat modified by the fourth and fifth terms of the equations and by additional observations; but at present they may be considered fair approximations. The mean excess of rainfall (6·19 inches) is almost the mean of the 5·19 and 7·20 inches previously obtained, and the 16·73 inches of river-fluctuation are nearly the same as the 16·20 inches found by taking the means of the depths in the adopted maxima and minima years. The durations of the periods, and the intervals from minimum to maximum and from maximum to minimum, given by the equations are also not very different from those given directly by the observations.

(21.) Although the mean depths of the rivers have apparently been decreasing, yet the range of variation has altered little. It would thus appear that there is some general cause which operates irrespectively of local causes, and that its effects usually override all other effects. This is shown by the differences between the greatest and least depths for consecutive periods of ten to thirteen years.

The more numerous the observations the more evident does a connexion between sun-spots and rainfall become. At first (1872) the rainfall at only three stations (Mauritius, Adelaide, and Brisbane) was examined. To these Mr. J. Norman Lockyer, in a paper "On the Meteorology of the Future" ('Nature,' vol. vii. p. 142), added the rainfalls of the Cape and of Madras, strongly expressing in favour of the hypothesis (even at that early stage) an opinion which, though not then accepted by some meteorologists, all subsequent investigations, including those of Mr. Blanford, Prof. Broklesby, Mr. Dawson, Mr. Ellery, Dr. Jelinek, Mr. R. H. Scott, and Mr. Symons, have amply justified*. The number of stations has, in short, gradually risen from three to 144, and the results of each successive investigation have been an improvement on their predecessors.

Not only has the number of stations been increased; the periods of observation have been greatly extended. At first we had only ten to forty-five years' observations, comprising at the utmost one to four sun-spot periods. We have now rainfall observations for seven and river-observations for thirteen sun-spot periods; and the fact that the law holds good with the earlier as well as with the later observations is significant. The variations in the level of the Elbe, from 1728 to 1777, followed the sun-spot variations as regularly as those of the rainfall and rivers have done in later times.

The amount of rainfall variation is greatest within the tropics, and seems to decrease as the latitude increases. This is a point, however, which requires further examination by considering the observations

* I have not seen Prof. Tyndall and Mr. Hennessy's contributions.

belonging to different zones. The positions of the belts of calms and variables may be found to have a secular variation.

It is to be borne in mind that the average excess of rainfall in the maxima years (6·19 inches) is obtained by taking all the observations of whatever description. Most of the observations are favourable, but others are unfavourable. If the former alone had been taken, the excess would be much larger. Now the rainfall at many of the stations seems to be permanently favourable, while at several others it seems to be permanently unfavourable *; that is, there are many stations at which the rainfall is invariably, or at least generally, greater in the maxima than in the minima years, while at some others the reverse takes place. As a rule, it would appear that the stations near the sea and fully exposed to winds sweeping over a considerable expanse of water are favourable, while the unfavourable ones are those exposed to winds passing over land and liable to be deflected by mountains and valleys. Bombay, Madras, Mauritius, Cape of Good Hope, Brisbane, Melbourne, Plymouth, and Charleston (U.S.) are among the favourable stations, and Calcutta, Milan, and Trieste amongst the unfavourable. At Bombay (exposed to the S. W. monsoon) there has been only one exception to the general law since 1817, and at the Cape of Good Hope, Mauritius, &c., as far as observation extends, there has been no exception at all. On the other hand, Milan furnishes an opposite example. What we have to do, then, is to separate the favourable from the unfavourable stations, and to study the rainfall of each class by itself. The *total* rainfall of the globe generally is about 6 inches greater in the maxima than in the minima sun-spot years; but there are local exceptions, and it is important to know their laws.

As the rainfall at a majority of stations fluctuates with the sun-spots, and as the amount of fluctuation for these stations is considerably greater than 6 inches, it would probably be of advantage to be able to predict the epochs of maximum and minimum sun-spots. Dr. De La Rue and Prof. Balfour Stewart have shown that the sun-spots are, to some extent, connected with the relative positions of the planets and sun. If, then, it were proved that the sun-spot period depends upon the configuration of the planets, and the rainfall period on sun-spots, it would be easy to predict the general character of the seasons for large portions of the globe. Even without this it is possible, as recently pointed out by Mr. Ellery, in his Annual Address to the Royal Society of Victoria, that there is so much interdependence in the rainfalls of different countries, that, with our present knowledge and with the aid of the telegraph, we may shortly be in a position to foretell whether a coming season is likely to be a wet or a dry one. The results of the

* These are few in number. Observations for long periods show that the law of fluctuation holds good at a great majority of stations.

present investigation warrant the inference that, generally, the rainfall of the next two or three years will be below the average rainfall of the years 1870–3, and that, though some places may suffer from floods, more will suffer from drought. From all the information I have been enabled to collect, it is not improbable that the rainfall of this year (1875), remarkable though it is for destructive floods in various parts of the world, will be less than the average. Floods are, apparently, characteristic of the setting in of the minimum period of sun-spots, especially on the continent of Europe. But these floods are local, and the large vintage in Central Europe is an indication that, generally, the rainfall there for at least several months of the year has not been excessive.

A completely satisfactory proof of a connexion between sun-spots and rainfall requires that the variation in the rainfall must necessarily follow from the variation in the sun-spot area. We may show that the two periods, as far as observation extends, are equal, that the intervals between their maxima and minima epochs are equal, and that the times of the epochs themselves are exactly what might be expected. It might also be argued that periodic constitutional changes in the sun, as indicated by the solar spots, must produce atmospheric changes. But granting all that, it may be said that so long as there is a bare possibility of explaining the phenomena otherwise, the evidence is incomplete. There may be two independent causes at work, one producing a sun-spot and the other a rainfall cycle, and the two causes and effects may have run nearly parallel to each other for many years; but it does not follow that they will always do so.

Such a possibility may exist, but it seems to be a rather remote one; and in order, if possible, to make it still more remote, it may be desirable to compare the amount of sun-spots and rainfall for each day and month.

But supposing it were fully established that the rainfall and sun-spot variations are produced by one and the same cause, it may be asked whether the corresponding eleven-year period of magnetic variation, discovered by Sir Edward Sabine, has also the same cause; and if so, by what process are such apparently dissimilar effects as rainfall and magnetic variations produced by a common agent? I would hazard the opinion that the proximate cause of the sun-spot, magnetic, and rainfall cycles is a secular variation in the intensity of solar heat, the solar spots or cyclones being, like terrestrial cyclones, most frequent when the temperature is greatest, that the sun radiating more heat in some years than in others evaporation and rainfall are greater in the former than in the latter, and that the changes in solar radiation affect the earth's magnetism. This opinion seems to receive some support from the circumstance that, according to some remarks recently made by Sir George Airy at a meeting of the Institution of Civil Engineers, and to researches

by Mr. Blanford ('Nature,' vol. xii. p. 188), solar radiation is greater in the rainiest years, that is, in the years of most sun-spot. That the rainiest years should be the years of greatest solar radiation, is, as was argued in a paper read before the Meteorological Society of Mauritius on the 16th of January, 1873, what analogy would lead us to expect.

March 16, 1876.

Dr. J. DALTON HOOKER, C.B., President, in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "Preliminary Reports to Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff, on Work done on board the 'Challenger.'" By JOHN MURRAY, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

II. "Preliminary Report to Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Staff, on the true Corals dredged by H.M.S. 'Challenger,' in deep water, between the dates Dec. 30th, 1870, and August 31st, 1875." By H. N. MOSELEY, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

III. "Preliminary Report to Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff, on Observations made during the earlier part of the Voyage." By the late Dr. RUDOLF VON WILLEMÖES-SUHM, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.

IV. "Preliminary Report to Professor WYVILLE THOMSON, F.R.S., Director of the Civilian Scientific Staff, on Crustacea observed during the Cruise of H.M.S. 'Challenger' in the Southern Sea." By the late Dr. RUDOLF VON WILLEMÖES-SUHM, Naturalist to the Expedition. (Published by permission of the Lords of the Admiralty.) Received February 14, 1876.