PROCEEDINGS

AND

TRANSACTIONS

OF THE

LIVERPOOL BIOLOGICAL SOCIETY.

VOL. XXXV.

SESSION 1920-1921.

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1921.

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PROCEEDINGS

OF THE

LIVERPOOL BIOLOGICAL SOCIETY.

OFFICE-BEARERS AND COUNCIL

Ex-Presidents:

1886—1887	Prof. W. MITCHELL BANKS, M.D., F.R.C.S.
1887—1888	J. J. DRYSDALE, M.D.
1888—1889	Prof. W. A. HERDMAN, D.Sc., F.R.S.E.
1889—1890	Prof. W. A. HERDMAN, D.Sc., F.R.S.E.
1890—1891	T. J. MOORE, C.M.Z.S.
1891—1892	T. J. MOORE, C.M.Z.S.
1892—1893	ALFRED O. WALKER, J.P., F.L.S.
1893—1894	JOHN NEWTON, M.R.C.S.
1894—1895	Prof. F. GOTCH, M.A., F.R.S.
1895—1896	Prof. R. J. HARVEY GIBSON, M.A.
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1897—1898	ISAAC C. THOMPSON, F.L.S., F.R.M.S.
1898—1899	Prof. C. S. SHERRINGTON, M.D., F.R.S.
1899—1900	J. WIGLESWORTH, M.D., F.R.C.P.
1900—1901	Prof. PATERSON, M.D., M.R.C.S.
1901—1902	HENRY C. BEASLEY.
1902—1903	R. CATON, M.D., F.R.C.P.
1903—1904	Rev. T. S. LEA, M.A.
1904—1905	ALFRED LEICESTER.
1905—1906	JOSEPH LOMAS, F.G.S.
1906—1907	Prof. W. A. HERDMAN, D.Sc., F.R.S.
1907—1908	W. T. HAYDON, F.L.S.
1908—1909	Prof. B. MOORE, M.A., D.Sc.
1909—1910	R. NEWSTEAD, M.Sc., F.E.S.
1910—1911	Prof. R. NEWSTEAD, M.Sc., F.R.S.
1911—1912	J. H. O'CONNELL, L.R.C.P.
1912—1913	JAMES JOHNSTONE, D.Sc.
1913—1914	C. J. MACALISTER, M.D., F.R.C.P.
1914—1915	Prof. J. W. W. STEPHENS, M.D., D.P.H.
1915—1916	Prof. ERNEST GLYNN, M.A., M.D.
1916—1917	Prof. J. S. MACDONALD, L.R.C.P., F.R.S.
1917—1918	JOSEPH A. CLUBB, D.Sc.
1918—1919	Prof. W. RAMSDEN, M.A., D.M.
1919—1920	HUGH R. RATHBONE, M.A., J.P.

SESSION XXXIV, 1920-1921.

President:

Prof. P. G. H. BOSWELL, O.B.E., D.Sc

Vice-Presidents:

HUGH R. RATHBONE, M.A., J.P.
Prof. W. A. HERDMAN, C.B.E., D.Sc., F.R.S.

Hon. Treasurer:

W. J. HALLS.

Hon. Librarian:

MAY ALLEN, B.A.

Hon. Secretary:

W. RIMMER TEARE, A.C.P.

Council:

S. T. BURFIELD, B.A.,
R. CATON, M.D., F.R.C.P
J. A. CLUBB, D.Sc.
J. W. CUTMORE.
Prof. W. J. DAKIN, D.Sc., F.L.S.
G. ELLISON.
ALWEN M. EVANS, M.Sc. (Miss)
Prof. J. JOHNSTONE, D.Sc.
W. S. LAVEROCK, M.A., B.Sc.
J. H. MILTON, F.G.S.
Prof. R. NEWSTEAD, M.Sc., F.R.S.
Prof. W. RAMSDEN, M.A., D.M.

Representative of Students' Section ;

Miss M. BOWEN, B.Sc.

REPORT of the COUNCIL.

During the Session 1920-21 there have been seven ordinary evening meetings. The annual excursion was held on June 18th, when a visit was paid to the Grosvenor Museum at Chester, and a very enjoyable afternoon was spent.

The communications made to the Society at the ordinary meetings have been representative of many branches of Biology, and the various exhibitions and demonstrations thereon have been of the utmost interest and value.

The form of the meeting on March 14th was somewhat of a new departure. The President received the members and a number of guests in the Zoology department, which, together with the Geology and Oceanography departments, was thrown open to inspection.

On May 6th, Prof. J. B. Farmer, F.R.S., D.Sc., of the Imperial College of Science had intended to address the Society, but was prevented by indisposition from doing so. It is hoped that he will be able to be present at one of the meetings of next session.

The Library continues to make satisfactory progress, and additional important exchanges have been arranged.

The Treasurer's statement and balance sheet are appended.

The members at present on the roll are as follows :—

Ordinary members	48
Associate members	12
Student members, including Students' Section, about	30
Total	90

SUMMARY of PROCEEDINGS at the MEETINGS.

The first meeting of the thirty-fifth session was held at the University, on Friday, October 15th, 1920.

1. The Report of the Council on the Session 1919-1920 (see "Proceedings," Vol. XXXIV, p. viii) was submitted and adopted.

2. The Treasurer's Balance Sheet for the Session 1919-1920 (see "Proceedings," Vol. XXXIV, p. xvi) was submitted and approved.

3. The following Office-bearers and Council for the ensuing Session were elected:—Vice-Presidents, Hugh R. Rathbone, M.A., J.P., Prof. Herdman, D.Sc., F.R.S.; Hon. Treasurer, W. J. Halls; Hon. Librarian, May Allen, B.A.; Hon. Secretary, W. Rimmer Teare, A.C.P.; Council, S. T. Burfield, B.A., M.Sc., R. Caton, M.D., F.R.C.P., J. A. Clubb, D.Sc., J. W. Cutmore, Prof. W. J. Dakin, D.Sc., F.L.S., G. Ellison, Alwen M. Evans, M.Sc. (Miss), Prof. J. Johnstone, D.Sc., W. S. Laverock, M.A., B.Sc., J. H. Milton, F.G.S., Prof. R. Newstead, M.Sc., F.R.S., Prof. W. Ramsden, M.A., D.M.

4. Prof. P. G. H. Boswell, D.Sc., delivered the Presidential Address on "Sedimentation, Environment, and Evolution in Past Ages" (see "Transactions," p. 3). A vote of thanks proposed by Dr. Caton, seconded by Prof. Johnstone, was passed.

The second meeting of the thirty-fifth session was held at the University, on Friday, November 12th, 1920, Dr. Clubb presiding.

1. Prof. Herdman submitted the report which he had prepared for The Liverpool Marine Biology Committee drawing attention to special portions and illustrating his remarks by slides and specimens. (See "Transactions," p. 29.)

The third meeting of the thirty-fifth session was held at the University, on Friday, December 10th, 1920. The President in the Chair.

1. A paper by Miss E. Catherine Herdman on "Dinoflagellates and other Organisms causing Discolouration of the Sand at Port Erin" (see "Transactions," p. 59).
2. A paper by Miss R. C. Bamber, M.Sc., on "Some Experiments on the Water Vascular System of Echinus" (see "Transactions," p. 64).

The fourth meeting of the thirty-fifth session was held at the University, on Friday, January 14th, 1921. The President in the Chair.

1. Prof. Herdman exhibited a butterfly's wing displayed on a card in a wonderful manner by a Japanese craftsman.
2. Mr. Burfield, B.A., M.Sc., exhibited several West African specimens, together with the foetus of a whale (*Megapter longimana*).
3. Mr. Cutmore read some notes on "The Inheritance of Coat Colour in the Varieties of *Rattus rattus*" (see "Transactions, p. 71).
4. Mr. E. Neaverson, B.Sc., gave an account of modern ideas on the Evolution of Ammonites.

The fifth meeting of the thirty-fifth session was held at the University, on Friday, February 11th, 1921. The President in the Chair.

1. In his unavoidable absence, Prof. Johnstone forwarded the Report for 1920 on the Lancashire Sea-Fisheries Laboratory (see "Transactions," p. 73).
2. Mr. R. J. Daniels, B.Sc., explained the result of the investigations on the connection between sea-temperatures and tides.
3. Mr. W. Birtwistle discussed the scales and otoliths of fish in relation to their age and development.

The sixth meeting of the thirty-fifth session was held at the University, on Monday, March 14th, 1921. The President received the members and a number of visitors in the Zoology department, in the Library of which refreshments were provided. By kind consent of Prof. Dakin and Prof. Johnstone, the President was enabled to throw not only the Geology, but the Zoology and Oceanography departments open to his guests. Specimens and apparatus were exhibited, and the members of the staffs of all three departments explained them to those present.

The seventh meeting of the thirty-fifth session was held at the University, on Friday, May 6th, 1921. The President in the Chair.

By invitation of the President, Prof. Farmer of the Imperial College of Science had consented to address the Society on "Alpines," but was, unfortunately, too ill to be present. At short notice, the President prepared and delivered an account of a Geological Survey of the south of the Isle of Man conducted by a party at Easter last. The lecture was illustrated by many slides and proved of great interest.

The eighth meeting of the thirty-fifth session was held on Saturday, June 18th. A visit to Chester had been arranged mainly by Prof. R. Newstead, F.R.S., who met the members and conducted them to the Grosvenor Museum. Here Prof. Newstead and Mr. Alfred Newstead, F.E.S., Curator, described the various exhibits, the Roman and Natural History sections claiming special attention.

At a meeting held in the Museum it was unanimously resolved, on the motion of the President, that Herbert R. Rathbone, Esq., C.C., be elected President for the ensuing session. Dr. Clubb was appointed delegate of the Society to the British Association Meeting at Edinburgh.

Warm thanks are due to the Chester Education Committee, the Chester Archæological Society, and the Chester Society of Natural Science, as well as to Prof. Newstead and the Curator, for the kind hospitality extended to the Society at the Museum.

LIST of MEMBERS of the LIVERPOOL BIOLOGICAL SOCIETY.

SESSION 1920-1921.

A. Ordinary Members.

(Life Members are marked with an asterisk.)

ELECTED.	
1908	Abram, Prof. J. Hill, M.D., F.R.C.P., 74, Rodney Street, Liverpool.
1919	Adami, Dr. J. G., F.R.S., Vice-Chancellor, The University, Liverpool.
1909	*Allen, May, B.A., Hon. Librarian, University, Liverpool.
1918	Baldwin, Mrs., M.Sc., Zoology Dept., University, Liverpool.
1913	Beattie, Prof. J. M., M.A., M.D., The University, Liverpool.
1903	Booth, Chas., Cunard Building, Liverpool.
1919	Boswell, Prof. P. G. H., O.B.E., D.Sc., President, The University, Liverpool.
1912	Burfield, S. T., B.A., M.Sc., Zoology Department, University, Liverpool.
1886	Caton, R., M.D., F.R.C.P., 7, Sunny Side, Prince's Park, Liverpool.
1886	Clubb, J. A., D.Sc., Free Public Museums, Liverpool.
1920	Dakin, Prof. W. J., D.Sc., F.L.S., The University, Liverpool.
1917	Duvall, Miss H. M., M.Sc., Zoology Department, University, Liverpool.
1910	Ellison, George, 52, Serpentine Road, Wallasey.
1920	Elton, Charles, " Wensted," Grassendale Park, Liverpool.
1902	Glynn, Prof. Ernest, M.D., F.R.C.P., 67, Rodney Street.
1886	Halls, W. J., Hon. Treasurer, 2, Townfield Road, West Kirby.
1896	Haydon, W. T., F.L.S., 55, Grey Road, Walton.
1886	Herdman, Prof. W. A., D.Sc., F.R.S., Vice-President, University, Liverpool.

1893 Herdman, Mrs. W. A., Croxteth Lodge, Ullet Road, Liverpool.

1912 Hobhouse, J. R., 19, Ullet Road, Liverpool.

1902 Holt, Dr. A., Rocklands, Thornton Hough, Cheshire.

1903 Holt, Richard D., India Buildings, Liverpool.

1920 Johnstone, Angus, 63, Church Road, St. Michael's, Liverpool.

1898 Johnstone, Prof. James, D.Sc., University, Liverpool.

1918 Jones, Philip, " Brantwood," St. Domingo Grove, Liverpool.

1896 Laverock, W. S., M.A., B.Sc., Free Public Museums, Liverpool.

1915 Macdonald, Prof. J. S., B.A., F.R.S., The University, Liverpool.

1917 Milton, J. H., F.G.S., Merchant Taylors' School, Great Crosby.

1904 Newstead, Prof. R., M.Sc., F.R.S., University, Liverpool.

1913 Pallis, Mark, Tätoi, Aigburth Drive, Liverpool.

1915 Prof. W. Ramsden, M.A., D.M., University, Liverpool.

1921 Rathbone, Herbert R., C.C., 35, Ullet Road, Liverpool.

1903 Rathbone, Hugh R., M.A., J.P., Vice-President, Greenbank, Liverpool.

1890 *Rathbone, Miss May, 29, Upper Berkeley Street, London, W.1.

1894 Scott, Andrew, A.L.S., Piel, Barrow-in-Furness.

1908 Share-Jones, J., D.Sc., F.R.C.V.S., University, Liverpool.

1886 Smith, Andrew T., " Solna," Croxteth Drive, Liverpool.

1920 Southwell, T., School of Tropical Medicine, University, Liverpool.

1903 Stapledon, W. C., " Annery," Caldy, West Kirby.

1913 Stephens, Prof. J. W. W., M.D., University, Liverpool.

1915 Teare, W. Rimmer, A.C.P., Hon. Secretary, 12, Bentley Road, Birkenhead.

1903 Thomas, Dr. Thelwall, 84, Rodney Street, Liverpool.

1905 Thompson, Edwin, " Woodlands," 13, Fulwood Park, Liverpool.

1889 Thornely, Miss L. R., Hawkshead, Ambleside.

1888 Toll, J. M., 49, Newsham Drive, Liverpool.

1920 Walker, Prof. C., D.Sc., M.R.C.S., The University, Liverpool.

1918 Whitley, Edward, Bio-Chemical Laboratory, University.

1920 Yorke, Prof. Warrington, M.D., School of Tropical Medicine, University, Liverpool.

B. Associate Members.

1916 Atkin, Miss D., High School for Girls, Aigburth Vale Liverpool.

1915 Bisbee, Mrs., M.Sc., Zoology Department, The University, Liverpool.

1914 Cutmore, J. W., Free Public Museums, Liverpool.

1918 Evans, Miss Alwen M., M.Sc., School of Tropical Medicine, University, Liverpool.

1916 Gleave, Miss E. L., M.Sc., Oulton Secondary School, Clarence Street, Liverpool.

1905 Harrison, Oulton, 3, Montpellier Crescent, New Brighton.

1920 Kewley, Miss Helen C., 10, Park Road N., Birkenhead.

1919 Mayne, Miss C., B.Sc., 17, Laburnum Road, Fairfield.

1919 Sleggs, G. F., B.Sc., Zoology Dept., University, Liverpool.

1915 Stafford, Miss C. M. P., B.Sc., 312, Hawthorne Road, Bootle.

1917 Swift, Miss F., B.Sc., Queen Mary High School, Anfield.

1912 Wilson, Mrs. Gordon, High Schools for Girls, Aigburth Vale, Liverpool.

C. University Students' Section.

President: Miss M. Bowen, B.Sc.

Secretary; Miss D. M. R. Allan, B.Sc.

(Contains about 30 members.)

D. Honorary Members.

S.A.S., Albert I., Prince de Monaco, 10, Avenue du Trocadéro, Paris.

Bornet, Dr. Edouard, Quai de la Tournelle 27, Paris.

Fritsch, Prof. Anton, Museum, Prague, Bohemia.

Hanitsch, R., Ph.D., Oxford.

THE LIVERPOOL BIOLOGICAL SOCIETY.

Cr. IN ACCOUNT WITH W. J. HALLS, HON. TREASURER. **Dr.**

1920, Oct. 1st to Sept. 30th, 1921.	£	s.	d.
By Balance from last Session	61	1	10
,, Subscriptions	24	3	0
,, ,, (in Arrears)	12	12	0
,, ,, (By Bank)	1	1	0
,, ,, (Associates)	1	1	0
,, Sale of Volumes	5	16	10
,, Interest from Investment	5	13	6
,, Bank Interest	1	18	10
	£113	8	0

1920, Oct. 1st to Sept. 30th, 1921.	£	s.	d.
To Northern Art Reproduction Co.	0	19	6
,, Insurance of Library	2	4	0
,, Messrs. Tinling & Co.	65	1	9
,, Tea A/c	2	19	11
,, Postage of Volumes	7	4	6
,, Hon. Secretary's Expenses	1	5	10
,, Balance in Bank	29	14	10
,, Cash in hand	3	17	8
	£113	8	0

Audited and found correct,

JOSEPH A. CLUBB.

LIVERPOOL, *October 7th*, 1921.

TRANSACTIONS

OF THE

LIVERPOOL BIOLOGICAL SOCIETY.

PRESIDENTIAL ADDRESS.

By P. G. H. Boswell, A.R.C.Sc., D.Sc.

George Herdman Professor of Geology in the University of Liverpool.

(Read October 15th, 1920.)

During the past session the Society has sustained the loss of two of its most distinguished members. Henry Charles Beasley died on December 14th, 1919, at the age of 83. He occupied the Presidential Chair of this Society during the session 1901-2, and was Secretary of the Liverpool Geological Society from 1890 to 1900, and its President for the sessions 1887-9, 1904-6, and 1908-9.

His work on fossil footprints gave him a wide reputation, and he accumulated an excellent collection of Triassic footprints largely from Storeton and other quarries in this district. In addition he obtained a fine series of photographs of various footprints scattered throughout the museums of the country. He published many papers on the subject in the "Proceedings of the Liverpool Geological Society," and wrote reports for the British Association Committee which dealt with the Investigation of the Fauna and Flora of the Trias of the British Isles, of which Committee he was for a time Secretary. This work was recognised by the award to him in 1906 of the proceeds of the Barlow-Jameson Fund of the Geological Society of London, and by the posthumous award of the recently-instituted medal of the Liverpool Geological Society.

His splendid collection of footprints was purchased last year by Councillor C. Sydney Jones and presented to the Liverpool Public Museum; his albums of photographs were presented to the Liverpool Geological Society, and his other geological material has been acquired by the Geological Department of the University.

Mr. Beasley was imbued with the spirit of the fine old British amateur geologists. Although active commercial duties left him scanty leisure for geology, he pursued the Science with unabated vigour until illness compelled him to relinquish the work. His kindly and helpful disposition endeared him to his friends.

On May 28th, 1920, at the early age of 42, LEONARD DONCASTER, Derby Professor of Zoology in the University of Liverpool, passed away. Perhaps the most brilliant of the younger school of British zoologists, he was early attracted to the problems of variation and heredity, to which he applied the exact methods of cytological research. A believer in the theory of Mendelism, he was led on to problems relating to the determination of sex, his work upon which constitutes a milestone in the progress of biology. His books upon "The Determination of Sex" and "The Study of Cytology" remain a monument to his memory as well as an indication of what we have lost by his early death.

We knew him as a colleague for barely a short session, but his humanity, charm, and uprightness commanded our affection and respect. To use Professor Herdman's words, his death was nothing less than a calamity to the University of Liverpool and, one would add, to the cause of Science.

SEDIMENTATION, ENVIRONMENT, AND EVOLUTION IN PAST AGES.

When we review the two chief classes of rocks which constitute the crust of the earth, the igneous or fire-formed rocks, and the clastic or sedimentary rocks, we cannot fail to note the difference in the extent to which we know them. The characters of the igneous rocks have been studied by geologists in greater detail than those of the sedimentary rocks, so much so, in fact, that the petrology of the former—their origin, history, and the control of their mineral constitution by physical laws—has reached the stage of philosophic treatment. In contrast to this, the very wealth of organic remains found in most of the clastic or sedimentary rocks has in many cases diverted attention from their mineral and mechanical characters and has left the field of the petrology of sediments relatively obscure. On the one hand we find that the branch of geological science which deals with igneous rocks is becoming more and more amenable to mathematical treatment; on the other hand, the study of sediments has only in recent years become quantitative.

It is one of the tenets of geology that the present is the key to the past. But in many cases we have no certain information as to the conditions under which ancient sediments were laid down; criteria are lacking because our acquaintance with the mode of formation of similar deposits at the present day is insufficient and inexact. This lack of knowledge is the more to be regretted since, apart from the features displayed by the entombed fossils themselves, the nature and character of the sediments provide the only clues to the environments in which the organisms dwelt, and which may have caused or modified the evolution of lineages. The environmental conditions would not always leave their impress upon the rocks, but it is probable that many which did so have left traces that are insufficiently recognized or even wrongly interpreted. Broader climatic changes have affected deposits so markedly that the corresponding conditions have doubtless been rightly adduced, but the effects of the lesser changes are only now being recognized.

Sedimentation.—Certain fundamental considerations in regard to the formation of sedimentary rocks first, perhaps, deserve emphasis.

As an ideal case, let us imagine that a continental area composed of an igneous rock, such as granite, is subjected to denudation, the gradient of the rivers being sufficient to transport the bulk of the resulting detritus to the seashore. As the transporting power of the rivers is checked on their entering the sea, pebbles and gravelly detritus formerly rolled along their beds will be deposited. Along-shore and tidal currents distribute the material right or left, and storms pile it up as beaches, where it often becomes mixed with other coarse material resulting from the direct erosion of the land by the sea. The pounding of the waves completes the rounding of the constituents already begun by the rivers, and a belt of shingle extending from above high-water mark to varying depths, often below low-water mark, is the result.

Beyond the shingle belt, the river carries its sand, which in turn settles down when the velocity of the stream falls to a few millimetres per second. In due time the sand is distributed as a seaward belt fringing and interdigitating with the shingle. Similarly a band of silt is deposited, and lastly, the finest portion of the burden, the mud, sinks to the bottom. It was formerly considered that the last constituent, the mud or clayey material, was laid down only when the water was practically still, and that its deposition therefore indicated fairly deep water well below the influence of waves or shore currents. On the contrary, deposition of mud, resulting as it does from the flocculation of the river-borne clay particles by the dissolved salts in sea-water,* proceeds *pari passu* with the deposition of sand and silt or even fine shingle. For this reason, the majority of sediments, both ancient and modern, are of mixed " grade " and carry more or less clayey and silty material. Perfection of grading (that is, the attainment of perfect evenness of size) is a true phenomenon and is rarely met with in geological strata or present-day sediments. Only by the long-continued action of wind and water currents, particularly wind, are clastic materials sorted effectively.

In Fig. 1, representing ideal conditions, *a*, *b*, *c*, and *d* indicate in section the belts of shingle, sand, silt and mud respectively. It is instructive to consider the effect on their distribution of earth-movements such as are continually in progress. Omitting from present consideration the change in the proportion of the various river-borne constituents resulting from increased or diminished denudation due to the consequential greater or less elevation of the country (see p. 10), it is evident that upon subsidence of the area, a corresponding series of deposits will be laid down upon the new sea-bed represented by XX. In consequence of the creep of the sea over the land, each belt of detritus a', b', c', and d' will occur slightly landward of the corresponding one below, and not exactly vertically over it. A continuation of the subsidence will result in a further series a'', b'', c'', and d'' occupying the position indicated. If the movement has been gradual and not intermittent, the planes XX, YY, which are true time-planes, may be obliterated, and the fact that the deposits *a*, *b*, *c*, and *d*, or a', b', c', and d', are contemporaneous, may not be obvious.

Subsequent elevation and possibly denudation may result in such a series of rocks forming the surface of the land. In the event of *a*, *b*, *c*, and *d* not containing fossils, or, what provides equal difficulty, containing different fossil forms as a

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* River-water containing salts of calcium and magnesium in solution also flocculates mud and causes its deposition.

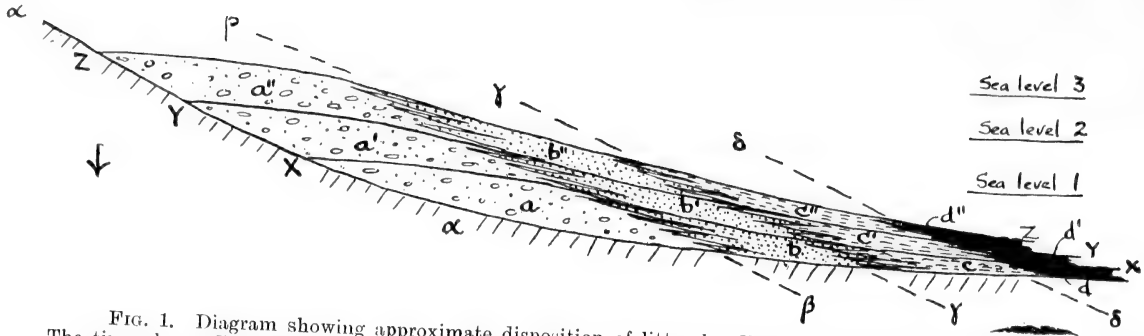

FIG. 1. Diagram showing approximate disposition of littoral sediments on a subsiding sea-bottom. The time-planes *ZZ*, *YY*, *XX* will be strongly marked only if there are pauses in sedimentation. The planes *αα*, *ββ*, *γγ*, etc., mark off lithological divisions from one another, and may, when the sediments are consolidated, be mistaken for bedding-planes. The steeper the shore-line, the greater will be the discordance between the time-planes and the lithological-planes.

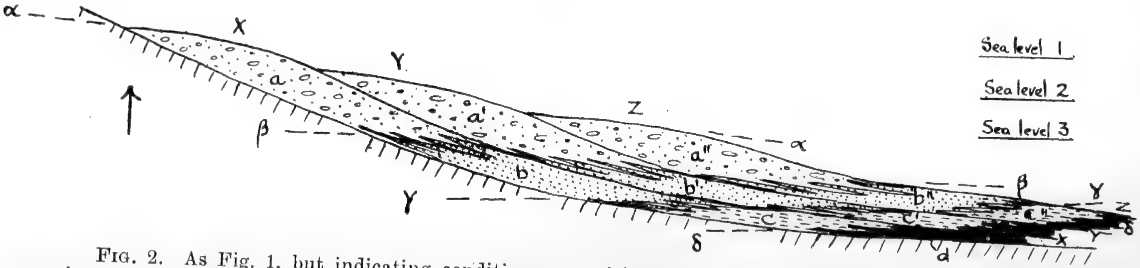

FIG. 2. As Fig. 1, but indicating conditions on a rising sea-bottom. The deposits *a*, *b*, *c*, *d* are again contemporaneous, as are also *a*ꞌ, *b*ꞌ, *c*ꞌ, *d*ꞌ, etc. The planes *XX*, *YY*, *ZZ* are true time-planes, and *αα*, *ββ*, *γγ*, *δδ* mark off lithological divisions, and may be interpreted later as "bedding-planes."

result of differing environment, a strong tendency will exist for a, a', a'', etc., to be grouped together on account of lithological similarity. Such an occurrence is almost inevitable if the deposits are in due course mapped geologically, for the time-planes XX, YY are difficult to follow, and the planes $\alpha\alpha$, $\beta\beta$ become more strongly developed because of the variation in lithology above and below them; they are, in fact, the stratigraphical planes or bedding-planes as commonly known, planes which are usually and tacitly assumed to be true time-planes, but which actually cut across the latter. Only under exceptional conditions of fossil preservation, and then by accurate and detailed zonal study alone, can the true contemporaneity of deposits be determined.

The complementary case of a rising shore is represented ideally in Fig. 2, where the deposits are seen to be thrown successively seawards as elevation occurs. Again the lithological planes $\alpha\alpha$, $\beta\beta$ cut across the true time-planes XX, YY, and the deposits a, b, c, and d, and a', b', c', and d', are respectively contemporaneous. After subsidence, " interformational conglomerates," such as that bounded by $\alpha\alpha$ and $\beta\beta$, may be formed.

In plan, the effects of this discordance between the two sets of planes would appear as Fig. 3, where the letters have the same significance as in Figs. 1 and 2. Since topography, drainage, soil, and vegetation are largely dependent upon the lithological character of the underlying rocks, the lines representing the traces of the planes $\beta\beta$, $\gamma\gamma$ would probably be mapped as the " boundaries " of the " formation." The time-planes, revealed by the contained fossils, would run obliquely through the " formation " as XX, YY, etc. (the broken lines). Nevertheless, the planes $\beta\beta$, $\gamma\gamma$ are actually parallel to the shore-line, whilst XX, YY are not.

From Figs. 1 and 2, it is evident that the steeper the shore, the greater will be the discordance between $\alpha\alpha$, $\beta\beta$, $\gamma\gamma$, etc., and XX, YY, ZZ, etc. The shallower and flatter the bottom, the more nearly are the two sets of planes coincident, but they can never coincide whilst dry land and sea both exist in proximity. If, therefore, we are able to discover in the outcrops of strata the degree of discordance, we obtain evidence of the character of the earth-movement at the time of deposition.

If the subsidence is rapid, the landward shifting of a', a'' and b', b'' in relation to each other and to a, b is respectively greater and they will become much attenuated, partly as a result of the greater area over which a given quantity of débris will be spread, and partly owing to the decreased erosion due to the lowering of the land. The more rapid the subsidence the more obvious will be the phenomenon of overlap, and the greater the amount of transgression. The existence of overlap when the downward movement is gentle and continuous is not necessarily shown by lithology, but may be revealed by the organic remains if the conditions were suitable for development and preservation of life.

Rapid elevation will clearly give rise to penecontemporaneous erosion of the series of deposits formed when the land stood at a lower level, and the new series of deposits may contain rolled fragments derived from the older series. The plane of junction between the series a, b, c, d, and a', b', c', d' may appear only as an ordinary bedding-plane, although it is actually of the nature of a disconformity. As in the case of rapid subsidence, the result upon the outcrop will be discontinuity of particular lithological phases. But in all probability the most noteworthy result of the elevation will be the sudden increase in the quantity of detritus due to the activity of the agencies of denudation upon the elevated land. The rapidity of the movement will prevent the coarser materials from being either well-graded or well-rounded. Evidence of penecontemporaneous erosion may well be obscured in the abundance of new sediment. If the elevation be gentle, the increase of sedimentation will be gradual, and the phenomena of penecontemporaneous erosion and seaward thickening will be more evident.

The sequence of sediments considered above is an ideal one and can arise only where gravelly, sandy, and clayey detritus together with dissolved material is brought down from the land. At the present day extensive areas of igneous rocks form but a small portion of the land-masses of continents, and the greater part of the continental margins is composed of ancient sediments which have, in the normal course of events, been differentiated more or less effectively into the lithological series discussed above. Offshore deposits derived from such sediments will necessarily vary according to the constitution of their parent material. Clay may thus form the littoral belt entirely, or it may even lie on the landward side of a sand-belt. It is probable that the character of the local land-mass determines more than any other factor the distribution of the sediments in the offshore belt, or even of those beyond it.

If the above theoretical considerations may be adopted, we should expect to find some evidence, among the extraordinary variety of rocks in Britain, of such occurrences in the geological past. For obvious reasons, examples may not be numerous—evidence may not be preserved, or investigation may not yet have been carried out in sufficient detail. Attention may, however, be drawn to certain notable cases.

The crossing of the time-planes by the lithological planes is well illustrated by the series of fossiliferous sands occupying the uppermost portion of the Lias and the lowermost of the Inferior Oolite in the West of England. The sands extend from the Dorset coast to the Cotteswolds and have been variously termed Bridport Sands, Yeovil Sands, Midford Sands, Cotteswold Sands, etc., after the localities at which they occur.

The careful zonal work of Mr. S. S. Buckman* has shown that their age varies from place to place, for they yield an ammonite fauna in which many sub-divisions can be recognized. The Lias, generally speaking, is a clay-formation, and the Inferior Oolite consists chiefly of limestones. In the area considered, a shallower phase characterised by the deposition of calcareous sands set in towards the end of Liassic times and continued throughout part of Inferior Oolite times. But this phase of shallowing and deposition of detrital sandy material passed as a wave southwards, maintaining a peculiar, unusual, and easily recognizable lithology and petrography. The similarity in grade and mineral composition of the sands from Bridport to the Cotteswolds is indeed extraordinary. Expressed diagrammatically, the sands appear in plan as in Fig. 3,

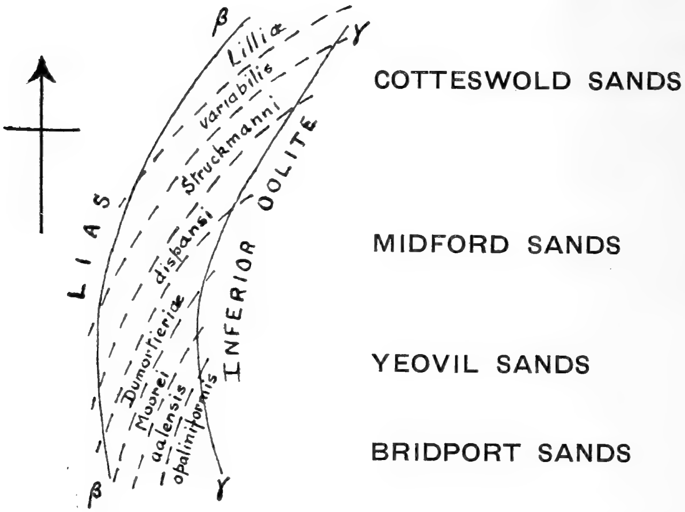

FIG. 3. Diagrammatic representation of the time-planes in the Lias-Inferior Oolite Sands, from the Dorset Coast to the Cotteswolds.

where the belt *aa*, *ββ* is the lithological deposit as it is mapped.

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* *Quart. Journ. Geol. Soc.*, Vol. 45 (1889), p. 440, and Vol. 66 (1910), p. 52.

The time-planes cross it as shown, the hemeræ* named after the various ammonites which characterise the horizons being indicated in the diagram. The portions of each sand-belt between a pair of dotted lines may be taken as practically contemporaneous.

The conditions thus indicate a gently rising and tilted shore-line, beginning as a shallow sea in the Cotteswold district whilst the area of Dorset was submerged under deeper water, and becoming progressively shallow over the belt towards what is now the English Channel.

The transgression of a lithological phase across time divisions marked by definite faunal assemblages may be illustrated by another of the many examples from the stratigraphy of Britain. Professor E. J. Garwood, in his description of the Carboniferous Limestone of the N.W. of England,† has discussed the evidence for the incoming of shallow-water conditions during the formation of the zones of *Michelinia* and *Productus corrugato-hemisphericus* in the district between Shap and Ravenstonedale. Coral-bearing limestones, indicative of clear-water conditions, give place to a sandy type of sedimentation which begins at the base of *Michelinia*-zone at Shap, and transgresses several faunal horizons in a southerly direction until at Ravenstonedale it appears only at the middle of the sub-zone of *P. corrugato-hemisphericus*, 100 feet above the base. The sandy conditions also persisted to a later date (i.e., to a higher horizon) in the former district. The actual thickness of sandy sediment is, however, greater in the south (Ravenstonedale) than in the north (Shap), despite the fact that it occupied less geological time in accumulation as measured by the faunal horizons.

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* The term " hemera " was introduced by S. S. Buckman (1893) : " to mark the acme of development of one or more species. It is designed as a chronological division . . ." (*Q.J.G.S.*, Vol. 49, p. 481.) The term " zone " is strictly a stratigraphical one.

† *Quart. Journ. Geol. Soc.*, Vol. 78 (1912), p. 449.

The effect of gentle subsidence of the shore has been shown to be the lapping of successive members of a rock-series over one another, each thus encroaching on the land area. Overlap of this type is found in the buried Mesozoic rocks under the Wealden area, where the Lias extends beyond and unconformably covers the Trias, and is in turn overlapped by the Bathonian (and possibly the Bajocian) which creeps up over the ancient and eroded surface of Coal Measures. Overlaps of the Purbeck rocks by the Wealden, and of the Wealden by the Lower Greensand also occur. In these examples, the subsidence appears to have been fairly gentle, although there is evidence of elevation and erosion at many levels, and the successive members of the Jurassic maintain approximately the characters they bear in the north-east of France where some of them crop out. Each also extends only a short distance beyond its underlying deposit, and little overstepping of the Palaeozoic rocks occurs.

Somewhat different is the case of the great overlap which began with the Gault, continued with the Upper Greensand, and culminated in the great spread of the Lower Chalk sea, termed "the Cenomanian Transgression." The Gault and Upper Greensand (Selbornian) sea, extending beyond the limits of the Lower Cretaceous, Jurassic, Triassic, and other rocks, washed the shores of the old Palaeozoic land now underlying the east of England. The Upper Greensand sea swept rapidly westward forming a plane of marine denudation and transgressing the various divisions of the secondary strata until it deposited its sands and gravels upon the Palaeozoic rocks of the west (Haldon Hills, Devon). The Cenomanian sea marked an even greater subsidence, which carried it beyond the north of Ireland and north-west of Scotland. The deposits of Greensand and Chalk (both of Cenomanian age) rest upon Jurassic rocks in these areas, and whilst denudation may have since removed them in part, they probably indicate by their outcrops the relative rapidity of the subsidence. It is likely, however, that the eastern area of Palaeozoic rocks subsided even more rapidly, so that it was speedily overstepped by a covering of Gault, Greensand, and Chalk.

The purity of the Upper and Middle Chalk and its freedom from terrigenous matter is doubtless related to the low altitude of the Cretaceous land-surface and the distance from large rivers or from those with other than a gentle gradient. These conditions followed naturally from the rapid and widespread depression in Cenomanian times.

In the earlier portion of this paper (p. 9 and Fig. 2), an "interformational conglomerate" was demonstrated as being produced during elevation and subsequent subsidence of the land. Such oscillatory action seems to have been connected with the formation of the Blackheath Pebble-beds in Eocene times. The extraordinarily wide area covered by this deposit of rounded flint pebbles (derived obviously from the flints of the Chalk) and its even thickness preclude the possibility of the whole deposit being contemporaneous. It is doubtless a lithological phase traversed by time-planes, but the absence of fossils of determinative character makes proof impossible. The overlap of the Thanet Beds by the Woolwich and Reading Beds, and of the latter by Blackheath Beds, which rest directly on the Chalk near its escarpment in Kent and Surrey, indicates an initial subsidence of the area; but the pebble-beds are essentially shallow-water deposits, and their wide extension from the Chalk, back over the Woolwich and Reading Beds in turn, indicates a gradual subsequent elevation, accompanied in all probability by penecontemporaneous erosion.

The existence of similar spreads of pebbly deposits is in itself evidence of instability. The Bunter pebble-beds of the Trias and the Old Red Sandstone conglomerates may be cited, although these deposits may be of the nature of intermontane detrital accumulations rather than interformational conglomerates.

A striking example of the relatively rapid elevation of a shore-line is furnished by the East Anglian Crag deposits (Pliocene). The Coralline Crag is indicative of deeper-water conditions than those of the overlying Red Crag. The Red Crag consists of shelly sands, obviously drifted into position in shallow bays which may have been partly land-locked. Judged by the fauna, the oldest Red Crag occurs around Walton-on-the-Naze in Essex, and the deposits become successively newer as we travel northwards into the area of the Norwich Crag. Mr. F. W. Harmer* has divided the Red and Norwich Crags into a series of zones. Whether the term " zone " can be justifiably applied to the divisions is a matter of no import, for there are certainly different faunal horizons. But the Red and Norwich Crag zones succeed one another northwards, and never overlie one another. In short, the elevation was sufficiently rapid to give rise to the conditions indicated in Fig. 2. It was pointed out on p. 10 that an accompanying phenomenon of rapid upheaval was penecontemporaneous erosion of the older and elevated members of the sedimentary series. The Crags provide an example of this, for broken and water-worn shells from the older Red Crag deposits occur in the newer zones.†

Environment.—It is well-known that the fossil remains found in sediments vary considerably in abundance and in character, probably as a result of the influence of the environment upon the organisms. So far as we know at present, the evidence of environment retained in clastic rocks is generally as detailed in the following paragraphs. Deductions regarding the environments of ancient times depend upon the fundamental principle of geology already enunciated, namely, that the present is the key to the past.‡ That we are only in the early

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* *Quart. Journ. Geol. Soc.*, Vol. 56 (1900), p. 705.

† P. G. H. Boswell. *Proc. Geol. Assoc.*, Vol. 24 (1913), p. 330.

‡ For a comparison of ancient climates and past conditions of sedimentation with those of the present day see Professor W. W. Watts, *Pres. Address Geol. Soc.*, Vol. 67 (1911).

stages of the interpretation of past conditions seems to be proved by the recent work of the American geologists, both on the ancient strata and on the special characteristics of formations being built up at the present time. When the study of modern sediments, aqueous and continental, has become more intensive, we shall doubtless be able to discover criteria at present unrecognized in the rocks of various ages, and to form in consequence more exact ideas as to the mode of origin, climate, and rainfall, relation to shore-lines and so forth.*

Indications of the environment at the time of formation of rocks may be yielded along the following lines :—

(1) *The Medium.* Air or water, as indicated by the fossils themselves.

(2) *Depth of Water*, as shown by the lithology of the deposit and the character of its fauna. Considerations of light and motion also arise here.

(3) *Climate* (by comparison with the present day), as indicated by (*a*) organisms, (*b*) lithology and petrology of the rock. Deposits laid down under glacial, temperate, sub-tropical and tropical conditions, in deserts or derived from deserts, and under the effects of heavy rainfall, each bear well-marked characteristics by which they can be recognized. These characteristics may be physical, as in the formation of dreikanter and rounded grains under desert conditions, and of striated and far-travelled rocks as a result of glacial action; or they may be chemical, as in the differing degree and nature of alteration of the constituent minerals of deposits formed by glacial action, under arid conditions or those of moist heat.†

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* Since the above was written, many papers read at a symposium on sedimentation by T. W. Vaughan, C. Schuchert, H. E. Merwin, E. W. Shaw, and others, have been published in the *Bull. Amer. Geol. Scc.*, Vol. 31 (1920), p. 401.

† See, for example, Barrell, J., "Relations between Climate and Terrestrial Deposits," *Journ. of Geology*, Vol. 16 (1908), p. 159, and "The Climatic Factor as illustrated in Arid America," by Ellsworth Huntington, with a contribution by C. Schuchert on "Climates of Geological Time," Publication 192, Carnegie Institution, Washington, 1914.

Not only do geological deposits yield evidence of ancient climates, but palæo-meteorological indications are sometimes obtained. An interesting case is provided by the veritable cemetery of Pliocene whales, sharks, etc., which occurs on the Belgian coast and has been described by M. Van den Broeck. According to Mr. F. W. Harmer* these cetaceans and fish were drifted by the north-westerly gales prevailing in Pliocene times into land-locked bays on the eastern shores of the ancient "North Sea," and were unable to escape; hence the enormous accumulation of vertebrate skeletons in the deposits there.

Similarly, the extensive growth of the roots of Coal Measure trees on one side, and their relatively slight growth towards the other in the Upper Carboniferous has been quoted as evidence of the direction of prevalent gales in those early days.

(4) *Salt-, brackish- or fresh-water.* At present the best evidence of these conditions is provided by the fossils themselves, having regard to their similarity or otherwise to modern marine, estuarine or fresh-water forms. But attempts are being made to apply other lithological criteria to the deposits in order that deductions may be made in the absence of fossils.

Although the ocean has become progressively more and more salt throughout geological ages, and is assumed to have originated, presumably as a saltless hydrosphere, about 100 million years ago,† it is noteworthy that in the Devonian period there lived a pelecypod *Archanodon*, so markedly similar to the freshwater mussel of to-day that there is little doubt but that its habitat was fresh-water; under other conditions, *Cardiola*, *Murchisonia*, *Nucula*, *Pleurotomaria*, and other gastropods, are found, bearing general characters similar to

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* *Proc. Geol. Assoc.*, Vol. 17 (1902), p. 421.

† For a summary of the evidence and deductions relating to this matter, see F. W. Clarke, "Data of Geochemistry," *Bull.* 695 (1920), U.S. Geol. Survey. But on the evidence of the accumulation of helium and lead in rocks bearing radio-active minerals, the Devonian is stated to have been formed about 380 million years ago.

living marine mollusca. In the Carboniferous Period which followed, deposits have been styled fresh-water or marine according to the characters of their mollusca, and it is evident that at least in these periods, if not earlier, the mollusca had adapted themselves to a fresh-water or a marine environment.

(5) *Palæogeographical conditions.* Much light may be thrown upon the ancient geography of the period by a study of the derived fragments and minerals in rocks, and by the variation in size and proportion of the constituents. The petrological character of the adjoining land-area, its relative altitude, and the presence or absence of large trunk rivers, may often be adduced from the character of the sediments. Ancient deltas have thus been traced. Judging from the evidence obtained by the "Challenger" expedition on the formation of glauconite, the presence of that mineral in rocks is presumptive evidence of oscillatory marine conditions, on the continental edge of great ocean basins where currents of different temperature or salinity mingle, and possibly near the mouths of rivers bringing little suspended matter into the ocean, but a considerable quantity of dissolved salts. The existence and direction of beneficial food-bearing or inimical mud-bearing currents may also be indicated.

(6) *Diastrophism.* The evidence yielded by sediments of secular movements of the earth's crust, slow or fast, was considered in some of its aspects in the earlier part of this address. The enormously-increased denudation consequent upon considerable elevation is reflected in the vast accumulations of the Flysch and Mollasse which fringe the Alps and represent the wreckage of a great thickness of that mighty mountain mass after the earlier stages of its uplift. On the other hand, the depression of the British area which gave rise to the great Cenomanian transgression was followed by the formation of the Chalk in a basin which subsided at least 1,000 feet during its deposition. The remarkably purity of

the Chalk, and its freedom from any quantity of terrigenous sediment can best be explained (in view of the fact that it contains shallow-water forms of life, and was bordered by land as close as N.W. Scotland and Ireland, the Harz Mountains, Scandinavia, and a belt which separated it in part from the *Hippurite*-sea of Southern France, the Alps, and Central Europe) by postulating a relatively low level and condition of peneplanation of the land, and distance from large rivers bringing terrigenous sediment.

Not only may gentle movements leave their mark upon the rocks, but earthquakes yield records which have of late been recognized more widely in ancient sediments than hitherto. Professor P. F. Kendall has adduced evidence of earthquake disturbances during the Coal Measure Period, many of the features of present-day earthquakes, such as rifts, fissures, undulations, ridges, hollows, pipes, "sand-blows," and over-riding having been found.* Similarly, the marvellous accumulation in the Old Red Sandstone of the distorted remains of innumerable fish may be evidence of earthquake shocks, submarine or terrestrial, such as those that to-day kill off large quantities of fish, the bodies of which are found floating on the surface. The Old Red Sandstone was deposited during a period renowned for its mountain-building movements with accompanying volcanic outbursts. Sir A. Geikie has suggested that mephitic vapours poured out by the volcanoes were the cause of the high death-rate and the large accumulation of fish remains.

(7) *The existence of other classes of organisms.* Often it is possible to adduce from the strata evidence as to the conditions of food-supply, the struggle for existence, and the reasons for the survival of certain families of organisms. Thus, the supposition as to a relationship between the decline of the trilobites, and the rise of the ganoid fishes, receives strong

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* *Proc. Geol. Soc.*, No. 1031, (1919), p. 28.

support when trilobites have been found in the stomachs of fossil fishes, and we are thereby tempted to trace a causal connexion.

In the matter of the broader aspects of evolution, it was suggested by J. Starkie Gardner* that the expansion, migration, and consequent evolution of the ruminants waited upon the rise of the grasses, and only when the latter became widespread in Eocene and Oligocene times was the food-supply of these animals ensured and migration and expansion of the stock possible. Again, Professor E. W. Berry, in a suggestive paper on "The Evolution of the Flowering Plants and Warm-blooded Animals," recently published,† has put forward tentative views to the effect that the rise of the birds was dependent upon the production of a food-supply in the shape of the fruits of the flowering plants, and thus followed that stage in the evolution of plants. He also suggests that the differentiation of the Eocene mammals was possible only because of the food value of such fruits, and, noting the concentration of energy in grain, points out that human development was not possible without it.

In his recently-published monograph on "The Environment of Vertebrate Life in the Late Palæozoic in North America,"‡ Professor E. C. Case describes the change which took place in the fauna from the long period of slow evolution in the singularly monotonous environment of the marine Pennsylvanian to the rapid evolution in the diversified environment of the Permo-Carboniferous. He regards the sudden expansion as due to climatic change accompanied by physiographic changes which led to an alteration in the level of the continent. He points out that in land life adapted to arid climatic phases we should expect to find a greater activity

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* *Proc. Geol. Assoc.*, Vol. 9, (1885-6) p. 448.

† *Amer. Journ. Science*, Series 4, Vol. 49, p. 207 (1920).

‡ Carnegie Institution Publications, No. 283 (1919).

and higher development, with special adaptation to resist violent changes of temperature, etc.

In his opening address to Section C (Geology) at the British Association, Cardiff, 1920, Dr. F. A. Bather quotes Professor Abel as maintaining that the varying " tempo " of evolution in the case of the sirenians and horses of the Tertiary can be correlated with the food-supply. The sirenians underwent a steady, slow change because although they migrated from land to sea, they retained the habit of feeding on soft water-plants. Horses, though remaining on land, evolved at first rapidly, and then more slowly, but up to Pliocene times always more quickly than the sirenians. Such evolution might be correlated with their change into eaters of grain, and their adaptation to a life on the plains where food of this character was available. The whales, like the sirenians, migrated at the beginning of Tertiary time from the land to the sea. But their rate of evolution was altogether different, hence very diverse forms resulted. At first they remained near the coasts, and kept to the ancestral diet, with consequent slow change. Then they took to hunting fish, and afterwards to eating cephalopods ; from Oligocene times onward the change was thus very rapid, and a great burst in evolution in Miocene times resulted. Finally, many turned to minute floating organisms as food, and from Lower Pliocene times to the present day the change has been very slow.

Dr. Bather rightly emphasizes the fact that any attempts to frame a causal connexion are bound to be speculative.

Numerous cases can be quoted from the geological record of the gradual changes in a fauna resulting from a gradually-changing environment. Two parallel examples may be mentioned of the effect produced on molluscan life by a gradual elevation of the sea-bed sufficient to cut off arms of the sea and produce lakes which continued to shrink. In the first example, the Permian inland seas, now represented by the dolomitic limestones and gypsum beds of N.E. England, show a fauna which bears affinities with that of the preceding period, the Carboniferous, but as a whole becomes impoverished in species and rarer in individuals. At the same time, distorted and dwarfed forms slowly appear—apparently as a result of the concentration of sea-salts which were eventually thrown out of solution upon the lake bottom as a result of evaporation.

In another example, the isolation of the great lakes, such as Tanganyika, and others, in Africa, resulted in gradually shrinking lakes throughout the Miocene period to the present day. The institution, however, of partial internal drainage systems into the lakes, together with tropical floods (in contradistinction to the aridity of the Permian), has led to the gradual sweetening of the waters. The fresh-water genera of mollusca with marine affinities, such as *Paramelania* and others, are typical of the peculiar fauna of the lake, a fauna which, although of Mid-Tertiary age, contains forms bearing resemblances to certain Jurassic fossils.

In other instances we are able to note the dying out or migration of species with changing climate. The gradual oncoming of the Glacial Period in Western Europe was heralded by the southward migration of a flood of northern mollusca, such as *Cardium grœnlandicum*, *Neptunea antiqua*, *Natica clausa*, *N. helicoides*, *Pecten* (*Chlamys*) *islandicus*, *Tellina prætenuis*, and others, into the area of northern Essex, and the consequent movement of the warmth-loving mollusca southward out of the British area.

Evolution.—Many of the organisms that occur as fossils can be grouped into series showing gradual transition from species to species and even genus to genus. Indeed, it has with truth been asserted that wherever the geological strata yield a complete record, transition or continuous development can be traced. Such transitions can be ascribed only to the effects of environment. Several lineages ("species series"), which are single genetic lines, have now been carefully worked out. It cannot be said that in the present state of knowledge the evolution of lineages can be definitely correlated with changing environment as indicated by the sediments containing them. Certain cases (e.g., the Micrasters of the Chalk* or the Ammonites of the Lias) show an evolution unaccompanied by any apparent change in sedimentation or, so far as we can judge, of the environment that would be reflected in the character of the sediment.†

But in such cases where lineages show progressive change in their constituent forms, and the sediments containing them an apparent constancy of environmental factors, we cannot yet assume that evolution has proceeded independently of environment.‡ Alternatively, we must face the fact that our knowledge of sediments, particularly of those characters which should be indexes of environmental change, is far from sufficient. Our obvious course is to study more intensively the conditions of sedimentation at the present day, and to apply the results of such work to the rocks of the past.

In the present state of knowledge it would almost seem that on the whole the environmental causes leading to minor changes in development have left their record in the sediments, but that the greater changes and the evolution of lineages cannot be correlated with known variations in lithology.

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* A. W. Rowe, *Quart. Journ. Geol. Soc.*, Vol. 55 (1899), p. 494.

† Mr. S. S. Buckman, in his "Inferior Oolite Ammonites" (*Monogr. Pal. Soc., Supplement*, p. xv. (1898), wrote: "It is a great mistake to suppose that Ammonites were influenced by the character of the deposit, though this error has been so widely taught that nearly every writer, myself included, has argued as if it were a fact. When Dorset, Somerset, and Gloucestershire are compared, it will be found that the same species lived when the deposit was argillaceous, arenaceous, or calcareous, and flourished equally well. Notably is this the case when the Middle Lias of Dorset and of Somerset are compared; or the Lias-Oolite deposits of Dorset, Somerset, and Gloucestershire, and these again with the Continent."

‡ In the case of organisms such as ammonites, evolution may have taken place elsewhere, and migration have brought them into the position in which they are now found.

Much light was thrown upon the deposits of ancient times by the results of the "Challenger" Expedition in 1873-76, albeit the work was confined very largely to deep-sea deposits. From the geological as well as the biological, chemical, and physical standpoints, the benefits which are likely to accrue from a new "Challenger" Expedition, such as that suggested recently by the President of the British Association for the Advancement of Science,* cannot be over-estimated. Apart from the storehouse of new facts in nature always ready to be drawn upon, we now realise more clearly than in 1872 what problems require elucidation and what fields lack exploration.

Our knowledge, for example, of the terrigenous belt which fringes the continents is inadequate, and seems to be relatively less than that of the depths of the oceans. Nevertheless, most of the fossiliferous strata, which it is our duty and pleasure to study, were actually deposited as ancient terrigenous belts.† We need more exact information regarding the exact conditions of sedimentation to-day, and their influence upon plant and animal life. Even the terminology of the subject cannot be regarded as adequate or settled.‡ Few or no accurate and quantitative descriptions of modern sediments exist.§

It may therefore be an advantage if tentative suggestions are here put forward regarding points upon which a new "Challenger" Expedition might throw much light, and about which our present knowledge is insufficient. A re-examination

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* Herdman, Professor W. A., Pres. Address, *Rept. Brit. Assoc.*, Cardiff, 1920 (1921).

† Compare for example, Professor W. W. Watts, Pres. Address, *Geol. Soc.*, 1911, p. lxxvi.

‡ For example, Professor W. A. Herdman suggested in 1895 the term "neritic" to include those shallow-water, detrital deposits full of organic remains, deposits which do not find a place in Murray's "Challenger" scheme.

§ In the "Challenger" reports, deposits of various-sized grains are termed indiscriminately "sands" or "muds." The only quantitative work which seems to have been accomplished is that by Dr. Sven Oden recently on the mechanical composition of Globigerina Ooze, Radiolarian Ooze, and Red Clay collected on the expedition. See *Proc. Roy. Soc.*, Edinburgh, Vol. 36 (1916), p. 219.

of much of the geological material collected on the former expedition would doubtless yield valuable results, but there can be no question as to the advantage of collecting material more systematically and fully (so far as terrigenous deposits are concerned), and noting as far as possible the exact conditions of accumulation.

The following suggestions are not intended to be exhaustive; they are rather those which occur to one interested particularly in the petrology of sediments :—

GEOLOGICAL INVESTIGATIONS WHICH IT IS DESIRABLE THAT A NEW "CHALLENGER" EXPEDITION SHOULD UNDERTAKE.

1. A more comprehensive and detailed scheme of classification of deposits, especially the terrigenous group.
2. The description of all deposits, so far as possible, on a quantitative basis, i.e., by mechanical analyses, with a terminology founded on such a basis. The full determination, qualitatively and quantitatively, by modern petrological methods of the mineral constituents of sediments.
3. Investigation of the methods of mechanical precipitation of sediments in sea-water, and the effect on size of grain or aggregate of the salinity (including lime-contents, etc.) and temperature (upon which the viscosity of the water depends).
4. The relation of the sediment (grain-size and general chemical character) to the depth of water in which laid down; the consideration of what is the deepest water indicated by any particular type of sediment, as bearing upon the question of permanence or instability of the continents and oceans, and on the origin of certain rocks.
5. Further investigation of the effects of chemical precipitation or replacement of deposits under varying conditions

of depth, i.e., under varying pressure and temperature in sea-water, and of varying content of silica, calcium, magnesium, and carbon dioxide ; and on the formation of dolomite,* colloidal silica (e.g., flint), etc.

6. Precipitation through such organic agency as that of bacteria, as suggested in the case of limestones.† (In this connexion, the present-day analogue of the Chalk cannot be regarded as globigerina ooze).
7. The relation of the character of sediments to rising and sinking adjacent land areas from which they are derived ; the criteria in each case—mechanical, mineral, and chemical ; the effect on organisms ; the composition of the sea-water in each case.
8. Further investigation of coral-reef formation. Evidence of upheaval or submergence provided by the relief of islands and the form of the coast-line.
9. The petrological character and possible origin of the boulders on the sea-bottom—especially in the case of the various " narrow " seas.‡
10. The possibilities of deep-sea boring, by Joly's or other apparatus, and the bearing of the evidence yielded on Recent and Tertiary geological history and climatic conditions, and on the question of the permanence of the oceans.§

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* See Watts, Professor W. W., in discussion upon Professor E. W. Skeats's paper. *Q.J.G.S.*, Vol. 61 (1905), p. 141.

† G. H. Drew " On the Precipitation of Calcium Carbonate in the Sea by Marine Bacteria, etc." Publication No. 182, Carnegie Institution, Washington, 1914.

‡ See Peach, B. N., *Proc. Roy. Soc.*, Edinburgh, Vol. 32 (1912), p. 262. Cole, Professor G. A. T., and Crook, T., *Mem. Geol. Surv.*, Ireland, " Rock-Specimens dredged from the Floor of the Atlantic " (1910). Herdman, Professor W. A., and Lomas, J., 7th, 8th, 9th, 12th Ann. Reports, Liverpool Marine Biol. Committee, 1894-5-6 and 8. Also *Proc. Liv. Geol. Soc.*, Vol. 8 (1898), p. 205.

§ On deep-sea boring apparatus, by which it is considered that a depth of several feet might be bored in the sea-floor, see Joly, Professor J., *Sci. Proc. Roy. Dublin Soc.*, New Series, Vol. 8 (1897), p. 509, and Vol. 14 (1914), p. 256. Also Evans, J. W., *Rept. Brit. Assoc.*, Bournemouth, 1919 (1920), p. 179.

11. Investigation of the petrology of sediments in relation to neighbouring land-masses, temperature of water, etc. Distribution of minerals from volcanic rocks. The stability of minerals.
12. Determination in sediments of allothigenous (primary) and authigenous (secondary) minerals. The two generations of minerals as indicated by size. The formation of glauconite.
13. The landing of parties on such islands or places on the mainland difficult of access (e.g., the island of Rockall), and collection of specimens.
14. Considerations of the habitat and migration of organisms. The possible evidence of environment yielded by sediments. Relation to lime and other contents of sea-water (lime-secreting habit, etc.).

The rocks of the earth's crust and their organic remains present problems that may be attacked by biologists and geologists from very different points of view. Both would doubtless now agree with Huxley in his dictum that " The primary and direct evidence in favour of evolution can be furnished only by palæontology. The geological record, so soon as it approaches completeness, must, when properly questioned, yield either an affirmative or a negative answer : if evolution has taken place, there will its mark be left ; if it has not taken place, there will lie its refutation."

But in the study of sedimentation, of past environments, and of the evolution of organisms, there is more than this. Suess, in " Das Antlitz der Erde," has summarized the wider conception in the striking sentences which follow. " It is the organic remains, no doubt, which afford us our first and most important aid in the elucidation of the past. But the goal of investigation must still remain in the recognition of those great physical changes in comparison with which the changes in the organic world appear only as phenomena of the second order, as simple consequences."

THE

MARINE BIOLOGICAL STATION AT PORT ERIN

BEING THE

THIRTY-FOURTH ANNUAL REPORT

DRAWN UP FOR THE

OCEANOGRAPHY DEPARTMENT OF THE UNIVERSITY OF LIVERPOOL.

By Professor W. A. Herdman, C.B.E., F.R.S.

The Port Erin Biological Station was transferred by the Liverpool Marine Biology Committee to the University of Liverpool on December 31st, 1919,* and from that date became the marine laboratory of the department of Oceanography. This change in responsibility and administration has, however, caused no change in the scientific work of the institution. Research workers and students are admitted on the same terms as before, and the series of Annual Reports and other publications will be issued in future by the University in continuation of those produced by the Committee. Professor James Johnstone, who is now (from October 1st, 1920) the Head of the department of Oceanography, has asked me to draw up the present Report, as the Port Erin establishment has been under my direction during the greater part of the past year. On account of this being a year of transition from the old dispensation to the new, when no general investigations of special note were undertaken, and also in order to effect such economy as is possible in printing, I have decided to report merely upon the usual statistics of the Biological Station, along with short summaries of some of the researches carried on by those working in the laboratory.

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*See last Annual Report, p. 3.

The increase in number both of those working at the Biological Station, and of those visiting the Aquarium, is remarkable. Last year (1919) we had 60 laboratory workers and over 23,000 visitors; this year, there were about 100 researchers and senior students, and nearly 36,000 visitors to the Aquarium. From Liverpool University we had Professors Dakin, Johnstone, Ramsden, Harvey-Gibson, and Herdman, Mrs. Bisbee, Mr. Burfield, Miss Knight, Miss Fry, and others; from Oxford, Professor B. Moore, Mr. E. Whitley, and their assistants; from Birmingham, Professor Gamble and students; from Manchester, Dr. and Mrs. Tattersall and students; from Reading, Professor Cole, Miss Eales, and a party of students; from Aberystwyth, Mr. Douglas Laurie and students; from Nottingham, Miss Bexon and students; Professor Stephenson from Lahore; and from Cambridge, Mr. H. H. Thomas, and a party of senior students from Newnham College.

The work of the staff at the Biological Station has been carried on as usual, and large collections of the plankton in the bay have been made throughout the year.

As on previous occasions the statistics as to the use made of the institution throughout the year will be given in the form of a "Curator's Report" (see below).

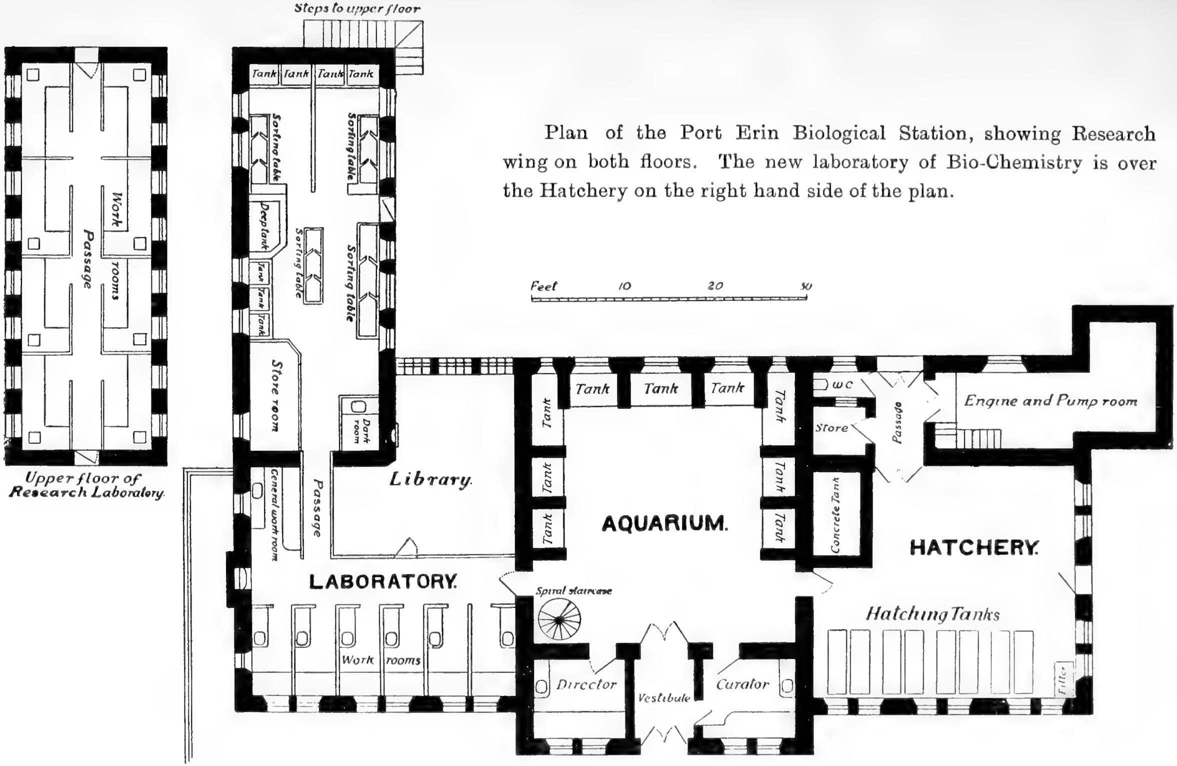
It may be useful to those proposing to work at the Biological Station that the ground plan of the buildings, showing the laboratory and other accommodation, should be inserted in this Report as on previous occasions (see p. 31).

Curator's Report.

Mr. Chadwick reports to me as follows on the various departments of the work at the Station during 1920:—

"Ninety-six workers occupied our laboratories during the past year, the majority being undergraduates from the departments of Zoology and Botany of the University of

Plan of the Port Erin Biological Station, showing Research wing on both floors. The new laboratory of Bio-Chemistry is over the Hatchery on the right hand side of the plan.



Liverpool. The Universities of Cambridge, Oxford, Birmingham and Manchester, and the University Colleges of Reading, Nottingham and Aberystwyth, were also represented by researchers and students.

"Miss Knight, of the department of Botany of the University of Liverpool, devoted the whole of July and September to research upon the life-histories of certain marine algæ. Professor B. Moore, with his son Mr. T. Moore, Mr. E. Whitley and Mr. T. A. Webster as coadjutors, continued his research into the seasonal variation in the alkalinity of sea-water, and was followed in the same line of research in August by Mr. E. N. Allott, of the department of Chemistry, University of Oxford. During the Easter vacation, Professor Harvey-Gibson, assisted by Miss Knight, was engaged in preparing drawings to show the diagnostic characters of the species of Algæ, for his forthcoming book on the subject. In April, and again in September, Mrs. Bisbee devoted herself to the physiology of Echinoderms, with special reference to the direction of the currents in the madreporites of starfishes and sea-urchins. During the Easter vacation, Miss C. Mayne continued her work on the animal ecology of Port Erin Bay, and Mr. G. F. Sleggs devoted some time to further work upon the common barnacle, *Balanus balanoides*.

"In addition to Professor Herdman's special plankton investigations carried on between March and September, the ordinary official bi-weekly tow-nettings were taken by the Assistant Curator throughout the year, with only very occasional interruptions due to unfavourable weather. General faunistic work was carried on vigorously by all our biologist workers, and amongst the large number of species collected were some exceptionally large specimens of *Lucernaria* sp., not previously recorded from Manx waters. These were found by Professor Dakin and others on the boulder-strewn beach of Bay-ny-Carrickey.

"Miss Catherine Herdman, during both the Easter and the Summer vacations, continued her investigation into the occurrence and the changes in the Amphidiniums and other Peridiniales in the sand of Port Erin beach, and succeeded in discovering several new forms, which were exhibited alive at the Cardiff meeting of the British Association.

List of Workers, 1920.

February 9*th and* 10*th.*
Miss M. Knight.

During the Easter vacation (*March and April*).
Miss M. Knight.
Professor Herdman.
Miss E. C. Herdman.
Professor J. Johnstone.
Professor Stephenson.
Professor R. J. Harvey-Gibson.
Miss P. Fry.
Mr. H. Hamshaw Thomas.
Professor B. Moore.
Mr. T. Moore.
Mr. E. Whitley.
Mr. T. A. Webster.
Miss D. Bexon.
Miss I. Bayliss.
Miss B. Cockshott.
Mr. H. A. Storey.
Miss G. Clegg.
Miss H. Good.
Miss Horrobin.
Professor W. J. Dakin.
Miss L. Thorpe.
Miss E. L. Gleave.
Mrs. Bisbee.
Miss M. E. Roper.
Miss M. A. Pocock.
Miss I. M. Allen.
Miss R. Hilton.
Mr. G. F. Sleggs.
Miss C. Mayne.
Miss M. Hobbins.
Professor Ramsden.
Professor F. J. Cole.
Miss N. B. Eales.
Miss D. R. Crofts
Miss E. Trewavas.
Miss N. F. Soyer.
Mr. A. S. Wright.
Professor Gamble.
Miss N. E. Boycott.
Miss O. M. Parsons.
Mr. J. G. H. Frew.
Mr. R. Douglas Laurie.
Mr. J. R. W. Jenkins.
Mr. E. A. Lewis.
Mr. E. E. Watkin.
Mr. R. A. Little.
Mr. W. M. Speight.
Mr. Burfield.
Miss N. Carter.
Miss G. F. Selwood.
Dr. W. M. Tattersall.
Mrs. Tattersall.
Mr. F. Neave.
Miss M. Bowen.
Miss M. A. Wilson.
Miss O. V. Jones.
Miss E. Lewis.
Miss G. E. Jeffcote.
Miss E. M. E. Gardner.
Miss D. Hanson.
Miss Hughes
Miss A. E. Chesters.
Miss Staidler.
Miss M. Simpson.
Miss D. Allen.
Miss K. M. Stoddart.
Miss Tregoning
Miss D. Hookins.
Miss M. Baggs.
Miss Clayton.
Miss Roper.
Miss M. A. Pike.
Miss M. Critchley.
Miss M. Murray.
Miss J. Graham.
Miss Hall.
Miss O. Bangham.
Miss Ashford.
Miss W. Kehoe.
Miss B. Atherton.
Miss J. J. Anderton.
Miss D. Stephenson.
Miss B. M. Illingworth.
Miss E. Angel.
Miss K. M. Huyton.
Miss H. V. Davies.
Miss D. M. Dawson.
Miss N. Dawson.
Miss M. Knowles.
Miss D. Bell.
Miss A. Butterfield.

During the Summer vacation (July to September).
Miss M. Knight.
Miss A. Bishop.
Professor Herdman.
Miss E. C. Herdman.
Mr. E. N. Allott.
Mr. W. Birtwistle.
Miss I. M. G. Butler.
Mrs. Bisbee.
Miss D. Hanson.

October 29th to November 1st.
Miss M. Knight.

The Fish Hatchery.

"The stock of plaice collected for spawning purposes during the autumn of 1919 consisted of 124 survivors of the previous year's stock—82 brought from Luce Bay by the fishery steamer 'James Fletcher,' and 110 caught off Niarbyl and purchased from local fishermen, making a total of 316 fish. Of this number 27 are known to have died before the end of the year, so that the hatching season of 1920 opened with 289 fish.

"The season began on February 9th—an unusually early date—when 15,750 eggs were placed in the hatching boxes. A few of the fish must have begun spawning three weeks earlier than this, for amongst the first lot of eggs skimmed from the ponds a few newly-hatched larvæ were found. The number of eggs skimmed on one day did not exceed 100,000 until March 10th, and the largest daily numbers —378,000 and 399,000—were recorded on the 17th and 22nd respectively. Upwards of 200,000 were recorded on March 13th, 19th, 20th, 23rd, 24th, and 30th. The total number of eggs collected is 4,756,800, and of larvæ set free 4,010,000. Both these totals represent a substantial advance upon the results of the previous year, and justify confidence that with more settled conditions a much larger output of larval fish in the near future may be expected.

"The Hatchery Record, giving the number of eggs collected and of larvæ set free on various days, is as follows:—

Eggs collected.	Date.	Larvæ set free.	Date.
25,200	... Feb. 9 to 12	22,050	... Feb. 23
25,200	... „ 14 to 18	18,900	... March 8

Eggs collected.	Date.	Larvae set free.	Date.
109,250	Feb. 21 to March 1	91,400	March 19
518,700	March 3 to 10	428,400	„ 29
96,600	„ 11	71,400	„ 30
231,000	„ 13	173,300	April 1
153,300	„ 16	387,450	„ 3
378,000	„ 17	228,900	„ 6
252,000	„ 19	484,050	„ 8
672,000	„ 20 and 22	506,100	„ 9
483,000	„ 23 and 24	200,550	„ 12
258,300	„ 25 to 27	567,000	„ 15
688,800	„ 29 to April 5	334,950	„ 23
389,800	April 6 to 9	296,100	„ 26
346,500	„ 10 and 12	122,850	„ 29
69,300	„ 17 and 19	43,050	May 4
38,850	„ 21 and 23	24,150	„ 8
21,000	„ 27 to May 6	9,400	„ 14
4,756,800		4,010,000	

Lobster Culture.

"Fifteen berried lobsters—the same number as last year—were purchased from the local fishermen. The yield of larvæ was, however, much greater this year than last, for while in 1919 the total number was only 9,702, or nearly 647 per lobster, this year the total was 28,720, or a fraction over 1,914 per lobster. The inadequate number of rearing jars at the disposal of the Assistant Curator rendered necessary the liberation of a large proportion of the larvæ in their first and second stages, 27,600 being dealt with in this way. Eleven hundred and twenty were placed in the rearing jars, and of this number 278, or about 1 in 4, were successfully reared and set free as lobsterlings.

The Aquarium.

"The Aquarium attracted 35,730 visitors during the season, a number far larger than that of any previous year. A new edition of the Guide to the Aquarium was first offered for sale on July 19th, and though, owing to the greatly increased cost of printing, it was found necessary to raise the price from threepence to sixpence, 843 copies were sold. The display of local fishes was more representative than it has been since pre-war days. Plaice hatched in three consecutive years, and larval lobsters in various stages of development, were exhibited, and attracted much attention.

(Signed) H. C. CHADWICK."

REPORT OF THE EDWARD FORBES EXHIBITIONER.

An "Edward Forbes Exhibition" was founded* in 1915, at the University of Liverpool, in commemoration of the pioneer marine biological work done in this district by the celebrated Manx naturalist, who was born about a hundred years ago. The object of the Exhibition is to enable some postgraduate student of the University to proceed to the Port Erin Biological Station for the purpose of carrying on some piece of biological research, more or less in continuation of the line of work opened up by Forbes, or an investigation which has grown out of such work.

The Edward Forbes Exhibitioner for the year 1920 is Miss Laura Thorpe, B.Sc., who spent several weeks during the Easter vacation in an investigation of the food-contents of the alimentary canal of various common molluscs and other invertebrates of the seashore. Unfortunately, Miss Thorpe sprained her ankle on a collecting expedition at Poolvaash early in the time, and was laid up for some days and unable to make any further observations on the beach, although when able to work she was kept supplied with fresh material by the other Liverpool students. Miss Thorpe has submitted a detailed report upon all the species she was able to examine, but as she proposes to continue her interrupted work during

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*The Regulations in regard to the Exhibition will be found at p. 52.

next Easter vacation, we have agreed to postpone a fuller report to a future occasion, and merely to record now that she found :—

Purpura lapillus feeding almost wholly on the rock-barnacles (*Balanus*), the appendages of which were found in abundance in the alimentary canal of the mollusc.

Patella vulgata feeding on the smaller algæ, as remains of red, green, and brown sea-weeds (such as *Polysiphonia*, *Ptilota*, *Rhodochorton*, and *Confervæ*) were identified, along with the silicious cases of diatoms, such as *Coscinodiscus* and *Eucampia*, and some sponge spicules both silicious and calcareous.

Littorina littorea feeding at that time on green algæ.

Trochus zizyphinus feeding on the algæ *Polysiphonia* and *Ectocarpus*, along with remains of diatoms, the Hydroid *Obelia* and sponge spicules.

OTHER RESEARCH WORK AT PORT ERIN.

Larval Fish and Plankton Food.

It was pointed out recently by Dr. Johan Hjort that as the young fish larvæ hatched in the sea in spring are dependent for food, after they have used up the supply of yolk derived from the egg, upon the diatoms and other minute organisms of the phyto-plankton, which also make their appearance in the sea in spring, it is most important that the young fish should not be hatched before the diatoms have become abundant. The phyto-plankton varies to some extent as to its abundance and date of appearance from year to year, the maximum ranging from March to May, and it is possible that in a late year, unless the first larvæ are correspondingly late, the fish may be hatched out in quantity before their natural food is present in sufficient abundance, and there may be an enormous mortality of larvæ which will affect the young fish population of that year, and greatly reduce the numbers in the commercial fisheries for some years.

We have data for many years (from 1907) in regard to the phyto-plankton in the sea off Port Erin, but it is not easy to determine exactly when, in the open sea, the pelagic fish-eggs have hatched out in quantity. We have, however, at the Port Erin hatchery, the records, extending back to 1904, of the numbers of eggs obtained from the spawning plaice in our pond, the dates of hatching and the temperature of pond and sea taken twice daily—and it is probable that these larvæ, although hatched under a roof, afford some clue to what is going on in the sea at the time. The whole matter is discussed more fully in the Lancashire Sea-Fisheries Laboratory Report for 1919, pp. 82-88, but as the enquiry was carried on at Port Erin it requires this brief mention in the Annual Report, and I wish to place on record that Miss Maisie Hobbins, B.Sc., while working at the Biological Station in April, gave me great assistance in abstracting and comparing the records of phyto-plankton and of hatching, of temperatures of pond and sea, and of dates of spawning and temperature of water. The plaice spawning in our pond at Port Erin was unusually early in 1920, some fertilised eggs being produced in January, and the temperature records show that the average for the preceding winter months was high compared with recent years. The mild winter seems to be accompanied by early spawning of the plaice. There were, however, fewer hours of sunshine than the average recorded for the spring months, and this may have affected the photo-synthesis and reproduction of the phyto-plankton as the diatoms were late in appearing in any quantity. It is possible, then, that the early-hatched larvæ found insufficient food in the sea and that the "year class" of such fish for 1920 may not be largely represented in the commercial fisheries of the future.

A careful comparison of our data for the thirteen years (1907-19) shows that in nine cases (1907, 1910-12, and 1915-19) the phyto-plankton in the sea preceded the hatching of the plaice larvæ, and that it was only in the remaining four years (1908, 1909, 1913, and 1914) that there was apparently some risk of the larvæ finding no suitable food, or very little, in the sea. The evidence so far seems to show that if the fish larvæ from the hatchery are set free in the sea as late as March 20th they are fairly sure of finding suitable food; but if they are hatched as early as February they may run some chance of being starved. This investigation is only started, but seems promising. It should be repeated and extended in other localities and in future years, and a comparison should be made, if possible, between the results obtained in the laboratory and the statistics for`commercial fisheries when these are given in sufficient detail and completeness.

Photo-synthesis and Nitrogen Fixation.

Professor Benjamin Moore, F.R.S., with Mr. E. Whitley and Mr. Webster, have continued their very interesting and fundamental investigations on photo-synthesis, including an enquiry into the sources of the carbon and nitrogen compounds formed in the growing green marine plant. Their results have been communicated to the Royal Society and will be published in due course, but Professor Moore and Mr. Whitley propose to continue this line of investigation further at Port Erin next year.

Micro-fauna of the Beach.

Miss E. C. Herdman (Newnham College, Cambridge) devoted many weeks, in spring and summer, to a detailed examination of the micro-fauna and flora of the sand on Port Erin beach. Beginning with the so-called "Amphidinium operculatum," the occurrence of which in brown patches on the sand between tide-marks has been recorded in previous reports, she extended her investigation to other species of

Dinoflagellates and some diatoms, and was able to supplement and correct the views of previous observers. She found that the organisms in question were more abundant at spring tides than during neaps, that the different organisms remained in their own patches and that there was no alternation between Dinoflagellates and diatoms such as had been described. By having successive samples of sand sent from Port Erin, she was able to exhibit the several forms of Amphidinium alive under the microscope at the Cardiff meeting of the British Association, and, after consultation with Professor Kofoid from California, who is preparing a monograph on the group, it was found that the various shapes which had been supposed to be merely varieties of *Amphidinium operculatum* are really at least three distinct species which are being described by Professor Kofoid as *A. herdmani*, *A. asymmetricum* and *A. sulcatum*, and are all new to our British records. There are also one or more species of *Gymnodinium*, a *Polykrikos*, and a few unidentified colourless, naked Dinoflagellates ; but as Miss Herdman is laying before the Liverpool Biological Society a separate paper on her investigation, with figures of the organisms observed, which will follow this report in the volume of Transactions, it is unnecessary to give further details here.

ALGOLOGICAL INVESTIGATION.

Miss Margery Knight, M.Sc., who has made many visits to Port Erin during the past year, and has devoted all available time to a detailed study of the habits and life-history of the common brown sea-weed *Pylaiella littoralis*, has furnished me with the following short summary of the results of her work :—

"*Pylaiella littoralis* is found in abundance, either as an epiphyte on *Ascophyllum nodosum*, *Fucus vesiculosus*, *Fucus serratus*, or growing independently on smooth rocks or stones in the pools at or below half-tide level. The plant shows two clearly differentiated forms of reproductive cells, viz.: (*a*) motile gonidia (asexual), and (*b*) motile gametes (sexual). Observations on *Pylaiella* during the spring and summer months have revealed a periodicity or rhythmic alternation of these reproductive cells, comparable with that found by Professor Lloyd Williams in *Dictyota dichotoma.*

"There is also a very definite cycle of development of *Pylaiella* plants on the three 'hosts.' At the time when the first gametangial stage has been reached by the *Pylaiella* growing on *Ascophyllum nodosum*, the young plants are just making their first appearance on the now rapidly-growing plants of *Fucus vesiculosus.* At a later period one can detect the embryo plants of *Pylaiella* on *Fucus serratus.* The cycle is then completed by the development of young plants on the new shoots of *Ascophyllum*, whose maturer parts bear the now battered and decrepit older generation of *Pylaiella.*

"It is proposed to continue the research along these lines:—

(*a*) Systematic observation of the behaviour of *Pylaiella* during the winter.

(*b*) Investigation of the cytological changes underlying the alternation of sexual and asexual reproductive cells.

(*c*) The relation of the epiphyte to the 'host' plant."

Plankton Investigation.

In the course of the plankton work, which is carried out continuously at Port Erin, there has been this year one special investigation which may be briefly described. It has been much discussed in the past whether the plankton is so regularly distributed that two hauls of the same net, taken at the same place and, as nearly as possible, simultaneously, will give almost identical results. With a view of testing the matter further, on seven separate occasions, in April, May, August, and September, when the conditions at sea seemed favourable, I took from the motor-boat " Redwing " a series of four or six hauls of the vertical Nansen net in rapid succession, from depths of 8 to 20 fathoms up to the surface. Superficially, at the time of emptying the catches from the net into their bottles those of each series seemed very much alike, and even when measured carefully in the laboratory some of the series gave identical quantitative results—for example, six successive hauls from 8 fathoms were all of them 0.2 c.c., and four out of five from 20 fathoms were 0.6 c.c.; but qualitatively the volume was made up rather differently in the successive hauls of a series. The same organisms were present for the most part in all the hauls of each series, and allowing for the well-known seasonal variations the chief groups of organisms are present in much the same proportions. For example, in a series where the Copepoda average about 100, the Dinoflagellates average about 300 and the Diatoms about 8,000, but the percentage deviation of individual hauls from the average may be as much as plus or minus 50, or even occasionally a good deal more. The estimated numbers of each organism (about fifty species) in each of the thirty-four hauls have been worked out, and the details will be published in the Sea-Fisheries Report for 1920; but, pending further statistical treatment, the impression one receives from looking at the figures is that if on each occasion one haul only in place of four or six had been taken, and if one had used that haul to estimate the abundance of any one organism in that sea-area, one might have been about 50 per cent. wrong in either direction—while the probable error of the method allows of a range of only from about 10 to 15 per cent. This seems to indicate a greater variation in the successive hauls than can be accounted for by the probable error of the experiment.

EVALUATION OF THE SEA.

This Biological Station was started by a body of men who were engaged in faunistic work—that is, in collecting and identifying various groups of marine animals, and such work is always necessary in exploring a new district, and moreover, it is never finished but must always go on to some extent, even when accompanied by more difficult experimental research. Every year we keep adding something to the published records of our fauna and flora. With the long list of additions made in our last Annual Report (the accumulations of some years) we brought the total number of species for our Liverpool district up to about 2,500. But it is quite possible that some common but minute species have been overlooked; in the present report several new kinds of Dinoflagellates have been recorded, and last summer we added a large species of *Lucernaria*, which had not been previously noticed in the Irish Sea.

But in addition to such faunistic and ecological work, the study of the conditions under which the animals live, we have advanced in our research work at the Biological Station into comparative anatomy and morphology, into embryology and life-histories, and into physiology and biochemistry. And now, in my final words, I wish to direct attention to an extension of faunistic work which will, I believe, become an important investigation at marine biological stations, and is eminently suitable for team-work where a number of zoologists and botanists are gathered together in co-operation. It is the collection of material for a rough census or approximation to the numbers of different kinds of common animals and plants found in a particular area, and their rate of growth and reproduction, the study of the environment of each kind, and the attempt to determine the conditions which limit their distribution or affect their abundance. This is really no new study, but it requires to be systematised and extended. We have made some small contributions to portions of it in the past in our own reports, and work of a similar nature is seen in the Clare Island Survey, article "Marine Ecology" by R. Southern (1915), in Sumner's "Intensive Study of the Fauna," etc., in Bulletin of the Bureau of Fisheries for 1908, in Orton's "Contribution to an Evaluation of the Sea," etc. (M.B.A. Journal, 1914), and in my "Spolia Runiana IV" (Linnean Journal, 1920). But the earliest, most important and most complete investigation is that of Dr. C. G. Joh. Petersen and his assistants in the Reports of the Danish Biological Station for some years back, and especially the Report for 1918. He uses a bottom-sampler, or grab, which can be lowered down open and then closed on the bottom so as to bring up a sample square foot or square metre (or in deep water one-tenth of a square metre) of the sand or mud and its inhabitants. With this apparatus, modified in size and weight for different depths and bottoms, Petersen and his fellow-workers have made a very thorough examination of the Danish waters, and have arrived at certain numerical results as to the quantity of animals in the Kattegat expressed in tons, and have shown the dependence of all these animals, directly or indirectly, upon the great beds of *Zostera* in the Kattegat. Such estimates are obviously of great biological interest and, even if only rough approximations, are a valuable contribution to our understanding of the metabolism of the sea, and of the possibility of increasing the yield of local fisheries. It seems probable that the estimates of relative and absolute abundance of such organisms may be very different in different seas under different conditions. The work will have to be done in each great area, such as the North Sea, the English Channel, and the Irish Sea, independently. This is a necessary investigation, both biological and physical, which lies before the oceanographers of the future, upon the results of which the preservation and further cultivation of some sea-fisheries may depend.

Our own contributions to the subject in the Irish Sea so far deal only with a few of the shore and shallow-water animals, and Miss Catherine Mayne, B.Sc., in several visits to Port Erin has given me much assistance in counting and measuring and weighing the more abundant animals and plants, and in preparing a series of diagrams showing the areas occupied by selected species on a typical square foot on different parts of the shore. Some of these data were made use of in a paper printed this year by the Linnean Society ("Spolia Runiana IV"), from which I may take as examples the following three very abundant animals, all free-swimming when young but fixed in the adult condition, and all of value as food of marketable fishes :—

(1) The gregarious polychaet worm *Sabellaria alveolata*, which builds masses of sandy tubes on the rocks at Hilbre Island and elsewhere, and where 40 square yards may contain over a million worms (See fig. 1, p. 51).

(2) The common rock-barnacle *Balanus balanoides*, from the base of Bradda Head at Port Erin, where there may be about 3,000 barnacles on a square foot of rock (Fig. 2, p. 53).

(3) The edible mussel *Mytilus edulis*, the most abundant and most generally useful mollusc in our seas. The rocks at Hilbre Island and elsewhere may be covered with a layer of young mussels which are so closely placed as to be absolutely continuous, while Professor Johnstone has calculated that a mussel-bed in Morecambe Bay may have 16,000 young mussels to the square foot, and may produce per unit of area nearly a hundred times the amount of flesh for food that is produced by cultivated land (Fig. 3, p. 56).

My object in referring to these still incomplete investigations is to direct the attention of our students and local naturalists to what seems a natural and useful extension of faunistic work, for the purpose of obtaining some approximation to a quantitative estimate of the more important animals of our shores and shallow water, and their relative values as either the immediate or the ultimate food of marketable fishes.

"L.M.B.C. MEMOIRS."

Although the Liverpool Marine Biology Committee has now been dissolved, it is thought well to retain the former title for this series of publications. They have become well-known in laboratories and are referred to in literature as the "L.M.B.C. Memoirs," and it would only lead to confusion to change the title, although they are no longer published by a Committee but by the Oceanography department of the University.

Since our last report was published, no further Memoirs have been issued to the public. HIMANTHALIA, by Miss L. G. Nash, M.Sc., is ready to print; Miss E. L. Gleave, M.Sc., has nearly completed her Memoir on DORIS, the Sea-lemon; Mr. Burfield, is writing the Memoir on SAGITTA; Mrs. Bisbee has made further progress with TUBULARIA, and still other Memoirs are in preparation.

The following shows a list of the Memoirs already published or arranged for:

I. ASCIDIA, W. A. Herdman, 60 pp., 5 Pls.
II. CARDIUM, J. Johnstone, 92 pp., 7 Pls.
III. ECHINUS, H. C. Chadwick, 36 pp., 5 Pls.
IV. CODIUM, R. J. H. Gibson and H. Auld, 3 Pls.
V. ALCYONIUM, S. J. Hickson, 30 pp., 3 Pls.
VI. LEPEOPHTHEIRUS AND LERNÆA, A. Scott, 5 Pls.
VII. LINEUS, R. C. Punnett, 40 pp., 4 Pls.
VIII. PLAICE, F. J. Cole and J. Johnstone, 11 Pls.
IX. CHONDRUS, O. V. Darbishire, 50 pp., 7 Pls.
X. PATELLA, J. R. A. Davis and H. J. Fleure, 4 Pls.
XI. ARENICOLA, J. H. Ashworth, 126 pp., 8 Pls.
XII. GAMMARUS, M. Cussans, 55 pp., 4 Pls.
XIII. ANURIDA, A. D. Imms, 107 pp., 8 Pls.
XIV. LIGIA, C. G. Hewitt, 45 pp., 4 Pls.
XV. ANTEDON, H. C. Chadwick, 55 pp., 7 Pls.
XVI. CANCER, J. Pearson, 217 pp., 13 Pls.
XVII. PECTEN, W. J. Dakin, 144 pp., 9 Pls.

XVIII. Eledone, A. Isgrove, 113 pp., 10 Pls.
XIX. Polychaet Larvæ, F. H. Gravely, 87 pp., 4 Pls.
XX. Buccinum, W. J. Dakin, 123 pp., 8 Pls.
XXI. Eupagurus, H. G. Jackson, 88 pp., 6 Pls.
XXII. Echinoderm Larvæ, H. C. Chadwick, 40 pp., 9 Pls.
XXIII. Tubifex, G. C. Dixon, 100 pp., 7 Pls.
Himanthalia, L. G. Nash.
Doris, E. L. Gleave.
Tubularia, R. C. Bisbee.
Aplysia, N. B. Eales.
Terebella, C. P. M. Stafford.
Balanus, G. F. Sleggs.
Sagitta, S. T. Burfield.
Actinia, J. A. Clubb.
Zostera, R. Robbins.
Halichondria and Sycon, A. Dendy.
Oyster, W. A. Herdman and J. T. Jenkins.
Sabellaria, A. T. Watson.
Ostracod (Cythere), A. Scott.
Asterias, H. C. Chadwick.
Botrylloides, W. A. Herdman.
Nematode, T. Southwell.

As the result of a slight fire in the Zoology Department of the University, a portion of the stock of L.M.B.C. Memoirs has been partially destroyed. There are a certain number of damaged copies of some of the Memoirs which are stained or singed externally, but are still quite usable, and are suitable for laboratory work. It has been decided to offer these at prices ranging according to the condition from one-half to one-fourth of the published prices, as follows:—Memoir I., Ascidia, 6d. to 9d.; VI., Lepeophtheirus and Lernæa, 6d. to 1s.; VII., Lineus, 6d. to 1s.; XIII., Anurida, 1s. to 2s.; XIV., Ligia, 6d. to 1s.; XV., Antedon, 6d. to 1s. 3d.

Memoirs should be ordered from the University Press, Liverpool.

Appended to this Report are:—

(A) The Laboratory Regulations—with Memoranda for the use of students, and the Regulations in regard to the "Edward Forbes Exhibition" at the University of Liverpool;

(B) The Financial Statement, List of Subscribers, and Balance Sheet for the year.

Appendix A

LIVERPOOL MARINE BIOLOGICAL STATION
AT
PORT ERIN.

General Regulations.

I.—This Biological Station is under the control of the Oceanography department of the University of Liverpool, and the Director of the Laboratory is the Professor of Oceanography.

II.—In the absence of the Director, the Station is under the temporary control of the Resident Curator (Mr. H. C. Chadwick), who will keep the keys, and will decide, in the event of any difficulty, which places are to be occupied by workers, and how the tanks, boats, collecting apparatus, etc., are to be employed.

III.—The Resident Curator will be ready at all reasonable hours and within reasonable limits to give assistance to workers at the Station, and to do his best to supply them with material for their investigations.

IV.—Visitors will be admitted, on payment of a small specified charge, at fixed hours, to see the Aquarium and Museum adjoining the Station. Occasional public lectures are given in the Institution by members of the staff.

V.—Those who are entitled to work in the Station, when there is room, and after formal application to the Director, are :—(1) Annual Subscribers of one guinea or upwards to the funds (each guinea subscribed entitling to the use of a work place for three weeks), and (2) others who are not annual subscribers, but who pay the Treasurer 10s. per week for the accommodation and privileges. Institutions, such as Universities and Museums, may become subscribers in order that a work place may be at the disposal of their students or staff for a certain period annually; a subscription of two guineas will secure a work place for six weeks in the year, a subscription of five guineas for four months, and a subscription of £10 for the whole year.

VI.—Each worker is entitled to a work place opposite a window in the Laboratory, and may make use of the microscopes and other apparatus, and of the boats, dredges, tow-nets, &c., so far as is compatible with the claims of other workers, and with the routine work of the Station.

VII.—Each worker will be allowed to use one pint of methylated spirit per week free. Any further amount required must be paid for. All dishes, jars, bottles, tubes, and other glass may be used freely, but must not be taken away from the Laboratory. Workers desirous of making, preserving, or taking away collections of marine animals and plants, can make special arrangements with the Director in regard to bottles and preservatives. Although workers in the Station are free to make their own collections at Port Erin, it must be clearly understood that (as in other Biological Stations) no specimens must be taken for such purposes from the Laboratory stock, nor from the Aquarium tanks, nor from the steam-boat dredging expeditions, as these specimens are the property of the Institution. The specimens in the Laboratory stock are preserved for sale, the animals in the tanks are for the instruction of visitors to the Aquarium, and as all the expenses of steam-boat dredging expeditions are defrayed from the funds, the specimens obtained on these occasions must be retained (*a*) for the use of the specialists working at the Fauna of Liverpool Bay, (*b*) to replenish the tanks, and (*c*) to add to the stock of duplicate animals for sale from the Laboratory.

VIII.—Each worker at the Station is expected to prepare a short report upon his work—not necessarily for publication—to be forwarded to the Director before the end of the year for notice, if desirable, in the Annual Report.

IX.—All subscriptions, payments, and other communications relating to finance, should be sent to the Accountant, the University of Liverpool. Applications for permission to work at the Station, or for specimens, or any communications in regard to the scientific work should be made to the Director, Department of Oceanography, University, Liverpool.

MEMORANDA FOR STUDENTS AND OTHERS WORKING AT THE PORT ERIN BIOLOGICAL STATION.

Post-graduate students and others carrying on research will be accommodated in the small work-rooms of the ground floor laboratory and in those on the upper floor of the new research wing. Some of these little rooms have space for two persons who are working together, but researchers who require more space for apparatus or experiments will, so far as the accommodation allows, be given rooms to themselves.

Undergraduate students working as members of a class will occupy the large laboratory on the upper floor or the front museum gallery, and it is very desirable that these students should keep to regular hours of work. As a rule, it is not expected that they should devote the whole of each day to work in the laboratory, but should rather, when tides are suitable, spend a portion at least of either forenoon or afternoon on the sea-shore collecting and observing.

Occasional collecting expeditions are arranged under guidance either on the sea-shore or out at sea, and all undergraduate workers should make a point of taking part in these.

It is desirable that students should also occasionally take plankton gatherings in the bay for examination in the living state, and boats are provided for this purpose at the expense of the Biological Station to a reasonable extent. Students desiring to obtain a boat for such a purpose must apply to the Curator at the Laboratory for a boat voucher. Boats for pleasure trips are not supplied by the Biological Station, but must be provided by those who desire them at their own expense.

Students requiring any apparatus, glass-ware or chemicals from the store-room must apply to the Curator. Although a few microscopes are kept at the Biological Station, these are mainly required for the use of the staff or for general demonstration purposes. Students are therefore strongly advised, especially during University vacations, not to rely upon being able to obtain a suitable microscope, but ought if possible to bring their own instruments.

Students are advised to provide themselves upon arrival with the " Guide to the Aquarium " (price 6d.), and should each also buy a copy of the set of Local Maps (price 2d.) upon which to insert their faunistic records and other notes.

Occasional evening meetings in the Biological Station for lecture and demonstration purposes will be arranged from time to time. Apart from these, it is generally not advisable that students should come back to work in the laboratory in the evening ; and in all cases all lights will be put out and doors locked at 10 p.m. When the institution is closed, the key can be obtained, by those who have a valid reason for entering the building, only on personal application to Mr. Chadwick, the Curator, at 3, Rowany Terrace.

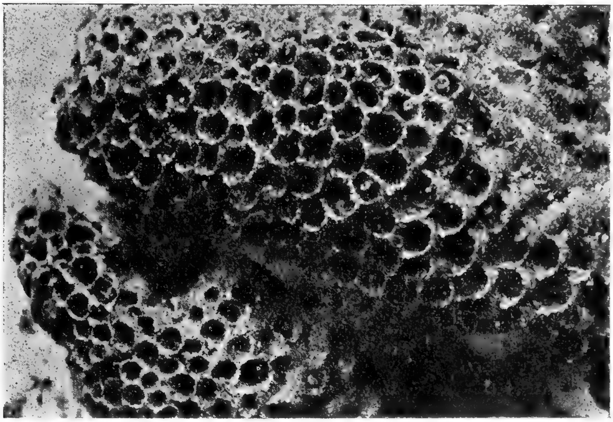


FIG. 1. *Sabellaria alveolata,* from Hilbre Island. Nat. size.

REGULATIONS OF THE EDWARD FORBES EXHIBITION.

[Extracted from the *Calendar* of the University of Liverpool for the Session 1920-21, p. 427.]

"EDWARD FORBES EXHIBITION.

"Founded in the year 1915 by Professor W. A. Herdman, D.Sc., F.R.S., to commemorate the late Edward Forbes, the eminent Manx Naturalist (1815-1854), Professor of Natural History in the University of Edinburgh, and a pioneer in Oceanographical research.

The Regulations are as follows :—

(1) The interest of the capital, £100, shall be applied to establish an Exhibition which shall be awarded annually.

(2) The Exhibitioner shall be a post-graduate student of the University of Liverpool, or, in default of such, a post-graduate student of another University, qualified and willing to carry on researches in the Manx seas at the Liverpool Marine Biological Station at Port Erin, in continuation of the Marine Biological work in which Edward Forbes was a pioneer.

(3) Candidates must apply in writing to the Registrar, on or before 1st February.

(4) Nomination to the Exhibition shall be made by the Faculty of Science on the recommendation of the Professor of Zoology.

(5) The plan of work proposed by the Exhibitioner shall be subject to the approval of the Professor of Zoology.

(6) Should no award be made in any year, the income shall be either added to the capital of the fund, or shall be applied in such a way as the Council, on the recommendation of the Faculty of Science, may determine.

(7) The Council shall have power to amend the foregoing Regulations, with the consent of the donor, during his lifetime, and afterwards absolutely; provided, however, that the name of Edward Forbes shall always be associated with the Exhibition, and that the capital and interest of the fund shall always be used to promote the study of Marine Biology."

EDWARD FORBES EXHIBITIONERS.

1915	Ruth C. Bamber, M.Sc.
1916	E. L. Gleave, M.Sc.
1917	C. M. P. Stafford, B.Sc.
1918	Catherine Mayne, B.Sc.
1919	George Frederick Sleggs, B.Sc.
1920	Laura Thorpe, B.Sc.

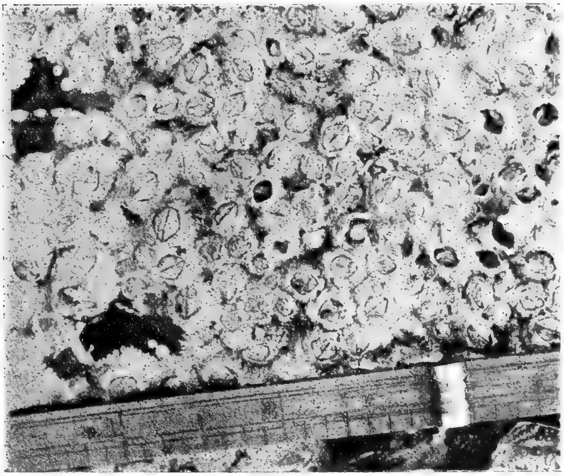


FIG. 2. *Balanus balanoides*, on rocks at Port Erin. Nat. size.

APPENDIX B.

FINANCIAL STATEMENT.

On December 31st, 1919, the Honorary Treasurer of the Liverpool Marine Biology Committee handed over the accounts of the Port Erin Biological Station to the Accountant of the University of Liverpool, with the following assets :—

	£	s.	d.
Balance in Treasurer's hands	2	10	7
Memoir Fund (for printing)	229	4	4
Extension Fund (for buildings)	37	4	9
Ministry of Agriculture and Fisheries Fund (for Fisheries research)	91	3	6

CAPITAL ACCOUNT.

1. British Workman Public House Co., 99 shares £1 each, fully paid.
2. The Trustees of the British Association (1896) Fund also transferred to the University their fund of about £1,000 to be held for the benefit of the researches carried out at Port Erin in continuation of the work of the Liverpool Marine Biology Committee. This has since been invested in £1,135 16s. 7d. Funding Loan, 4%, 1960-1990.

The Isle of Man Government, by the terms of the agreement, makes an annual grant of £200 in aid of the work of the Hatchery, and the balance of that grant, amounting to £95 12s. 5d., for the current year, was paid over to the Accountant as from the date of the promulgation of the Act in July. This amount was received in September, 1920, and therefore does not appear in the present accounts.

The List of Subscriptions and Balance Sheet will be found on the following pages. The accounts are made up to 31st July, 1920, the end of the University financial year.

LIST OF SUBSCRIPTIONS TO 31ST JULY, 1920.

	£	s.	d.
Brunner, Mond & Co., Northwich...	1	1	0
Brunner, J. F. L., 43, Harrington Gardens, London, S.W.	2	2	0
Brunner, Roscoe, Belmont Hall, Northwich ...	2	2	0
Gibson, Prof. R. J. Harvey, The University, Liverpool	1	1	0
Graveley, F. H., Indian Museum, Calcutta ...	0	10	6
Hill, G. J.	1	1	0
Holt, Dr. A., Rocklands, Thornton Hough ...	1	0	0
Hutton, J. A., Woodlands, Alderley Edge ...	5	0	0
Isle of Man Natural History Society	2	2	0
Jarmay, Sir John, Hartford, Cheshire	1	1	0
Livingston, Charles, 16, Brunswick-st., Liverpool	1	1	0
Manchester Microscopical Society...	1	1	0
Meade-King, R. R., Tower Buildings, Liverpool...	0	10	0
Mond, R., Sevenoaks, Kent...	5	0	0
Petrie, Sir Charles (The late)	2	2	0
Rathbone, Miss M.	1	1	0
Roberts, Mrs. Isaac, Thomery, S. et M., France ...	1	1	0
Robinson, Miss M. E., Holmfield, Aigburth, L'pool	2	1	0
Roper, Miss M. E., Newnham College, Cambridge	1	0	0
Smith, A. T., 43, Castle-street, Liverpool... ...	1	1	0
Thomas, Dr. W. Thelwall, Rodney-street, Liverpool	1	1	0
Thornely, Miss, Field Head, Out Gate, Ambleside	0	10	0
Thornely, Miss L. R., Field Head, Out Gate, Ambleside	2	2	0
Toll, J. M., 49, Newsham-drive, Liverpool ...	1	1	0
Walker, A. O., Ulcombe-place, Maidstone ...	3	3	0
Watson, A. T., Tapton Crescent-road, Sheffield ...	1	1	0
Whitley, E., 13, Linton-road, Oxford	2	2	0
	£43	18	6

SUBSCRIPTIONS FOR THE HIRE OF "WORK-TABLES."

University, Liverpool	£10	0	0
Victoria University, Manchester	10	0	0
University College, Reading	4	4	0
University College, Nottingham	5	5	0
	£29	9	0

FIG. 3. *Mytilus edulis*—Part of a mussel bed at Morecambe Bay.

OCEANOGRAPHY: PORT ERIN ACCOUNT.

Account of Receipts and Payments for the Period 1 January to 31 July, 1920.

(From University Accounts, as published.)

Payments

	£	s.	d.
General Account—			
To Share of Curator's Salary (including Insurance)	42	10	0
,, Share of Assistant's Salary	12	10	3
,, Fuel, Light, Cleaning, &c.	0	18	3
,, Books, Apparatus and Supplies	9	2	3
,, Sundries	5	14	4
,, Printing, Stationery and Postage	1	12	8
,, Balance in hand	141	4	5
	£213	12	2

Receipts

		£	s.	d.
General Account—				
By Balance—1 January, 1920		2	10	7
,, Interest on Investments		21	2	11
,, Subscriptions and Donations		43	18	6
,, Universities and University Colleges for Hire of Work Tables		29	9	0
,, Port Erin:—				
Laboratory Fees	£25 0 0			
Admissions to Aquarium	36 1 9			
Specimens	40 14 1			
		101	15	10
,, Bank Interest		14	15	4
		£213	12	2
Memoir Fund—By Balance—1 January, 1920		229	4	4
By Sales		0	13	0
,, Net Proceeds of Publication		9	13	1
Balance in hand		£239	10	5
Ministry of Agriculture and Fisheries—				
By Balance—1 January, 1920		91	3	6
To Wages		3	0	0
Balance in hand		£88	3	6
Extension Fund—By Balance—1 January, 1920		£37	4	9

OCEANOGRAPHY: PORT ERIN ACCOUNT.

BALANCE SHEET, 31 JULY, 1920

LIABILITIES	£	s.	d.	£	s.	d.
99 Years Lease of Port Erin Biological Station and Fish Hatchery from 5 July, 1920 ... ... (*Vide The Biological Station and Fish Hatchery Transfer Act*, 1920)	per contra					
Donations:—						
Transfer from Liverpool Marine Biological Committee	909	14	3			
Mr. John Rankin	80	0	0			
				989	14	3
General Account	141	4	5			
Memoir Fund	239	10	5			
Ministry of Agriculture and Fisheries ...	88	3	6			
Extension Fund	37	4	9			
				506	3	1
				£1495	17	4

We have examined the above Balance Sheet and certify that it is correct.

HARMOOD BANNER & SON,
Chartered Accountants.

LIVERPOOL, 27 *August*, 1920.

ASSETS	£	s.	d.	£	s.	d.
99 Years Lease of Port Erin Biological Station and Fish Hatchery from 5 July, 1920 ... ... (*Vide The Biological Station and Fish Hatchery Transfer Act*, 1920)	per contra					
Investments at Cost:—						
99 Shares in British Workmen's Public House Company, Limited	121	5	6			
Funding Loan 4 %, 1960-1990, £1135 16s. 7d.	788	8	9			
Victory Bond 4 %, £100	80	0	0			
				989	14	3
Cash in Bank of Liverpool and Martins, Limited Heywood's Branch	501	3	1			
Cash in hands of Curator	5	0	0			
				506	3	1
				£1495	17	4

C. SYDNEY JONES,
Treasurer.

NOTES ON DINOFLAGELLATES AND OTHER ORGANISMS CAUSING DISCOLOURATION OF THE SAND AT PORT ERIN.

By E. Catherine Herdman,
Newnham College, Cambridge.

(Read 10th December, 1920.)

In the Annual Reports of 1911 and 1912, accounts were given of greenish-brown patches on the sandy beach at Port Erin. These were shown to be due to the presence, sometimes in large numbers, of an actively motile Dinoflagellate described as *Amphidinium operculatum* and sometimes of abundant Diatoms. The discoloured patches of sand were seen to vary in size and position from time to time and, in the individual patches, it seemed that Dinoflagellates were replaced by Diatoms and these, in turn, by more Dinoflagellates. It was observed that the discolouration disappeared shortly before the patch of sand was covered by the rising tide, and only reappeared after that part of the beach was once more exposed. No Amphidinia were present in tow-nettings taken in a few inches of water over the position occupied by the discoloured patches. It was therefore assumed that, at these times, the organisms had gone down to the deeper layers of sand. The variation in extent of the patches seemed to be greater, on the whole, at neaps than at springs, and it was suggested that possibly some correlation existed between the abundance of Dinoflagellates and the state of the tides. A considerable divergence of form was noticed between the individual Amphidinia, but it was thought that they were probably all varieties or possibly different stages in the life history of the one species.

This summer, in July, August, and September, some further observations were made on the occurrence and distribution of the various organisms responsible for the discolouration. The patches were examined daily from July 28th to August 17th, and from September 6th to September 28th, and were found to vary greatly in extent. This variation showed a periodicity corresponding with the tides, but in the opposite direction from that recorded in 1911 and 1912. The various organisms were present in enormous numbers at spring tides, so that the greater part of the south end of the beach was discoloured, while, at neap tides, the patches were small, isolated, and much less clearly marked. Another point on which this year's observations do not agree with those made in 1911 and 1912 is the alternation of different organisms on the same patch of sand. Throughout the time when the beach was examined this summer, although neighbouring patches were produced by different organisms, each patch was always characterised by one predominant organism, so that it was possible to predict the cause of discolouration in any sample of sand, provided its position on the beach were known. Again, while most of the patches disappeared about half an hour before that area of sand was reached by the rising tide, a few of them were always visible on the surface, even when covered by water. According to the previous reports, the Amphidinia showed positive heliotropism. Experiments made this year all seemed to show that the movements were negatively heliotropic, but it was evident that they were affected more by variations in the amount of water present than by different intensities of light.

Several species of Diatoms were found forming patches which could generally be distinguished by their rather bright brown colour and by the fact that, for the most part, they remained on the surface at high tide.

The Dinoflagellata were represented by at least three species of Amphidinium, one or more species of Gymnodinium, Polykrikos, and a few unidentified, colourless, naked Dinoflagellates. Several of these forms were figured in the reports of 1911 and 1912 as varieties or different stages of *Amphidinium operculatum*, but they have since been described by Kofoid as distinct species and, as they seem to keep definitely to their respective positions on the beach for considerable periods without changing, it is probably more satisfactory to regard them as species rather than varieties. The differences in form are made clear in the accompanying outline sketches (p. 62).

Amphidinium herdmani, Kofoid, corresponds to the "short" form figured in the report of 1911 as *A. operculatum*. It differs from *A. operculatum* as described and figured by Claparède and Lachmann in 1868 in the size and shape of the operculum.

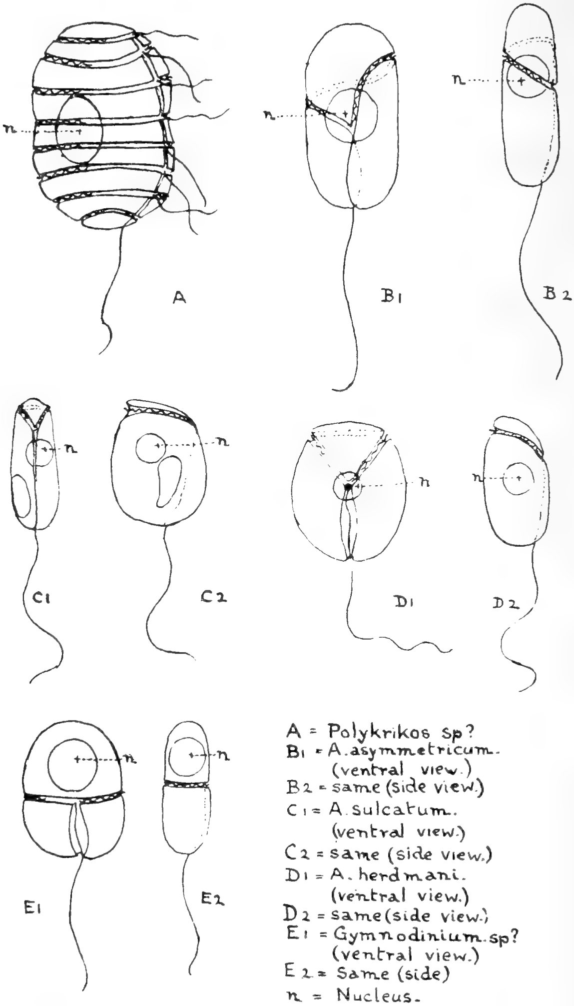
A. asymmetricum, Kofoid, is the same as the "long" form of *A. operculatum* described in 1912.

A. sulcatum, Kofoid, is not among the forms figured in the previous reports, but occurred abundantly this summer. It seems to be the only species of Amphidinium which remains at the surface when covered by water. In the laboratory, while *A. herdmani* and *A. asymmetricum* will live and multiply on damp sand but do not flourish in the presence of too much water, *A. sulcatum* will multiply in sea water alone to such an extent as to form, in a few days, a thick slimy scum.

Gymnodinium sp. ? was present in considerable numbers over a very restricted area. It was found only in and close to a trickle of rather fresh water draining down from behind the harbour steps. (See Sketch Map, p. 63.) It was always associated with large numbers of Diatoms, and was found on the surface at all times of the tide. It also multiplied in water in the laboratory.

Polykrikos sp. ? occurred fairly regularly on certain parts of the shore though never in such abundance as to cause discolouration. (See Sketch Map.)

Euglena spp. ? The two species of *Euglena* each occurred in one isolated patch only (see Sketch Map) and were often not present in appreciable numbers at neap tides. They both disappeared before the tide reached them. The discolouration

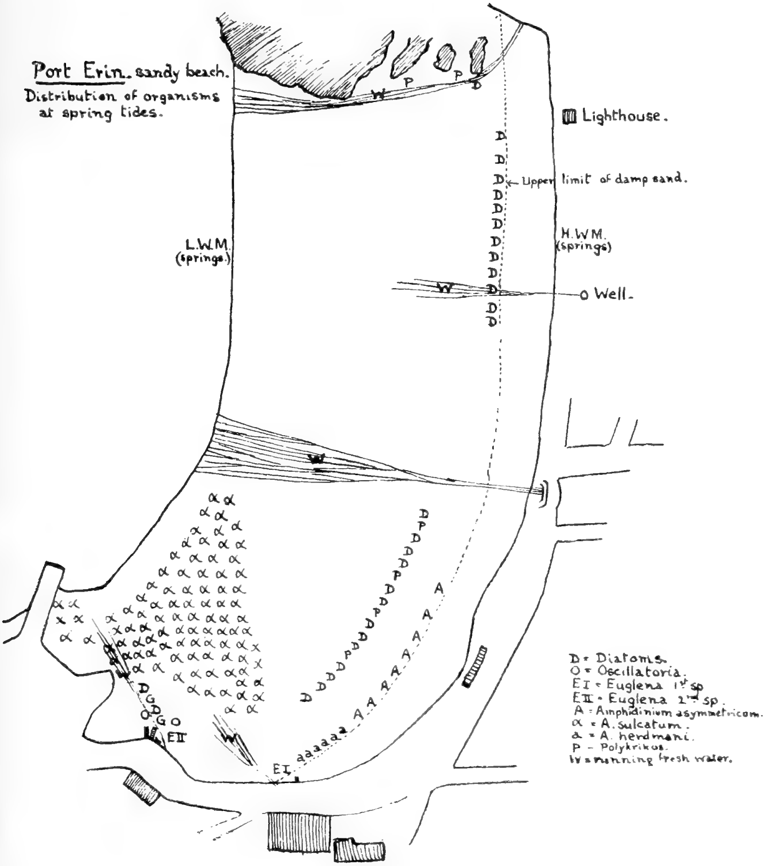


A = Polykrikos sp?
B1 = A. asymmetricum.
(ventral view.)
B2 = same (side view.)
C1 = A. sulcatum.
(ventral view.)
C2 = same (side view.)
D1 = A. herdmani.
(ventral view.)
D2 = same (side view.)
E1 = Gymnodinium. sp?
(ventral view.)
E2 = Same (side)
n = Nucleus.

produced by them was distinctly greener than that caused by the Dinoflagellates.

Diatoms. Brown patches were caused by several species belonging to the genera *Navicula*, *Pleurosigma*, and others.

Oscillatoria sp. ? The only other organism which ever appeared so abundantly as to cause discolouration was *Oscillatoria.* This was almost always present in and around the trickle of fresh water in the harbour, and occasionally increased so as to form small dark green patches. (See Sketch Map.)



NOTE ON SOME EXPERIMENTS ON THE WATER VASCULAR SYSTEM OF ECHINUS.

By Ruth C. Bamber, M.Sc.

[Read December 10th, 1920.]

In 1887, Professor Marcus Hartog* published a paper on "The True Nature of the 'Madreporic System' of Echinodermata, with Remarks on Nephridia," in which he put forward the view that "we must needs regard the madreporic system and the 'vasal' part of the vasoperitoneal sac as constituting a left nephridium, the right having failed to receive a duct."

Previous to this, the generally accepted view was that water enters the water vascular system through the madreporite, and is probably lost gradually by passing out through the walls of the tube feet, etc.

Hartog supports his view by experiments which seem to prove that there is an *outward* current through the madreporite, as would be expected if the water vascular system is an excretory organ. Fresh specimens of Echinus were opened and the madreporic canals removed and slit longitudinally on one side: they were then examined in the perivisceral fluid and he reports a strong inrush of particles through the slit, and a corresponding outward flow through the cut end towards the madreporite. The madreporite of an Echinus and of several starfishes, with part of the stone canals attached, were removed and examined in sea water with powdered charcoal in suspension. No particles ever settled on the madreporites. Normal and eviscerated specimens of Antedon were examined disc upwards in sea water, with charcoal in suspension. No particles were observed to settle on the discs except along the imperforate ambulacral grooves.

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* London, *Ann. Mag. Nat. Hist.*, 1887, pp. 321-326.

Hartog concludes, "the above experiments show clearly that the perforations of the madreporite in Echinus and Asterias, and of the disc in Comatula, are purely excretory, and serve to eliminate the excess of water taken up by the body." These experiments and the view they seem to support met with much criticism.

Cuénot* claimed that ciliary action on the madreporite would give Hartog's results, without any outward current. He considered "qu'il n'y avait ni courant d'entrée, ni courant de sorti; tout ce que l'ou peut admettre, à la regueur, c'est qu'il se produit une diffusion lente au contact des pores madréporiques entre le liquide des cavités environnantes et l'eau de mer ballotée en tors sens par les cils." He did not support this view by experiment. Later†, he suggested that the cilia lining the stone canal keep up the pressure in the water vascular system by constantly tending to produce an *inward* current.

Ludwig‡ brought forward experimental evidence to prove that there is an *inward* current through the madreporic pores. He examined different adult Echinoderms, also Auricularia larvae, in perivisceral fluid, with or without particles added, and reported a distinct *inward* current through the madreporite and down the stone canal.

MacBride§ also claims that the current is *inwards*. After keeping *Amphiura squamata* living for several days in sea water with carmine or lamp black in suspension, he found, on cutting sections, that some particles were present in the pore canals.

In 1913, Mr. Burfield and myself, working at the Port Erin Biological Station, repeated some of Hartog's experiments and added others, as follows:—

EXPERIMENT 1. The madreporite, with the stone canal

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* Cuénot, L. Leipzig, *Zool. Anz.*, Vol. XIII, pp. 315-318 (1890).

† Cuénot, L. Bruxelles, *Arch. Biol.*, Vol. II, pp. 313-680 (1891).

‡ Ludwig, H. Leipzig, *Zool. Anz.*, Vol. XIII, pp. 377-379 (1890).

§ MacBride, E. W. London, *Quart. Journ. Micros. Sci.*, Vol. XXXVIII, pp. 339-411 (1896).

attached, was removed from a fresh Echinus, and examined in sea water with particles of carmine in suspension. The particles were always driven back from the madreporite just as they were about to settle. The behaviour of these particles strongly suggested ciliary action on the madreporite.

Experiment 2. In order to test for any outward flow through the madreporite apart from the action of cilia on its surface, a fresh Echinus was obtained and its madreporite carefully scraped. The madreporite with the stone canal attached was then removed from the animal and examined in sea water with the particles in suspension. All particles were still driven off from the madreporite as though by an outward current.

Experiment 3. A madreporite with the stone canal attached was placed in a vessel of sea water with particles in suspension, and left for several hours. It was then found that a mass of particles had collected around the cut end of the canal suggesting that there had been an inflow there, and consequently, an outflow through the madreporic plate.

Experiment 4. Stone canals and ampullae were examined in sea water under a binocular microscope. A continuous circulation was distinctly seen by the movement of the corpuscles in the fluid of the ambulacral system. In the ampullae the direction of this circulation was very indefinite, but in the stone canal there was a very distinct central current towards the madreporite, and peripheral currents towards the oral surface. The peripheral current seemed to be the result of ciliary action on the lining of the canal.

Experiment 5. Coloured fluid was injected into fresh specimens through the interambulacral areas. The punctures were sealed with plasticine, and the animals kept in fresh sea water for several days (different coloured fluids were used; e.g., methyl blue, methyl green or fuchsin in sea water; also carmine in perivisceral fluid). This experiment gave no result. The animals were apparently not healthy ; the whole of the interior stained, but there was no sign of any colour being excreted anywhere.

These experiments seemed to support Hartog's view, but were by no means conclusive.

In 1915 I carried out other experiments, and have continued them either at Easter time or during the summer, every year since then, at Port Erin.

It seemed doubtful whether evidence obtained from *dissected* madreporites and stone canals could be relied upon; therefore in the following experiments dissection has been avoided as much as possible.

EXPERIMENT 1. Stone canals were examined under a binocular microscope without being removed from the animal. This is easily done by cutting a window on each side of the animal and examining it in a glass vessel filled with sea water. The currents seen agreed with our previous observations ; there is a peripheral current towards the oral surface, apparently caused by cilia lining the stone canal, and a central current towards the madreporite. It is impossible to decide from observation which of these is the main current, but the fact that both are present perhaps accounts for the directly opposite reports of Hartog and Ludwig. Observations made with a binocular microscope leave no doubt on this point.

EXPERIMENT 2. Living specimens of Echinus were examined in sea water with charcoal or carmine in suspension. No particles were ever seen to settle on the madreporite, although they settled freely elsewhere. A large number of specimens have been examined in this way, and always give the same result. As one observes the phenomenon the impression strengthens that the action is due to cilia on the surface, and not to a steady outward current, in spite of our previous experiment with a well-scraped madreporite.

EXPERIMENT 3. To test for surface ciliary action the madreporite of a fresh Echinus was touched with a brush dipped in formaline. The animal was immediately plunged into fresh sea water to prevent the action of the formaline from spreading beyond the surface of the madreporite. This animal was then examined in sea water with particles in suspension, and no longer gave any suggestion of an outward current through the madreporite. Particles settled freely over its whole surface.

Obviously any appreciable outward action is due to the cilia on the surface of the madreporite or just inside the madreporic pores, and not to an outward current. This, of course, does not disprove a very gentle or an intermittent outward flow, such as one might expect from an excretory organ. Feeding experiments were therefore attempted to settle whether or not any excretory matter finds its way out of the animal through the madreporic system.

Experiment 4. A dozen Echini were fed with dry methyl blue. They were then kept under observation in running water for several days. No colour appeared anywhere on the surface, and on opening the animals it was found that the methyl blue was simply coated with mucus, and was not being absorbed at all. No results have so far been obtained from any feeding experiment.

Experiment 5. Dry methyl blue was put into the coelom through a little puncture in the interambulacral area. The puncture was sealed up with putty and the animal kept in fresh sea water. After one night the whole peristome and the buccal branchiae were bright blue, but no colour appeared anywhere else on the surface, although the animal was kept under observation for many days. Many specimens have been treated in this way and always give the same result. This experiment, like the feeding experiments, gave negative results for the function of the madreporic system.

Experiment 6. To test for a possible *inward* current many specimens of Echinus were kept in fresh sea water coloured with methyl blue*. The animals were opened at intervals of one to five days, and every specimen showed colour in the axial sinus; many had the axial organ stained very deeply, two had a doubtful suggestion of colour in the stone canal directly under the madreporite, but not a single specimen showed any colour at all in the stone canal beyond this point. On another occasion an Echinus was kept in methyl blue and sea water for two days, then opened. The stone canal and polian vesicles were bright blue; there was no colour at all present in the axial organ.

These experiments seem to prove that there is no continuous current in either direction in the madreporic system. That fluid passes in through the madreporite seems certain, but apparently it passes sometimes into the axial sinus, sometimes into the stone canal. Gemmell† found, by cutting thin sections of fresh madreporites, that "the cilia on the surface of the madreporite act tangentially, and tend to sweep away any foreign particles. No pore-canal system as a whole has its cilia acting oralwards, but in each pore-canal there is a short superficial segment which shows the converse condition." Our observations agree with this report exactly, but do not throw very much light on the apparently erratic action of the whole system as shown in Experiment 6 above. From work on Asterias and Solaster, Gemmell found that the ciliation of the axial sinus is in an aboral direction. Whether this is true or not for Echinus also has not been ascertained to my knowledge. But be that as it may, the ciliation of the madreporic system clearly does not account for our observed facts. Probably, as Cuénot, MacBride and Gemmell have suggested, the

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* Methyline blue is useless for this experiment owing to the fact that living tissue reduces it to a colourless leucobase.

† Dr. J. F. Gemmell. London, *Phil. Trans. Roy. Soc.*, Series B., Vol. CCV, pp. 213-294 (1914).

action of the cilia lining the stone canal serves to keep up the pressure in the ambulacral system. If the pressure in this system is high no fluid will be able to enter the stone canal through the madreporite in spite of the action of its ciliary lining.

Cuénot has also suggested that fluid may enter the body cavity through the permeable axial organ, and this view seems to be supported by these experiments. There is no evidence to prove that excess fluid does not also leave both ambulacral system and body cavity through the madreporic system.

Apparently the whole question is one of balance between internal and external pressures.

ON THE INHERITANCE OF COAT COLOUR IN THE VARIETIES OF *RATTUS RATTUS.*

By J. W. Cutmore.

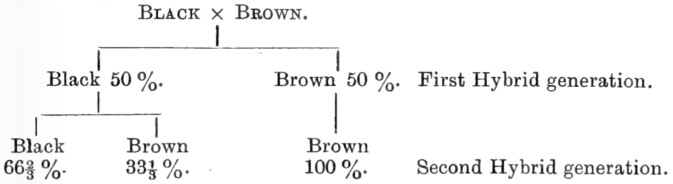
[Addendum to Paper in Vol. XXXIII, p. 70.]

Since the publication of the first part of my article I have completed my experiments on the *Rattus* group so far as I could with the accommodation at my disposal.

From an analysis of the results I find :—

(1) That mating *R. r. rattus* (black) to *R. r. frugivorus* or to *R. r. alexandrinus* (brown), gave an equal number of each colour.

(2) That mating brown Hybrid to brown Hybrid, off above, gave all brown offspring like themselves.



(3) That mating black Hybrid to black Hybrid gave eight black and four brown offspring. Six of the black young showed a white mark on the chest, similar to those mentioned by the late Professor Doncaster as indicating the mixed dominant character in his experiments with the common brown Rat, *R. norvegicus.* Professor Doncaster suggested to me that I should test these so marked; I am sorry it was not convenient for me to do so. One of the black Hybrids (the male) of the pair that produced both brown and black offspring had a white spot on its chest.

So far as my experiments went no black offspring were produced from brown Hybrids. I am sorry it was not convenient for me to test the brown young with white ventral patches. Brown offspring were produced from black Hybrids (see Table below and Chart above).

(4) That from the common brown Rat (*norvegicus*) mated to the domestic white Rat (*albino*), gave results in accord with the Mendelian laws of inheritance, and also in accord with the results published by the late Professor Doncaster in the *Proceedings of the Cambridge Philosophical Society*, Vol. XIII, Part 4.

(5) That from the pairs of *norvegicus* females mated to *rattus* males I had no results.

Table of matings and results to show the inheritance of the three varieties, *Rattus r. rattus, R. r. frugivorus, R. r. alexandrinus.*

Exp. No.	Female Parent.	Origin.	Male Parent.	Origin.	Result.	Sex.
1	*rattus*	wild caught	*frugivorus*	wild caught	6 *frugivorus* 2 *rattus*	3♂, 3♀ 2♀
2	*alexandrinus*	wild caught	*rattus*	wild caught	9 *rattus* 7 *alexandrinus* 1 *frugivorus*	8♂, 1♀ 4♂, 3♀ ♂
3	*rattus*	off No. 2	*frugivorus*	off No. 1	13 *rattus* 12 *frugivorus* 1 *alexandrinus*	7♂, 6♀ 5♂, 7♀ 1♂
4	*alexandrinus*	off No. 2	*alexandrinus*	off No. 2	17 *alexandrinus*	8♂, 9♀
5	*frugivorus*	off No. 1	*frugivorus*	off No. 1	13 *frugivorus*	5♂, 8♀
6	*rattus*	off No. 2	*rattus*	off No. 2	8 *rattus* 4 *alexandrinus*	6♂, 2♀ 4♂
7	*rattus*	wild caught	*rattus*	wild caught	7 *rattus*	3♂, 4♀

REPORT ON THE INVESTIGATIONS CARRIED ON IN 1920 IN CONNECTION WITH THE LANCASHIRE SEA-FISHERIES LABORATORY AT THE UNIVERSITY OF LIVERPOOL, AND THE SEA-FISH HATCHERY AT PIEL, NEAR BARROW.

EDITED BY
PROFESSOR JAMES JOHNSTONE, D.Sc.,
Honorary Director of the Scientific Work.

(With Text-Figures.)

CONTENTS.

INTRODUCTION.

This Report, like those that have been issued since 1914, must again be a small one. The reason for this is mainly the greatly-increased cost of publication, but there are also other difficulties peculiar to the circumstances of the time. There is no doubt that the fishery industries are in a very serious condition—perhaps even one of crisis—and so one is obliged to try to discover in what ways the scientific research now being carried on can be of immediate assistance. Obviously the investigations that are instigated by a statutory fishery authority in this country must have, for their ulterior objects, the attainment of results, or solutions, or information of some kind that will be of material advantage to the industry—that is their justification as economic research. Now one may submit that it ought to be the function of the industry, and of the administrators, to state the nature of the problems that confront them and to ask for such information as may be attainable; still it is, no less, the task of the investigators to study the economic conditions that prevail and to endeavour to acquire an attitude that will enable them to direct the scientific research along commercially useful lines. In the effort to attain such an attitude I, therefore, refer to the condition of the sea-fishing industries—so far as the information at my disposal goes.

The Trawl Fisheries.

There is little doubt that many of the conditions of the year 1920 were indicated in 1913—all that the war has done has been to accelerate a change that was apparent ten years ago. In 1911 failing markets were being experienced—as witness the Exhibition at Rusholme, in Manchester, in that year. The steam-trawling trade was nearly stagnant because the available home markets had fully been supplied then and little could be done to develop an export trade in fresh fish. So the "Fish-as-food" propaganda of that period took shape and was the expression of a real difficulty in disposing of the fish that could be landed. It came as a kind of shock during the war years when one realised that, for most English people, fish was not a satisfactory substitute for meat!

The vicissitudes of the steam-trawling industry during the years 1914-1921 would be of extreme interest if some one personally conversant with these affairs would write them up before the first vivid impressions fade. In 1918, 1919, and even early in 1920 there was an appearance of fictitious prosperity: it was generally believed that large "fortunes" had been made by the owners of fishing vessels, and there were many attempts at the flotation of new enterprises. The strike of skippers of trawlers at Fleetwood in March, 1920; the announcements made about that time of the "cost of production," and the failure to materialise of most of the new flotations did much to dispel the illusion of prosperity. The lowest earnings of Fleetwood skippers, I was informed, was £17 a week, and the double of that was not uncommon. At one port the lowest ratings on a steam-trawler had a weekly wage of £2, a daily bonus, while at sea, of 6/–, a share of 2d. in the £ on the earnings of the vessel, and free food while on board and fishing. I don't think these earnings, either of skippers or deck-hands were too big when one considers what is the nature of the work that is done, and I only quote the figures here as illustrating some of the costs of landing the fish. Coal, ice, and other consumable stores, had, it must be remembered, increased in cost in much about the same ratio as wages and bonuses. In June of 1920 a series of average costings taken at several fishing ports showed that it took about 4¼d. to land the average lb. of fish, while the latter sold at about 1½d. to 4½d. Far more serious, however, was the incredibly bad means of transport and distribution. When one compares the price obtained for the fish on landing with the price at which it was bought by the consumer in the retail fish shops it becomes evident that an extraordinarily large proportion of the latter price must have been absorbed by the expense of carrying away the fish from the ports and distributing it to the consumers, for it is probable that the retailers' profits were not enhanced in the same ratio as was that of the price paid by the consumers. Even the pre-war transport was far from being all that was desirable, and certainly that of the years 1919 and 1920 was very much worse—so one heard repeatedly of large quantities of fish that were unsaleable and had to be destroyed. There were " gluts " at many of the ports, and there was no means of utilising these except the manure factory. The cold-storage, about which one heard so much during the war years, and in regard to which there was so much unfinished scientific investigation, did not materialise. It appears now to be the case that the process of "turning round" the trawlers and drifters from war to fishing work was accomplished rather too quickly. A large number of steam-fishing vessels were built by the Government during the war and an attempt was made to hand many of these over to the "Mine-Sweepers' Co-operative Association"—a fine and generous project which deserved better than to be launched during a time of slump and abandoned in little over a year. This scheme, and the futile taking-over of the German "Reparation trawlers" are indications of the extent to which Ministers had "sized up" the situation of the steam-fishing industry in 1919. So much, then, for the conditions of the last two years—at the present time (March, 1920) there is the certainty, either of an extensive laying-up of trawlers when the Lent fishing season comes to an end, or of a marked break in wages.

Smack-fishing was thoroughly decadent long before the war period, and the years 1914-1919 hastened the rate of decline so that (unless, perhaps, the price of coal remains at its present value) this branch of deep-sea fishing will soon become extinct in England. About 1885-1890 there were nearly 100 fine smacks sailing out from Fleetwood and Hoylake: now there are 17, and it is said that even some of these are on the market. The history of the old Fleetwood vessel "Mary Ashcroft" is symbolic: She was built at Maldon, in Essex, in 1798, and after fishing in the North Sea for about half a century she was brought through the Caledonian Canal (in 1860) by Mr. Hugh Ashcroft and Pilot John Hesketh to Fleetwood, from where she fished till 1904 when she was wrecked on entering Whitehaven Harbour, and was then bought by Mr. Charles Pater, of that port, for £20; raised, refitted, and sent again to sea to be finally condemned as unseaworthy in 1917. Thus ended an honourable fishing career of 119 years during which those who worked this old vessel saw the great development of smacking, which culminated in 1885, and saw also the beginning of the process of decadence which is, apparently, now approaching completion.

The Herring Fisheries.

The pelagic fisheries had even worse luck than that which was experienced by trawling. There was never (in modern times) a home market for more than about half (at the very most) of all the herrings caught, and so the great drift-net fishery depended largely upon an export trade. This has had many ups and downs, but never so disastrous a period as that of 1914-1920. The two great markets were Russia and Germany, and the latter, of course, closed down on August 4th, 1914. With incredible difficulty the Russian market was kept open till the end of 1916 : in that year, for instance, a schooner took 200 barrels of salted herrings from Port St. Mary to Whitehaven, *en route* for Newcastle and Russia, and the freighage was 4/– a barrel across the Irish Sea. One cargo, worth £7,000, that did enter Russia cost £28,000 in freight and other charges. Another cargo (at least) was frozen up in the Gulf of Finland, and yet another had to be housed in sheds specially built at the port of landing. A new route was opened up, but in the end the political difficulties of the trade proved more formidable than did the natural ones and the export into Russia practically ceased. It is difficult to learn what was the volume of the trade with Russia and Germany during 1919 and afterwards, but certainly its methods must have resembled gambling rather than respectable business transactions. The great East Coast herring fishery carried on during 1919 and 1920 only because the Government guaranteed a price to the fishermen and took over the herrings packed.* This they seem to have done without either courage or conviction, for, early in 1921, it was announced that the guarantee would be withdrawn, and at the time of writing the chances are that

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* Which so far are largely unsold.

at least half of the East Coast herring vessels will be laid up during the coming season. Nevertheless, in view of the formidable menace of the rapidly-growing Norwegian and Dutch herring export trade it is hoped that the decision may be reconsidered. A contrast between the commercial policy, in regard to fishery, of this country in 1815 and 1919 would be very interesting did time and space permit one to make the investigation. In 1815, after the reopening of the Continental markets, the Government continued the bounties paid on vessels fitted out for deep-sea fishing, and for herrings, cod and ling cured for export, and it was only in 1830 that these " doles " were completely withdrawn—by which time the export trade had thoroughly been established. In 1921, however, after two years of what has been, in effect, a bounty on the herring fishery, the present Government has withdrawn the support it offered—and this in the face of a formidable Continental competitive trade which did not even exist in 1815.

The prosperity of the pelagic fisheries depends, then, on an export trade, and it is in this respect that scientific and industrial research come into consideration. The present method of curing herrings—by " gipping " and preservation in strong brine—was invented by a Dutchman in the 14th century, and it is still essentially the same method that is practised in Britain. It can be depended upon to keep herrings good for about a year, perhaps (so that the 1919 pack guaranteed and practically possessed by the Government must now be unsaleable). Just as it is in the chemical trades the method of " mass-production " seems to be a peculiarly British one, which largely excludes the manufacture of commodities in small quantities and prepared in numerous special ways. So while a great variety of herring conserves are prepared abroad British curers only export pickled herrings in large quantities, and but a negligible bulk of canned fish. During 1916 and 1917 a great deal was written and said about the establishment of an export fish-canning trade, particularly with regard to the practically unutilised British sprats. A good deal of scientific research work was initiated—and subsequently abandoned—but even this never got beyond the tentative laboratory phase. The application of laboratory methods to the investigation and improvement of the routine factory processes was never attempted—though such an extension is absolutely essential if the investigations are to benefit the industry. But even this display of interest in the canning trades had its effect, for there was a kind of incipient boom about the end of the war and several fish-canning enterprises on a large scale were projected, and certainly those engaged in the embryo British fish-canning industry were keenly alive to the value of experiment and investigation. Now an export trade is the essential condition for further development of the British herring, mackerel, pilchard and sprat fisheries, and headway in this can best be made by concentrating on canning. The pickled herring remains good for about a year and then rapidly and steadily deteriorates, while the herring or sprat canned in tomato sauce improves up to five years, or if canned in oil, up to ten years. In its keeping qualities, then, as well as in its much greater intrinsic and commercial value, the canned fish is obviously the basis of an export trade. But the bulk of the sprats and herrings at present canned in Great Britain are inferior in quality, and both scientific and industrial research is essential to the development of the trade.

As things are it is probable that something in the nature of a bounty on fish canned for export may also be indispensable. It would stimulate production, for an abatement of the Excess Profits Duty (which would have been, in effect, a bounty) might have led to greater output in 1917. Further, a bounty would have stimulated trade by leading to an improvement of the product—I assume that the payment of the " dole " would be made contingent upon a satisfactory inspection by a qualified official (as in the case of the branding of herrings by the Scottish Fishery Board). Thus the pack could gradually be made better. I see no objections to such a policy except those that are either doctrinaire, or bureaucratic, or simply foolish ones.

I think it is likely that the export herring trade of these Islands will ultimately regain its pre-war magnitude—if that is judged to be enough. Certainly it is unlikely greatly to exceed the level it attained just before the war. The great markets (Germany and Russia) are after all limited ones, and the South European and Eastern countries do not want pickled herrings (on the other hand there is an insatiable demand in the East for tinned fish of the sardine type). Already there is a great Norwegian trade, scientifically studied and organised, possessing a national unity, which seems to be very difficult to establish in this country, and turning out products of great excellence. Holland strives incessantly to regain her "place in the sun" which she possessed in the 16th century, and certainly the growth of her herring fisheries during late years has been remarkable. To rebuild the British herring export trade must therefore be a task of some difficulty, and I am convinced that in attempting it scientific and industrial research will be necessary, while State support, in the form of bounties, *may* be necessary.

The Inshore Fisheries.

It is not easy to obtain precise information as to the condition of the small-boat and longshore fisheries, but it is pretty clear that these also are on the decline. Trawling for fish by "nobbies" seems to have fallen off in Lancashire waters: thus, twenty years ago there used to be a small flotilla of Southport and Morecambe boats at Pwllheli for the summer fishing, but now one sees only an isolated vessel. There is little doubt that the growth of the holiday resorts has tended to transform the inshore fishermen into "bumboatmen," and against this tendency it is very difficult to strive. Just now, however, the efforts of the Fisheries Organisation Society seem to be having good results, as witness the Co-operative Societies at Fleetwood and Morecambe—enterprises that appear to me to have all the elements of success. There is no doubt at all that much more could be done to make shrimping and prawning as carried on by these Societies more highly profitable. I was told, at Morecambe, that there were, occasionally, "gluts" of shrimps, and that some means of preserving the "picked" product was very desirable. Here, then, there is an opportunity for industrial research: say, the preparation of fish and (real) Crustacean pastes; the "potting" of shrimps and prawns in various ways in hermetically-sealed glass vessels, and the preservation of picked shrimps by packing in sterilised bottles, as in the case of fruits. It is quite likely that all these methods may be sound ones from the commercial point of view, but they have all to be tested, and for this purpose machinery must be obtained. It would, no doubt, be difficult for the Co-operative Societies to obtain the plant and work this during the necessary experimental period. In short, a small experimental and demonstration factory is wanted, and, since there is little hope of obtaining this through the ordinary official channels, I make the suggestion to the Fisheries Organisation Society. So far as the inshore industry is concerned it is, hitherto, only the latter Society that has been able to "deliver the goods."

Musselling and Cockling.

The process of decadence is now nearly complete with regard to the shell-fisheries. The general ascription of the cause of enteric fever to sewage-polluted mussels and cockles has closed many markets and some mussel beds. I regard what has happened during the last dozen years as highly discreditable to public administration. The evidence that outbreaks of typhoid fever were set up by the contamination of mussels by sewage was, in all cases, strong enough *to justify remedial* *measures*, but I am pretty sure that in no case yet known would it have been legal evidence, strong enough to cause a judge to ascribe illness or death to the sewage contamination—at all events that has never been tested.

What mostly resulted from the investigations made by this Committee was a crop of administrative procedure. It was fairly easy for a local authority to set the machinery of the Shellfish Regulations in action: much easier, for instance, than to destroy the fly-breeding refuse in its own slums. That procedure involved no investigation other than procuring a sample and sending it to an analyst—or at the most making a "topographical survey." Even the methods of analysis have never been thoroughly tested and improved. There has been no recognised "standard of permissible impurity." There has been no adequate and systematic investigation of the general distribution of "coliform" sewage bacteria in the sea. There *have* been restrictions, and a confusion of administrative methods in the experience of which it gradually became evident that the local Fishery Authorities were practically impotent in the matter since their powers of regulation were inadequate, while the Central Authority was impotent for the same reason and also because of its want of resources. The authorities that do have the necessary regulating power—that is, the local Sanitary Committee and the Ministry of Health—have quite a different attitude with regard to the questions at issue.

So far as this Committee is concerned it cannot be said that it did not "explore every avenue" that promised escape from disaster. But the result is that the shell-fisheries are decadent, to say the least. Only in one part of the district (at Conway) has there been any success in dealing with the matter, and this success is to be traced to the outcome of scientific investigation carried on by the Ministry of Agriculture and Fisheries with the assistance of the Development Commission. So far as the mussel-fisheries of the Lancashire Coast are concerned there is little hope of similar measures being taken, and I can only suggest that the cleansing of polluted mussels for the markets is a matter for controlled private enterprise. I see no reason why this should not be successful, and no reason why the Fisheries Organisation Society should not enable a mussel-fisherman's Co-operative Society at Morecambe to construct and operate a mussel-cleansing tank.

The International Fisheries Investigations.

The above allusions to some of the difficulties under which the fishing industries labour are really pertinent, for it does not appear to me that fishery research just now has much relation to the problems that more immediately concern the fishermen and the owners of fishing vessels—whose existence is the reason why there are fishery administrators and investigators at all.

I attended the meeting of the International Council for the exploration of the sea, which was held in London, in March, 1920. This was the first post-war meeting, and it was very fortunate that it was possible. It is known that but for pressure brought to bear upon the Government during the war years, by the Board of Agriculture and Fisheries, the British contribution would have been withdrawn. In that case there is little doubt that the International organisation would have broken up, and, as things are, it is pretty certain that it could not have been resuscitated for some years to come. It is fortunate, then, that the Council met when it did and took up the threads dropped in 1914 : still, one must confess, it was disappointing to find that the representatives chose to look backwards rather than forwards in March, 1920.

To the scientific men the fishery problems were still the same as they were in 1914. Research, whether in fishery or in mathematics, must be entirely personal if it is to have complete success. Its mainspring is the curiosity and the desire to make new knowledge and find out things in the mind of the investigator, and it ought not to matter to him whether the results he is trying to obtain are useful or not—the result is the thing. One can easily " organise " scientific investigation to such an extent that this motive falls into the background—fortunately, as things are, such a degree of " scientific organisation " is not easily attainable! The problems upon which fishery investigators were engaged in 1914, then, easily and naturally slipped back again into prominence—and, of course, they still press for solution, and have to be taken up some time or other in the future.

What was really wanted in 1920 (and even at the end of 1918) was the point of view of the fishing industry rather than that of the administrators. Obviously it was the production of food commodities rather than the elaboration of legislative restrictions that the circumstances of the time indicated. The attitude of the fishing industry was well known, though the great commercial interests were unrepresented at the International Conference. It is remarkable that a much broader and more " statesmanlike " (using the word in its older and more creditable sense) view was taken by the industry than by the Statutory Fishery Authorities. I attended most of the meetings held by the Reconstruction Committees of the National Sea-Fisheries Protection Association in 1919 and 1920, and, even then, the present situation and its difficulties were (in great measure, at least) anticipated.* A coalescence of the activities of the various National and Departmental Statutory Authorities concerned with fisheries was strongly urged: it was hoped that the Association would be able to persuade the Government that fishery, in the international sense, was a proper subject for arrangement at the Peace Conference; codification of fishery law was urged; internationalisation of

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* For instances, in the " Memorandum " submitted to Mr. Prothero in 1918, and in the schemes of reconstruction prepared subsequently by the industry and its advisers.

the Island of Heligoland was suggested; a programme of scientific research was drafted; schemes of education and technical training for fisher lads were prepared—and so on. But what has since happened has fallen very far short of these ideals. There is still no suggestion, even, of education and training for fishermen, and, on the whole, scientific research is much less well provided for than it was in 1913. The Fisheries Bill promised in the King's speech in 1920 has not yet appeared. I don't suppose that fishery was even mentioned at the Peace Conference, and as for vesting the Prussian Marine Biological Station, and the revenues of the Island of Heligoland, in the International Fisheries Council—that, perhaps, would hardly have been regarded as "practical politics." To be sure it might only have been the occasion for an irritatingly bureaucratic and wasteful administration! Doubtless the reconstruction suggested by the fishing industry in 1918-20 will come about—sometime—and when it does it ought to be remembered what was its genesis.

Russia was not represented at the 1920 International Meeting, nor were the Germans, although informal communication with some of the latter investigators had been reopened, and it was known that the exploring vessel, "Poseidon," had been working since September, 1919. France, which had hitherto been unrepresented, sent a delegate and experts, and it was expected that the United States of America would also come in: this, however, has not yet been arranged, so far as I know.

The various sections of the Conference resumed their deliberations very much where the latter were suspended in 1914 except for one matter—the effect of the admiralty restrictions of 1914-18 upon the fish population of the North Sea.

Over-Fishing in the North Sea.

It had generally been agreed that there *was* over-fishing in some areas—particularly the North Sea—though there were exceptions to this attitude: that of Professor McIntosh, for instance, as expressed in his well-known book, "The Resources of the Sea." One must not forget that "over-fishing"—or rather, a progressive diminution in the quantity of socially valuable fish taken from the North Sea—has not yet been demonstrated beyond all shadow of doubt. But however that may be it was agreed that there had been much less trawling during the war years than was formerly the case, and so *there ought to have* accumulated a "stock" of large plaice. This was, of course, the species upon which most research had been made before the war, and the Council had already "adumbrated" certain tentative proposals (I think that is the best way to put it) with regard to international regulations. It was important, then, that the effect of the great decrease of exploitation should be estimated: were there more large plaice in the North Sea in 1920 than in 1913? The Danish experts brought forward what, to my mind, was an unconvincing argument that large plaice were more numerous in the latter year than in the former one, and the English investigators produced data which, I think, put the matter beyond dispute. But whether the increase in the larger plaice was to be traced to under-fishing in 1915-18, or to a natural periodicity was not so certain—I return to this point later. Anyhow, another year of "intensive plaice investigation" was decided upon and arrangements for the conduct of this were drafted. The nature of the possible restrictions to be submitted, later on, to the various governments was not formally discussed, but it was understood that these would probably take a certain form. Upon the condition that the Council would come to the scratch, as it were, and suggest *some* legislative restrictions depended the future of the investigations—this was the attitude, it must be remembered, at a time when a partial collapse of the British steam-trawling industry had already been anticipated, and when it was fairly certain that the exploitation of the home seas had fallen off, and was likely to continue to fall off. The restrictions that were in the minds of the delegates were, of course, legal size-limits and perhaps a closure of part of the "Flemish Bight." There was no general agreement as to the precise shapes of the restrictions—the Dutch delegates, for instance, adopted their traditional, national attitude of evasion. As to whether the restrictions that were in question could have been enforced—that question did not appear to matter. The discussion had, in fact, that kind of tone which one calls "academic." Obviously the closure against trawling, by steam and motor-driven trawl-vessels, of a large area of the North Sea well outside the territorial limits ; the prevention of landing of plaice of less than 20 or 22 cms. in length, according to the season, and the closure of the spawning area in the Flemish Bight would involve a rather considerable international police service. Whether it is practicable to provide this at a reasonable cost, and to render it efficient, was not considered.

The Herring Fisheries.

The Council took up the question of the "Herring Races" where it had been left in 1914. It was resolved that the biometric investigations that were in progress then should be renewed. It was decided to undertake an historical enquiry into the fluctuations of the fisheries for herrings which have been experienced in most European seas during the last three centuries. The Norwegian and Danish fishery services undertook the organisation of these investigations.

The Hydrographic Research.

The position of affairs was discussed in the hydrographic and plankton sections, and although arrangements for the resumption of the work, on much the same lines as it was conducted before the war, were thought out nothing practical has, so far, been done. As the Committee are aware, the periodic cruises made by the "James Fletcher" during the pre-war years have not been resumed, nor have the regular hydrographic investigations that were conducted by the British national fishery services in 1914 been restarted on the pre-war scale. It is apparent now that these monthly, or even quarterly cruises are impracticable because of the greatly increased cost of maintaining the vessels in full commission. Proposals for a greatly modified scheme of research were made by the representatives of the Ministry of Agriculture and Fisheries, and the principal feature of these was the collection of samples and observations by means of transatlantic and cross-channel passenger vessels. I think this modification of the older programme is thoroughly practical and adequate. With regard to the Irish Sea, for instance, it would mean sending assistant naturalists once a month on one or more of the vessels working between, say, Fishguard and Rosslare, Holyhead and Dublin, Liverpool and Douglas, and Fleetwood and Belfast, and it would, probably, be quite easy to make arrangements for that purpose with the various Companies. The new programme would mean cutting out the collection of samples of water from the bottom and intermediate levels, since to obtain these soundings are required. But it is likely that surface samples and observations would give us most of the data that are immediately wanted. I undertook, on behalf of the Department of Oceanography at Liverpool, to look after such work of this kind as would be possible in the Irish Sea and in the Atlantic with respect to vessels sailing from this port.

Plaice Investigations in the Irish Sea.

After the meeting of the International Council an arrangement was made between the Ministry of Agriculture and Fisheries and the Committee for the conduct of research into the "plaice problem." The grant of £1,650 made by the Development Commissioners in 1914 was renewed for the financial year 1920-21, and most of it was expended upon the part maintenance of the "James Fletcher" when engaged on this work and upon the payment of the salary and expenses of Mr. W. Birtwistle, who was appointed as Naturalist in the summer of 1920. Weekly samples of plaice were obtained from the various fishing grounds during the period June-December, 1920, and were sent to the Fisheries Laboratory at Liverpool, and the usual length measurements were made on board the vessel when fishing. In this way records of the lengths, when caught, of some 26,000 plaice were obtained on the fishing grounds, and detailed records of the length, sex, stage of maturity, weight, condition and food of about 6,000 plaice were made in the laboratory. Mr. Birtwistle and Mr. R. A. Fleming, Technical Assistant in the Oceanography Department, carried out these investigations. The work is tedious and uninteresting because of its routine nature, but sincerity and accuracy in doing it is essential if it is to have value. I am satisfied that invariable care and scientific accuracy characterised the investigation.

Another arrangement was made between the Ministry and Department of Oceanography with respect to the same research, and a sum of money was paid to the University for this purpose. Two "ichthyometric assistants," Mr. W. C. Smith and Commander A. E. Ruxton, were transferred from the Ministry's staff and were paid out of the sum granted. These workers went to sea in steam-trawlers, smacks and small boats and made observations and measurements of the fish caught in the ordinary routine of commercial trawling. In this way very valuable data were obtained from grounds unworked by the "James Fletcher"—the offshore regions between Lancashire and Isle of Man and the northerly grounds between the Island and the Solway Firth. The fish studied was the plaice, but I have gone over the records made by the measurers and have extracted the measurements of soles caught by the smacks. These are interesting since they form the first extensive series of observations on the characteristic lengths of soles caught offshore in the Irish Sea. I hope it may be possible to resume this work in May of 1921, when the sole spawning season occurs.

I have made a report on these results and have incorporated in it a summary of the Irish Sea plaice investigations carried on by the Committee during the years 1908-1913. This enables one to make a comparison between the post-war year 1920 and the pre-war period. When that has been done it becomes evident that the marked increase in the abundance of large plaice which characterises the Irish Sea no less than the North Sea grounds need not be due to the partial cessation of trawling brought about during 1913-18 by the wartime restrictions. In last year's report Mr. Daniel summarised the results of the very valuable series of trawling experiments made during the years 1890-1920 by Captain G. Eccles. These relate to a very typical "small-plaice" fishery ground, that off the Mersey Estuary, and they show an evident periodicity in the abundance of plaice in this region. During the years 1895-6 plaice were very abundant, and the same was the case during the years 1909-10. Again plaice were relatively very scarce during the years 1905-6 and 1915-16, so that during the time in which the Committee has been in existence there have been two cycles of abundance and poverty of plaice. I have shown, also, that there are very marked differences from year to year in respect of the proportion of baby plaice of six to twelve months old that are taken in the shrimp trawl-nets. This means that in some years great numbers of the plaice fry that have hatched out in the Irish Sea die—probably because there is, in those years, insufficient planktonic food in the water about the time when the fry are pelagic—that is, before they sink down to the sea-bottom as completely formed little flat-fish.

So when one allows for this periodicity in the abundance of plaice on the fishing grounds it is not at all certain that the effect of the wartime restrictions on trawling was to increase the natural stock of the larger sizes of plaice. It may merely be the case (and this is what the Mersey statistics indicate) that the years 1920-22 represent a natural maximum of abundance, while the years 1914-15 represent a minimum.

Investigations in the Solway Firth.

The special grant for plaice investigation made by the Ministry of Agriculture and Fisheries has enabled us to investigate, for the first time, the fishery in the Solway. The upper reaches of the Firth are a typical small-fish region while fairly large plaice occur, in the autumn months, just north and south of St. Bees' Head. At the entrance to the Solway lies an important plaice spawning ground, and ripe fish with clear, running eggs were taken there at the end of February. The shoals just south-west of Maughold Head, in Isle of Man, are a good plaice ground during the first months of the year, but later the larger fish leave there to spawn at the mouth of the Firth. These investigations are in progress, and I hope that we may be able to study this very interesting region during 1921. In the meantime Mr. W. C. Smith has made a provisional report on the Solway to the Ministry of Agriculture and Fisheries.

Work on the Mussel.

Mr. Daniel has now nearly completed a year's observations on the seasonal changes that are undergone by the common mussel. The investigation has been rather difficult since none of the ordinary methods of chemical estimation of the " proximate food principles," proteid, fat and carbohydrate, can be strictly adapted to this shellfish. Modifications in the known methods have to be elaborated in order that the investigation may be as precise as possible. It has been found that the common mussel is a very abundant source of the rare and expensive substance, *glycogen*, the proportion of which in mussel flesh is connected, in some way, with the spawning act of these shellfish. This investigation is far from being complete, and, so far, a complete spawning cycle has not been studied. A summary of the main results obtained so far is given in this Report by Mr. Daniel.

So far, then, the work of the Fisheries Laboratory has related partly to questions that interested us before the war period (and which, of course, must still be investigated) and partly to questions that are, in my opinion, of particular interest at the present time. To the former category belong the problems of over-fishing, size-limits, and the nature of restrictions designed to prevent impoverishment of the fishing grounds. These I regard as routine investigations which ought to be pursued in order that data may be available in the future when they become of pressing importance. So it is necessary, from this point of view, to collect statistical information with regard to such matters as the prevalent sizes of plaice, soles, cod, and some other important species of fish : the composition of the fish populations with regard to year classes and so on. By and by all this information will accumulate and can be worked up from new points of view.

To the latter category of investigations belong such as will assist in production—when the time comes that an export trade in fish may again attain large dimensions. These researches ought to relate to the methods of preservation of fish whether by refrigerating, curing, canning, or by other means industrially practicable. In dealing with them there are a host of questions which involve difficult and rather abstruse chemical and bacteriological investigations, and, unfortunately, it has not been possible yet to make a really promising beginning with such work. There is also the very important matter of the further utilisation of the enormous abundance of mussels, cockles, shrimps and prawns that exist in local waters. First of all a renewed survey of the shellfish beds on this coast is now necessary, and this ought to include not only an examination of the foreshore from the point of view of sewage pollution, but it ought also to include a natural history survey. The present trade in mussels as food commodities appears to be coming to an end, and nothing can prevent this but a rational attitude with regard to questions of pollution and a satisfactory standardisation of public health practice. This depends on research. Along with this must go further investigation into the methods of cleansing sewage-polluted shellfish, and the development of means of preserving these animals in one form or other. The latter remark applies also to the trade in shrimps and prawns. This is limited, as a trade in fresh or potted fish, and some more permanent methods of preservation must be devised.

One of the troublesome questions which the Committee may have to consider in the near future is that of size-limits with regard to plaice, and possibly other Irish Sea fishes. The matter does not seem to me to be urgent, for, just now, there is a marked decline in trawling, both with regard to steam vessels and smacks. Inshore fishing has also fallen to a notable extent, and the effect (" if any ") of this slackening in trawling ought to be equal at least to that of any restrictions on the size of fish that may legally be landed. It does not appear, then, that there is any good reason for the imposition of such restrictions—at the present time, at all events.

It is even doubtful (or at least, so I think) whether or not restrictions on the sizes of plaice landed on the North-west Coast of England would do any real good. If they benefited anyone at all it would be the steam trawlers and smacks fishing offshore in St. George's Channel and in the Irish Sea. Whether or not they would do so is not certain, and I don't think the benefit to the large vessels would be very apparent. Size-limits of 20 or 22 cms. in the Irish Sea would certainly be very difficult to enforce, and the present police organisation would, I think, fail in such an attempt if the inshore men offered any serious resistance.

Further, I think it very doubtful whether the prevention of landing of plaice less than 20 to 22 cms. long would result in a marked increase in the prevalent size of the plaice caught offshore. To my mind such restrictions may have to be accompanied by transplanting operations carried out on a fairly large scale if they are to be justified. It is only that further information may be obtained as to the nature of such transplanting that the plaice investigation is being continued, for we, probably, have all the statistical data that are required if the only question at issue is whether size-limits should be recommended, and if so, what limits. The whole question is discussed, in detail, in the report which I have made to the Ministry of Agriculture and Fisheries.

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UNIVERSITY, LIVERPOOL
March, 1921.

SUMMARY OF THE WORK AT PIEL.

By Andrew Scott.

Classes at Piel.

After an interval of five years, the classes in Navigation and Marine Biology for fishermen were resumed in the spring of 1920. The counter-attraction of high wages compared with the value of the Studentships kept the steam-trawler men at sea. Only the inshore men—the mussellers, cocklers, shrimpers, etc.—applied for enrolment. Three classes were held between 23rd February and 20th April. The second class began immediately after the first class ended. There was an interval of about a month between the second and third classes. Most of the men had been on various kinds of active service during the war.

Mr. R. J. Daniel, B.Sc., had charge of the teaching work, taking both the Navigation and Biology Courses. Dr. James Johnstone, who had carried on the Biology Course from the initiation of the scheme for educating the fishermen in the life-histories of economic marine animals, had entered upon his duties in the Oceanography Department at Liverpool University and was unable to be present until the last class.

The students in the first class were all Morecambe men. Those in the second class were selected from Morecambe, Fleetwood, Blackpool and Southport. The third class was again entirely composed of Morecambe fishermen. The Studentships for the Blackpool and Southport men were provided by their own Education Authorities. The Education Committee of the Lancashire County Council provided all the others.

The following are the names of the men who attended the classes :—

23rd February to 5th March.—Edward Baxter, John Baxter, R. Baxter, Rd. Baxter, William Baxter, James Swain, Amos Willacy, H. Willacy, Reuben Willacy, Daniel Woodhouse, F. Woodhouse and James Woodhouse—all from Morecambe.

8th March to 19th March.—John Alexander, Thomas Bell, John Bolton, Percy Bond, Mark Gerrard, Herbert Hodgson, Arthur Johnston, Morecambe ; William Curwen, Herbert Rawcliffe, Ernest Wilson, Fleetwood ; Robt. Bamber, R. Cartmell, Geo. Cornall, Blackpool ; John Ball, James Rigby, Southport.

19th April to 30th April.—W. Armistead, Richard Bartholomew, Walter Bell, Samuel Bond, Thomas Bond, Thomas Gerrard, Walter Gerrard, Thomas Mayor, George Mount and J. Woodhouse—all from Morecambe.

A class in Navigation and Marine Biology for school teachers was conducted by Dr. Johnstone and Mr. Daniel from August 2nd to 13th. A number of names had been received for this class, but only five gentlemen presented themselves when the work commenced. They were C. Saer, S. A. Palmer and C. E. Watson, Fleetwood ; Harold Milner, West Bromwich, and E. R. Bird, S. Lowestoft. The boarding-house accommodation at Rampside and Roa Island is very limited. It is almost impossible to secure rooms at short notice, especially during the early part of August as that is the summer holiday time at the large works in Barrow. In event of the August vacation class for teachers being continued it would be well to try to complete arrangements as early as possible in the spring.

Fish Hatching.

A return to this part of the work was made in the spring of 1920. Large plaice were collected in Luce Bay in October, 1919, and conveyed to the tanks at Piel, where they afterwards matured and provided a supply of eggs. For a time, at the end of 1919 and the beginning of 1920, there was every possibility that the Furness Railway would be unable to keep up the supply of gas essential for working the gas-engine. The lengthy strike of moulders at that period rendered it impossible to renew defective parts of the plant, especially the cast-iron retorts which had become badly cracked, allowing the gas to pass into the furnace instead of into the gasometer. The Gas Department of the railway did all it could to keep up the supply. The store tanks had to be filled up every tide, and the circulation cut down to a minimum to keep the fish alive as long as possible, in event of a breakdown, and allow time to effect temporary repairs. This probably accounts for a late spawning, as no fertilised eggs were obtained until 24th March. The last fry were set free on 15th May. Altogether 1,300,000 eggs were collected and incubated. Slightly over 1,000,000 fry were hatched and set free. No flounders were dealt with.

The Library.

One of the rooms was especially fitted up with cases of shelving during the year so that all the books could be collected together and made more easily accessible to workers. Miss Allen, Departmental Librarian at Liverpool University, came later on in the summer and rearranged the collection, and also prepared a Card Catalogue of it. There is space for considerable additions, and the catalogue will be easy to keep up to date.

Plankton.

573 samples of plankton, taken in connection with the intensive study investigations, were received and quantatively examined during 1920. The results are partly dealt with later on in the report. Samples for comparison were collected from time to time and examined.

Barrow Channel and the Oil Traffic.

Articles have appeared recently in the Press and elsewhere drawing attention to the probable destruction of pelagic life, including fish-eggs and larvae, by the rapid extension of the use of fuel oil in place of coal in all kinds of mechanically-driven vessels. It has been suggested that the accidental or wilful discharge of oil into the sea may produce a surface film which prevents the water absorbing air from the atmosphere so that eventually the surface organisms may be asphyxiated. If the microscopic food of the larval fishes were thus destroyed the larvae would starve to death. The destruction of larvae through the want of sufficient food is not at all improbable, but this is more likely to be brought about by an early spawning of the adult fishes and a late arrival in the spawning area of the winter and spring diatoms, etc. The investigations carried on by the Lancashire Sea-Fisheries Committee and by the Liverpool Marine Biology Committee, which extend over a period of nearly thirty years, show quite clearly that the arrival and abundance of the spring, summer, autumn and winter plankton varies from year to year.

Barrow, within recent years, has become a very extensive oil depot, and many millions of gallons arrive in tankers during the year. Many of these tankers burn fuel oil. A considerable export trade to distribute the oil is carried on by smaller vessels. The oil-carrying trade has largely developed since the laboratory was established at Piel in 1897. The whole of the sea-borne traffic passes quite close to the establishment, and any detrimental effect on the life in the channel would not have escaped notice. Large beds of mussels occur in the channel, and there is a general bottom fauna of zoophytes, sponges, echinoderms, worms, crustacea, mollusca, tunicata and fishes. Fully one-third of the periwinkles landed in the whole of the Lancashire and Western District are sent away from Piel Railway Station. These are collected along the sides of the channel at low-water, and so far as the records show there is no decrease in the output per man. In the period 1906-1914 the mean annual man average was slightly under six tons. In the period 1915-1917 it rose to nearly nine and a half tons. In 1920 the mean annual man average was nearly eleven tons. Mussel fishing is prohibited owing to danger of sewage contamination, but the beds have not diminished in area or apparent population. Formerly, very large succulent mussels were obtainable inside the dock area. These have practically disappeared since the building and fitting-out of submarines was started at the shipyard. This is generally attributed to the escape of acids from the battery tanks. Dead conger-eels and other fishes have been seen occasionally floating about in the vicinity of the fitting-out berths. The fishery for sea-fish in the channel is carried on throughout the year, but the results are very variable. The fishermen suggest various reasons for this such as too much steamer traffic, too much dredging, and so on. It is quite certain that the success of the plaice-fishery at any rate depends largely on the abundance of young mussels up to half an inch in length on the beds. As soon as the supply is consumed the fish leave the area. The repopulation of the beds is going on every year, but accidents occur, such as sanding up and washing away by storms and tides, and a fishery for plaice may only occur at irregular intervals. The permanent bottom fauna, which can be seen very well at low-water of a spring tide, has undergone no diminution. The plankton of the channel corresponds with what is found offshore and varies with the seasons. Fish eggs and larvae are frequently found in the spring samples.

In 1919 and 1920 complaints were received from the stake-net fishermen at Roosebeck that large quantities of thick oil refuse were coming ashore and filling the tails of the nets as the tide receded. Numbers of sea-birds were washing ashore in a dead and dying condition. The matter was gone into and the fishermen's reports were found to be correct. The receding tide for days at a time left the shores coated with oil, which made everything very slippery. Quantities of thick, black oily matter of a somewhat spongy consistency were also washing up, and in this were immersed dead and dying black ducks and divers. A point that was noted and also corroborated by the fishermen was the complete absence of dead or sickly fish, and the shell-fish, mussels, periwinkles, etc., were not being affected. It seemed to be quite clear that the oily matter, although it was apparently destroying the sea-birds, was not injuring the fish and shore fauna. The barnacles everywhere between tide marks set free their larvae in the spring of 1920 and 1921 in great abundance as in past years, and later on the young barnacles attached themselves to the bottoms of boats. The destructive action, so far as has been discovered, was entirely confined to the birds. What probably happened was that the birds regarded the floating masses as garbage of some kind and dived into them, or they may have come up accidentally into them after a dive some distance away. The whole bird would at once be covered with the frothy oily matter, which was very adhesive, and would finally become suffocated. At that time vessels were being reconditioned, and the refuse from the bilges, etc., was discharged into barges. It was then conveyed out into Morecambe Bay where it was discharged, and the southerly winds drove it ashore. The occurrence of oil refuse on the shores of the channel was reported to Mr. J. M. Mawson, the then representative of the Barrow Town Council on the Sea-Fisheries Committee, and it came to an end. No further complaints have been received from the local fishermen.

There are natural phenomena occurring every day at sea which set up perfectly smooth places on the wind-roughened surface. Shoals of pelagic organisms may become massed together by the action of wind and tides, and drift ashore as an oily tract. The winter invasion of *Noctiluca*, described in the Report for 1919 (p. 6), supplied a characteristic instance of wind action and surface drift on pelagic life. The whole of the north side of the water in the channel for a distance of nearly a foot out presented the appearance and consistency of brick red-coloured grease. It was due to a huge abundance of *Noctiluca* drifted into the harbour by a slight southerly wind. An uninstructed person might well be excused if he had reported this as grease.

The correct management of an aquarium depends upon one of two things. There must either be a constant circulation through the tanks, or little or no circulation but an abundance of growing vegetation. Aeration with a force pump has much the same result as the action of growing vegetation. Should the circulation stop through any cause, the animals in a tank which has no vegetation die off in the ratio of their vitality. Organisms such as *Noctiluca* have been kept alive in a perfectly still tank for a month. An aquarium with growing vegetation in it requires practically no circulation. We have a small freshwater aquarium that was started many years ago in connection with the classes for school teachers. Vegetation was induced to grow and it still continues in a flourishing condition. All that is needed is a cupful of tap water added at intervals to make up the loss from evaporation. Various organisms, such as *Hydra*, Copepoda, Cladocera and *Limnaea*, have become established and one generation succeeds another. A freshwater stickleback placed in the jar in August, 1920, remains alive and healthy after a lapse of eight months. Weeds and Diatoms, in the presence of light, are the chief aerators of the sea. The water is never perfectly still and the pelagic organisms are constantly moving up and down in it. A surface film of oil will not cut off the light sufficiently to prevent the algae and Diatoms keeping up the aeration. Its lighter specific gravity will also keep it clear of the pelagic organisms. When the film of oil stranded on the sands, the *Navicula*, and other species of Diatoms which form conspicuous brownish patches on the surface, were not destroyed although the film was spread over them. There is as yet, so far as Barrow Channel is concerned, no indication that the oil trade and the extending use in the consumption of fuel oil has had any harmful effect on the fauna and flora. The chief engineer of one of the tankers making frequent voyages to Barrow tells me there need be no discharge of oil or fuel oil into the water. That would be regarded as uneconomical by the owners and add to the running costs of the vessel. The oil is recoverable from the refuse.

REPORT ON PLAICE MEASUREMENTS, 1920.

By W. Birtwistle.

Although a few samples were examined in the early part of the year, the main investigations did not commence until June, and the bulk of the data was obtained between this month and the end of the year.

The measurements of length alone were all carried out on board on live fish, either in the sailing cutters or on the fishery steamer "James Fletcher," and the age and weight determinations were made in the Fishery Laboratory of the University of Liverpool from unselected samples of the ordinary catches. The three main areas sampled were Nelson Buoy, Mersey Estuary and North Wales.

Nelson Buoy Area is the area enclosed by a line drawn N.E. from Morecambe Bay Lightship to Walney, and a line drawn S.S.E. from Morecambe Bay Lightship until Formby Point is due East. Join these points for the southern limit. It does not include the area enclosed by a line drawn from Roa Island to Sunderland Shoulder.

Mersey Estuary includes all that area enclosed by a line drawn from Formby Point to Point of Ayr (Wales).

North Wales includes all that area between Point of Ayr and Point Lynas. It includes Beaumaris Bay to the northern entrance to the Menai Straits.

Summary of Fish measured at Sea.

Area.	Number.	Period.	
Nelson Buoy	8,046	June-December	6 inch Trawl.
North Wales	5,656	January-December	,,
Mersey Estuary	7,653	March-November	,,
,, ...	1,249	November-December	Shrimp Trawl.
Carnarvon Bay	414	April-August	6 inch Trawl.
Menai Straits	1,152	January-December	,,
Cardigan Bay............	1,177	April-September	,,
Luce Bay	194	October	,,
Morecambe Bay	415	August-December	Stake Nets at Flookburgh
Total	25,956		

Summary of Fish examined in Fishery Laboratory, Liverpool.

Area.	Number.	Period.	
Nelson Buoy	1,884	June-December	6 inch Trawl.
North Wales	1,616	June-December	,,
Mersey Estuary	710	May-November	,,
,, ...	866	November-December	Shrimp Trawl.
Menai Straits	829	January-November	6 inch Trawl.
Carnarvon Bay	34	July	,,
Total	5,939		

TABLES I to V are summaries of Length-Frequencies of fish taken on the various grounds by the 6 inch mesh Fish Trawl.

TABLE VI is a summary of Length-Frequencies of fish taken in the Mersey Estuary Area by the 2 inch mesh Shrimp Trawl.

TABLE VII is a summary of the Sex-Age Group-Frequencies taken in the North Wales, Nelson Buoy, Mersey Estuary Areas by the 6 inch mesh Fish Trawl from June to December.

TABLE VIII is a summary of the Sex-Age Group-Frequencies taken in the Mersey Estuary by the 2 inch Shrimp Trawl, from October to December.

TABLE IX is a summary showing the variations in value of the Length-Weight Coefficient *K* from the respective grounds from June to December. In this table is given the number of fish from which *K* has been calculated.

For indispensable assistance in the very laborious, routine, biometric work of this and the following report I am much indebted to Mr. A. Fleming, Technical Assistant in the Oceanography Department.

Tables I-V.

Summaries of the Length-frequencies of Plaice taken on the various Fishing Grounds during 1920, by the 6 inch mesh Trawl.

Table I. Carnarvon Bay Area.

Length.	April.		May.		June.		July.		August.	
	No.	%	No.	%	No.	%	No.	%	No.	%
14·5	...	...	...	...	1	0·98	...	...	...	...
15·5	...	...	...	...	2	1·96	...	...	2	10·00
16·5	...	...	...	...	5	4·90	...	...	2	10·00
17·5	1	2·70	...	...	1	0·98	1	0·54	4	20·00
18·5	1	2·70	...	...	1	0·98	...	...	2	10·00
19·5	...	...	3	4·29	4	3·92	1	0·54	3	15·00
20·5	3	8·11	4	5·71	5	4·90	2	1·08	1	5·00
21·5	1	2·70	3	4·29	7	6·86	3	1·62	2	10·00
22·5	6	16·22	2	2·86	7	6·86	9	4·86	2	10·00
23·5	1	2·70	4	5·71	12	11·76	11	5·94	1	5·00
24·5	1	2·70	...	...	10	9·80	19	10·27	1	5·00
25·5	3	8·11	3	4·29	8	7·84	16	8·65	...	...
26·5	2	5·40	3	4·29	12	11·76	23	12·43	...	...
27·5	3	8·11	10	14·29	12	11·76	25	13·51	...	...
28·5	1	2·70	8	11·43	7	6·86	16	8·65	...	...
29·5	2	5·40	6	8·57	1	0·98	33	17·84	...	...
30·5	2	5·40	9	12·86	3	2·94	11	5·94	...	...
31·5	...	...	1	1·43	1	0·98	8	4·32	...	...
32·5	2	5·40	7	10·00	...	...	3	1·62	...	...
33·5	...	...	...	...	...	...	2	1·08	...	...
34·5	...	...	3	4·29	...	...	2	1·08	...	...
35·5	1	2·70	1	1·43	1	0·98	...	...	...	...
36·5	...	...	1	1·43	1	0·98	...	...	...	...
37·5	1	2·70	1	1·43	...	...	...	...	...	...
38·5	...	...	...	...	...	...	...	...	...	...
39·5	...	...	...	...	...	...	...	...	...	...
40·5	...	...	...	...	...	...	...	...	...	...
41·5	1	2·70	1	1·43	...	...	...	...	...	...
42·5	2	5·40	...	...	1	0·98	...	...	...	...
43·5	...	...	...	...	...	...	...	...	...	...
44·5	...	...	...	...	...	...	...	...	...	...
45·5	...	...	...	...	...	...	...	...	...	...
46·5	...	...	...	...	...	...	...	...	...	...
47·5	1	2·70	...	...	...	...	...	...	...	...
48·5	...	...	...	...	...	...	...	...	...	...
49·5	1	2·70	...	...	...	...	...	...	...	...
50·5	...	...	...	...	...	...	...	...	...	...
51·5	1	2·70	...	...	...	...	...	...	...	...
Totals ...	37	99·95	70	100·03	102	99·96	185	99·97	20	100·00

Table II. North Wales Area. Redwharf Bay and Beaumaris Bay.
6 inch Trawl.

Length.	January.		February.		March.		April.		May.		June.	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
13·5	...	...	...	...	...	...	...	...	1	2·32	...	...
14·5	...	...	1	0·39	...	...	...	...	3	6·98	1	0·40
15·5	...	...	...	...	...	...	...	...	8	18·60	1	0·40
16·5	1	0·74	...	...	...	...	2	2·32	6	13·95	3	1·20
17·5	13	9·63	7	2·74	1	7·14	1	1·16	5	11·65	9	3·60
18·5	9	6·67	14	5·49	...	...	3	3·50	4	9·30	21	8·40
19·5	9	6·67	20	7·87	1	7·14	5	5·81	1	2·32	18	7·20
20·5	11	8·15	19	7·45	1	7·14	8	9•30	4	9·30	31	12·40
21·5	9	6·67	19	7·45	1	7·14	6	6·98	3	6·98	30	12·00
22·5	10	7·41	9	3·53	...	...	9	10·46	1	2·32	19	7·60
23·5	6	4·44	9	3·53	1	7·14	4	4·65	...	...	17	6·80
24·5	2	1·48	13	5·10	...	...	5	5·81	...	...	17	6 80
25·5	8	5·93	12	4·70	...	...	5	5·81	...	...	17	6·80
26·5	2	1·48	6	2·35	...	...	3	3·50	...	...	10	4·00
27·5	7	5·18	7	2·74	...	...	5	5·81	1	2·32	10	4·00
28·5	7	5·18	3	1·18	1	7·14	2	2·32	...	...	10	4·00
29·5	...	...	4	1·57	1	7·14	4	4·65	...	...	7	2·80
30·5	...	...	7	2·74	...	...	4	4·65	1	2·32	6	2·40
31·5	1	0·74	3	1·18	...	...	1	1·16	1	2·32	4	1·60
32·5	3	2·22	10	3·92	...	...	...	...	1	2·32	3	1·20
33·5	2	1·48	8	3·14	...	...	1	1·16	...	...	4	1·60
34·5	4	2 96	10	3·92	...	...	3	3 50	...	...	2	0·80
35·5	4	2·96	8	3·14	...	...	1	1·16	...	...	1	0·40
36·5	3	2·22	6	2·35	...	...	3	3·50	...	...	1	0·40
37·5	5	3·70	7	2·74	...	...	3	3·50	...	...	1	0·40
38·5	1	0·74	5	1·96	1	7·14	4	4·65	...	...	1	0·40
39·5	2	1·48	2	0·78	...	...	2	2·32	...	...	1	0·40
40·5	5	3·70	8	3·14	1	7·14	2	2·32	...	...	1	0·40
41·5	2	1·48	6	2·35	1	7·14	...	...	...	...	...	...
42·5	2	1·48	7	2·74	1	7·14	...	...	...	...	1	0·40
43·5	1	0·74	4	1·57	...	...	...	...	1	2·32	...	...
44·5	...	...	3	1·18	...	...	...	...	1	2·32	3	1·20
45·5	...	...	3	1·18	...	...	...	...	...	...	...	...
46·5	2	1·48	4	1·57	...	...	...	...	1	2·32	...	...
47·5	...	...	1	0·39	1	7·14	...	...	...	...	...	...
48·5	...	...	1	0·39	...	...	...	...	...	...	...	...
49·5	1	0·74	3	1·18	...	...	...	...	...	...	...	...
50·5	1	0·74	3	1·18	1	7·14	...	...	...	...	...	...
51·5	1	0·74	2	0·78	...	...	...	...	...	...	...	...
52·5	1	0·74	1	0·39	1	7·14	...	...	...	...	...	...
Totals ...	135	99·97	255	100·00	14	99·96	86	100·00	43	99·96	250	100·00

Table II. North Wales Area. Redwharf Bay and Beaumaris Bay. 6 inch Trawl—*continued.*

Length.	July.		August.		September.		October.		November.		December.	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
13·5	...	...	...	...	...	...	1	0·13	...	...	...	...
14·5	4	0·32	1	0·12	...	...	...	...	1	0·18	2	0·16
15·5	2	0·16	...	...	...	...	1	0·13	1	0·18	...	...
16·5	17	1·34	...	...	...	...	8	1·05	1	0·18	...	...
17·5	51	4·03	7	0·85	...	...	19	2·48	12	2·11	10	0·80
18·5	86	6·79	45	5·49	6	2·70	62	8·10	22	4·01	27	2·16
19·5	123	9·72	95	11·58	11	4·95	125	16·34	44	8·03	29	2·31
20·5	117	9·24	99	12·07	24	10·81	74	9·67	48	8·76	42	3·35
21·5	112	8·85	79	9·63	23	10·36	80	10·46	49	8·94	40	3·19
22·5	95	7·50	69	8·41	21	9·46	41	5·36	55	10·04	44	3·51
23·5	118	9·32	77	9·40	17	7·66	49	6·40	26	4·74	62	4·95
24·5	125	9·87	58	7·07	17	7·66	38	4·97	35	6·39	58	4·63
25·5	110	8·69	53	6·46	15	6·76	47	6·14	36	6·57	70	5·60
26·5	83	6 56	45	5·49	22	9·91	53	6·93	31	5·66	75	5·99
27·5	59	4·66	30	3·65	17	7·66	41	5·36	31	5·66	113	9·02
28·5	41	3·24	37	4·51	12	5·40	36	4·70	29	5·30	108	8·62
29·5	41	3·24	36	4·39	15	6·76	33	4·31	24	4·38	113	9·02
30·5	25	1·97	20	2·44	11	4·95	15	1·96	19	3·47	105	8·39
31·5	10	0·79	20	2·44	4	1·80	8	1·05	10	1·80	82	6·55
32·5	9	0·71	12	1·46	2	0·90	11	1·44	15	2·74	59	4·71
33·5	7	0·55	13	1·58	2	0·90	7	0·91	16	2·92	54	4 31
34·5	12	0·95	4	0·49	2	0·90	4	0·52	4	0·73	35	2·79
35·5	8	0·63	7	0·85	...	...	8	1·05	7	1·28	32	2·56
36·5	6	0·47	7	0·85	1	0·45	3	0·39	7	1·28	18	1·44
37·5	4	0·32	3	0·36	...	...	1	0·13	5	0·91	12	0·96
38·5	...	...	1	0·12	...	...	...	...	5	0·91	8	0·64
39·5	...	...	1	0·12	...	...	...	...	3	0·55	9	0·72
40·5	...	...	...	...	...	...	...	...	4	0·73	7	0·56
41·5	...	...	1	0·12	...	...	...	...	1	0·18	3	0·24
42·5	...	...	...	...	...	...	...	...	4	0·73	6	0·48
43·5	1	0·08	...	...	...	...	...	...	1	0·18	7	0·56
44·5	...	...	...	...	...	...	...	...	...	...	4	0·32
45·5	...	...	...	...	...	...	...	...	2	0·37	1	0·08
46·5	...	...	...	...	...	...	...	...	...	...	2	0·16
47·5	...	...	...	...	...	...	...	...	...	...	3	0·24
48·5	...	...	...	...	...	...	...	...	...	...	6	0·48
49·5	...	...	...	...	...	...	...	...	...	...	3	0·24
50·5	...	...	...	...	...	...	...	...	...	...	1	0·08
51·5	...	...	...	...	...	...	...	...	...	...	2	0·16
52·5	...	...	...	...	...	...	...	...	...	...	...	...
Totals ...	1266	100·00	820	99·95	222	99·99	765	99·98	548	99·91	1252	99·98

Table III. Nelson Buoy Area. 6 inch mesh Trawl.

Length.	June.		July.		August.		September.	
	No.	%	No.	%	No.	%	No.	%
14·5	...	...	...	...	...	...	2	0·09
15·5	11	1·25	...	...	1	0·08	10	0·47
16·5	24	2·73	1	0·18	9	0·73	6	0·28
17 5	119	13·54	8	1·47	39	3·17	37	1·74
18·5	170	19·34	52	9·58	102	8·30	74	3·47
19·5	166	18·88	67	12·34	123	10·00	139	6·52
20·5	145	16·50	39	7·18	162	13·18	203	9·53
21·5	81	9·21	33	6·08	138	11·22	246	11·54
22·5	48	5·46	20	3·68	108	8·79	274	12·86
23·5	45	5·12	25	4·60	110	8·95	239	11·22
24·5	30	3·41	37	6·81	87	7·08	191	8·96
25·5	16	1·82	44	8·10	73	5·94	154	7·23
26·5	9	1·02	39	7·18	55	4·48	114	5·35
27·5	1	0·11	51	9·39	49	3·99	90	4·22
28·5	3	0·34	38	7·00	57	4·64	96	4·50
29·5	2	0·23	32	5·89	38	3·09	75	3·52
30·5	...	...	16	2·95	31	2·52	51	2·39
31·5	2	0·23	14	2·58	20	1·63	37	1·74
32·5	...	...	5	0·92	9	0·73	28	1·31
33·5	...	...	8	1·47	7	0·57	37	1·74
34·5	...	...	7	1·29	4	0·33	14	0·66
35·5	2	0·23	2	0·37	3	0·24	5	0·23
36·5	1	0·11	2	0·37	1	0·08	5	0·23
37·5	...	...	1	0·18	1	0·08	1	0·05
38·5	...	...	1	0·18	2	0·16	1	0·05
39·5	2	0·23	...	...	...	...	...	...
40·5	...	...	...	...	...	...	...	...
41·5	1	0·11	...	...	...	...	1	0·05
42·5	1	0·11	1	0·18	...	...	...	...
43·5	...	...	...	...	...	...	...	...
44·5	...	...	...	...	...	...	...	...
45·5	...	...	...	...	...	...	...	...
46·5	...	...	...	...	...	...	...	...
47·5	...	...	...	...	...	...	1	0·05
Totals ...	879	99·98	543	99·97	1229	99·98	2131	100·00

Table III. Nelson Buoy Area. 6 inch mesh Trawl—*continued.*

Length.	October.		November.		December.	
	No.	%	No.	%	No.	%
14·5	...	...	...	...	...	...
15·5	...	...	...	...	...	...
16·5	...	...	2	0·09	...	...
17·5	3	0·50	18	0·79	1	0·26
18·5	6	0·99	60	2·64	1	0·26
19·5	19	3·14	111	4·88	6	1·56
20·5	29	4·79	167	7·34	8	2·08
21·5	51	8·43	222	9·76	12	3·13
22·5	65	10·74	255	11·21	16	4·17
23·5	67	11·08	294	12·92	32	8·33
24·5	81	13·39	290	12·74	32	8·33
25·5	64	10·57	236	10·37	56	14·58
26·5	47	7·77	143	6·29	61	15·88
27·5	35	5·79	100	4·40	33	8·59
28·5	32	5·29	93	4·09	31	8·07
29·5	22	3·64	82	3·60	26	6·77
30·5	19	3·14	59	2·59	16	4·17
31·5	32	5·29	40	1·76	22	5·73
32·5	9	1·49	36	1·58	13	3·38
33·5	11	1·82	30	1·31	6	1·56
34·5	4	0·66	7	0·31	5	1·30
35·5	3	0·50	19	0·83	3	0·78
36·5	2	0·33	2	0·09	1	0·26
37·5	3	0·50	2	0·09	2	0·52
38·5	...	...	1	0·04	...	...
39·5	1	0·17	...	...	...	...
40·5	...	...	...	...	...	...
41·5	...	...	1	0·04	1	0·26
42·5	...	...	1	0·04	...	...
43·5	...	...	4	0·18	...	...
44·5	...	...	...	...	...	...
45·5	...	...	...	...	...	...
46·5	...	...	...	...	...	...
47·5	...	...	...	...	...	...
Totals	605	100·02	2275	99·98	384	99·97

Table IV. Mersey Estuary. 6 Inch mesh Trawl.

Length.	March.		April.		June.		July.	
	No.	%	No.	%	No.	%	No.	%
12·5	...	...	6	0·53	4	0·33	...	...
13·5	...	...	11	0·98	19	1·55	7	0·57
14·5	12	3·38	93	8·30	70	5·71	35	2·86
15·5	24	6·76	224	19·96	164	13·40	102	8·34
16·5	27	7·60	181	16·13	189	15·42	144	11·77
17·5	58	16·34	175	15·60	186	15·17	187	15·29
18·5	72	20·28	124	11·05	196	15·99	140	11·45
19·5	81	22·82	72	6·42	128	10·44	83	6·79
20·5	20	5·63	58	5·17	84	6·85	65	5·31
21·5	22	6·20	52	4·62	53	4·32	54	4·41
22·5	16	4·51	52	4·62	46	3·75	51	4·17
23·5	11	3·10	40	3·56	23	1·88	44	3·60
24·5	10	2·82	18	1·60	25	2·04	61	4·99
25·5	1	0·28	13	1·16	15	1·22	39	3·19
26·5	1	0·28	2	0·18	10	0·81	42	3·43
27·5	...	...	1	0·09	3	0·24	20	1·63
28·5	...	...	...	...	6	0·49	25	2·04
29·5	...	...	...	...	2	0·16	29	2·37
30·5	...	...	...	...	...	...	19	1·55
31·5	...	...	...	...	...	...	8	0·65
32·5	...	...	...	...	...	...	12	0·98
33·5	...	...	...	...	...	...	7	0·57
34·5	...	...	...	...	...	...	5	0·41
35·5	...	...	...	...	...	...	8	0·65
36·5	...	...	...	...	...	...	9	0·74
37·5	...	...	...	...	...	...	4	0·33
38·5	...	...	...	...	...	...	3	0·24
39·5	...	...	...	...	...	...	1	0·08
40·5	...	...	...	...	...	...	7	0·57
41·5	...	...	...	...	1	0·08	5	0·41
42·5	...	...	...	...	1	0·08	2	0·16
43·5	...	...	...	...	...	...	1	0·08
44·5	...	...	...	...	...	...	2	0·16
45·5	...	...	...	...	...	...	...	...
46·5	...	...	...	...	...	...	...	...
47·5	...	...	...	...	...	...	1	0·08
48·5	...	...	...	...	...	...	1	0·08
Totals ...	355	100·00	1122	99·97	1225	99·93	1223	99·95

Table IV. Mersey Estuary. 6 inch mesh Trawl—*continued.*

Length.	August.		September.		October.		November.	
	No.	%	No.	%	No.	%	No.	%
12·5	...	...	...	...	13	0·77	...	...
13·5	7	0·54	...	...	7	0·42	...	...
14·5	37	2·88	5	0·67	86	5·12	...	...
15·5	147	11·43	10	1·33	256	15·31	...	...
16·5	163	12·67	26	3·47	281	16·79	...	...
17·5	133	10·34	46	6·14	165	9·87	1	1·54
18·5	122	9·49	43	5·74	142	8·49	1	1·54
19·5	117	9·10	58	7·74	132	7·89	4	6·15
20·5	71	5·52	70	9·35	95	5·68	...	...
21·5	82	6·39	64	8·55	96	5·74	6	9·23
22·5	59	4·59	77	10·28	89	5·32	4	6·15
23·5	40	3·11	56	7·48	45	2·69	3	4·61
24·5	54	4·20	56	7 48	51	3·05	3	4·61
25·5	37	2·88	48	6·41	45	2·69	11	16·92
26·5	34	2·64	31	4·14	22	1·31	2	3·07
27·5	34	2·64	33	4·41	27	1·61	3	4·61
28·5	42	3·26	34	4·54	25	1·50	3	4·61
29·5	26	2·02	26	3·47	23	1·38	7	10·77
30·5	16	1·24	14	1·87	22	1·31	4	6·15
31·5	25	1·94	7	0·93	16	0 96	3	4·61
32·5	10	0·78	11	1·47	10	0·60	...	...
33·5	12	0·93	9	1·20	10	0·60	2	3·07
34·5	6	0·46	10	1·33	6	0·36	1	1·54
35·5	1	0·08	3	0·40	3	0·18	1	1·54
36·5	3	0·23	1	0·13	3	0·18	...	...
37·5	1	0·08	4	0·53	...	...	1	1·54
38·5	4	0·31	1	0·13	...	...	2	3·07
39·5	...	...	2	0·27	1	0·06	...	...
40·5	1	0·08	1	0·13	1	0·06	1	1·54
41·5	1	0·08	...	...	...	...	1	1·54
42·5	...	...	1	0·13	...	...	...	...
43·5	...	...	1	0·13	...	...	...	...
44·5	...	...	...	...	...	...	...	...
45·5	...	...	1	0·13	...	...	...	...
46·5	...	...	...	...	...	...	...	...
47·5	1	0·08	...	...	...	...	1	1·54
48·5	...	...	...	...	...	...	...	...
Totals ...	1286	99·99	749	99·98	1672	99·94	65	99·95

Table V. Menai Straits. 6 inch Trawl.

Length.	January.		June.		July.		August.	
	No.	%	No.	%	No.	%	No.	%
11·5	11	3·28	1	9·1	...	...	...	...
12·5	5	1·49	1	9·1	...	...	...	...
13·5	34	10·15	1	9·1	2	3·51	...	...
14·5	31	9·25	2	18·2	7	12·28	5	15·62
15·5	42	12·58	2	18·2	13	22·80	5	15·62
16·5	35	10·45	2	18·2	9	15·79	6	18·75
17·5	21	6·27	...	...	9	15·79	2	6·25
18·5	11	3·28	1	9·1	7	12·28	5	15·62
19·5	21	6·27	1	9·1	3	5·26	2	6·25
20·5	25	7·46	...	...	2	3·51	1	3·12
21·5	19	5·67	...	...	1	1·75	2	6·25
22·5	19	5·67	...	...	...	...	...	...
23·5	22	6·57	...	...	1	1·75	...	...
24·5	17	5·08	...	...	...	...	...	...
25·5	5	1·49	...	...	...	...	...	...
26·5	7	2·09	...	...	...	...	...	...
27·5	2	0·60	...	...	...	...	...	...
28·5	3	0·90	...	...	...	...	...	...
29·5	5	1·49	...	...	1	1·75	...	...
30·5	...	...	...	...	...	...	...	...
31·5	...	...	...	...	...	...	...	...
32·5	...	...	...	...	...	...	...	...
33·5	...	...	...	...	...	...	...	...
34·5	...	...	...	...	...	...	...	...
35·5	...	...	...	...	...	...	...	...
36·5	...	...	...	...	...	...	1	3·12
37·5	...	...	...	...	...	...	...	...
38·5	...	...	...	...	...	...	...	...
39·5	...	...	...	...	...	...	...	...
40·5	...	...	...	...	...	...	2	6·25
41·5	...	...	...	...	1	1·75	...	...
42·5	...	...	...	...	...	...	...	...
43·5	...	...	...	...	...	...	...	...
44·5	...	...	...	...	...	...	1	3·12
45·5	...	...	...	...	...	...	...	...
46·5	...	...	...	...	...	...	...	...
47·5	...	...	...	...	...	...	...	...
48·5	...	...	...	...	53.5]...1	1·75	...	...
Totals ...	335	100·04	11	100·1	57	99·97	32	99·97

Table V. Menai Straits. 6 Inch Trawl—*continued.*

Length.	September.		October.		November.		December.	
	No.	%	No.	%	No.	%	No.	%
11·5	...	...	...	...	...	...	...	...
12·5	...	...	1	1·05	...	...	...	...
13·5	1	2·63	1	1·05	2	2·41	51	10·17
14·5	3	7·89	13	13·68	8	9·64	45	8·98
15·5	4	10·53	18	18·95	10	12·05	61	12·17
16·5	2	5·26	11	11·58	11	13·25	43	8·58
17·5	7	18·42	13	13·68	14	16·87	57	11·40
18·5	4	10·53	14	14·74	8	9·64	46	9·18
19·5	3	7·89	7	7·37	10	12·05	45	8·98
20·5	1	2·63	3	3·16	8	9·64	45	8·98
21·5	...	...	2	2·10	2	2·41	51	10·17
22·5	1	2·63	3	3·16	4	4·82	26	5·19
23·5	3	7·89	...	...	1	1·21	10	2·00
24·5	2	5·26	2	2·10	1	1·21	10	2·00
25·5	1	2·63	1	1·05	1	1·21	5	1·00
26·5	...	...	...	...	...	...	4	0·80
27·5	...	...	...	...	1	1·21	...	...
28·5	...	...	...	...	...	...	...	...
29·5	1	2·63	...	...	...	...	1	0·20
30·5	...	...	...	...	...	...	...	...
31·5	...	...	...	...	...	...	...	...
32·5	...	...	...	...	...	...	...	...
33·5	1	2·63	1	1·05	...	...	...	...
34·5	...	...	...	...	1	1·21	...	...
35·5	2	5·26	2	2·10	1	1·21	...	...
36·5	...	...	...	...	...	...	...	...
37·5	1	2·63	...	...	...	...	1	0·20
38·5	...	...	1	1·05	...	...	...	...
39·5	...	...	...	...	...	...	...	...
40·5	...	...	...	...	...	...	...	...
41·5	...	...	...	...	...	...	...	...
42·5	...	...	...	...	...	...	...	...
43·5	...	...	1	1·05	...	...	...	...
44·5	...	...	...	...	...	...	...	...
45·5	1	2·63	...	...	...	...	...	...
46·5	...	...	...	...	...	...	...	...
47·5	...	...	...	...	...	...	...	...
48·5	...	...	1	1·05	...	...	...	...
Totals ...	38	99·97	95	99·97	83	100·04	501	100·00

Table VI. Mersey Estuary. Shrimp Trawl.

Length.	May.		October.		November.		December.	
	No.	%	No.	%	No.	%	No.	%
4·5	...	...	...	...	1	0·21	...	...
5·5	...	...	...	...	3	0·64	1	0·13
6·5	2	3·57	...	...	2	0·42	4	0·53
7·5	7	12·50	...	...	1	0·21	4	0·53
8·5	10	17·86	...	...	8	1·70	7	0·93
9·5	7	12·50	...	...	47	10·00	54	7·17
10·5	6	10·72	...	...	78	16·60	122	16·20
11·5	2	3·57	5	19·23	74	15·74	150	19·92
12·5	3	5·36	3	11·54	53	11·28	148	19·65
13·5	1	1·79	4	15·39	35	7·45	107	14·21
14·5	3	5·36	3	11·54	36	7·66	59	7·83
15·5	4	7·14	2	7·70	31	6·60	36	4·78
16·5	1	1·79	2	7·70	22	4·68	22	2·92
17·5	1	1·79	3	11·54	17	3·62	11	1·46
18·5	1	1·79	1	3·85	17	3·62	10	1·33
19·5	2	3·57	1	3·85	12	2·55	5	0·66
20·5	3	5·36	2	7·70	8	1·70	5	0·66
21·5	1	1·79	...	...	5	1·06	2	0·26
22·5	1	1·79	...	...	7	1·49	5	0·66
23·5	1	1·79	...	...	4	0·85	1	0·13
24·5	...	...	...	...	4	0·85	...	...
25·5	...	...	...	...	2	0·42	...	...
26·5	...	...	...	...	2	0·42	...	...
27·5	...	...	...	...	...	...	...	...
28·5	...	...	...	...	...	...	...	...
29·5	...	...	...	...	1	0·21	...	...
Totals ...	56	100·04	26	100·04	470	99·98	753	99·96

Table VII. Summary of age group frequency. Areas: Nelson Buoy, North Wales, Mersey Estuary. Period: June to December.

Length.	I		II		III		IV		V		VI		VII		VIII		IX	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀	♂	
12·5	...	...	...	1	...	...	...	...	...	...	...	...	...	...	...	...	...	...
13·5	2	...	2	6	...	...	...	...	...	...	...	...	...	...	...	...	...	...
14·5	9	3	15	10	...	...	...	...	...	...	...	...	...	...	...	...	...	...
15·5	15	8	26	27	3	1	...	...	...	...	...	...	...	...	...	...	...	...
16·5	8	13	45	51	5	7	...	...	...	...	...	...	...	...	...	...	...	...
17·5	9	10	85	107	16	14	...	...	...	...	...	...	...	...	...	...	...	...
18·5	7	8	125	122	33	34	...	...	...	...	...	...	...	...	...	...	...	...
19·5	10	9	122	125	54	41	...	...	...	...	...	...	...	...	...	...	...	...
20·5	14	9	133	89	70	52	...	2	...	...	...	...	...	...	...	...	...	...
21·5	4	9	94	102	67	51	1	...	...	...	...	...	...	...	...	...	...	...
22·5	3	1	97	82	66	59	1	...	...	...	...	...	...	...	...	...	...	...
23·5	...	1	76	72	81	86	...	2	...	...	...	...	...	...	...	...	...	...
24·5	...	...	57	46	113	105	3	7	...	...	...	...	...	...	...	...	...	...
25·5	...	...	35	23	92	84	4	2	...	...	...	...	...	...	...	...	...	...
26·5	...	...	20	13	95	82	3	5	...	...	...	...	...	...	...	...	...	...
27·5	...	...	17	19	93	82	8	7	...	...	...	...	...	...	...	...	...	...
28·5	...	...	6	6	71	62	7	8	...	...	...	...	...	...	...	...	...	...
29·5	...	...	5	6	66	42	11	8	...	...	...	...	...	...	...	...	...	...
30·5	...	...	2	1	32	41	14	9	1	...	...	...	...	...	...	...	...	...
31·5	...	...	...	...	30	25	12	7	...	1	...	...	...	...	...	...	...	...
32·5	...	...	...	...	17	18	13	7	1	...	...	...	...	...	...	...	...	...
33·5	...	...	...	...	6	4	8	4	1	1	1	...	...	...	...	...	...	...
34·5	...	...	...	...	3	11	5	10	2	1	...	...	...	...	...	...	...	...
35·5	...	...	...	...	1	1	5	5	...	...	...	...	...	...	...	...	...	...
36·5	...	...	...	...	4	4	1	3	...	...	...	...	...	...	...	...	...	...
37·5	...	...	...	...	...	2	1	3	1	2	...	...	...	...	...	...	...	...
38·5	...	...	...	...	...	...	1	2	...	3	...	1	...	...	...	...	...	...
39·5	...	...	...	...	...	...	...	...	...	2	...	...	...	...	...	...	...	...
40·5	...	...	...	...	...	...	...	1	...	2	...	...	...	...	...	...	...	...
41·5	...	...	...	...	...	...	1	1	1	1	...	...	...	...	...	...	...	...
42·5	...	...	...	...	...	...	...	3	...	3	...	...	...	...	...	...	...	...
43·5	...	...	...	...	...	...	...	...	...	3	...	...	...	...	...	...	...	...
44·5	...	...	...	...	...	...	...	1	...	2	...	...	...	...	...	...	...	...
45·5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
46·5	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...	...	...
47·5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
48·5	...	...	...	...	...	...	...	...	...	3	...	2	...	...	...	...	...	...
49·5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
50·5	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
51·5	...	...	...	...	...	...	...	...	...	...	...	...	...	1	...	...	...	...
52·5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	1
Totals ...	81	71	962	908	1018	908	99	97	7	24	1	4		2				1

Table VIII. Age group frequency—October to December—Mersey Estuary—Shrimp Trawl.

Length.	O		I		II		III		IV	
	♂	♀	♂	♀	♂	♀	♂	♀	♂	♀
4·5	2	2	...	...	...	...	...	...	...	...
5·5	1	2	...	...	...	...	...	...	...	...
6·5	1	1	...	...	...	...	...	...	...	...
7·5	...	1	5	...	...	...	...	...	...	...
8·5	...	2	8	8	...	...	...	...	...	...
9·5	2	...	32	46	1	...	...	...	...	...
10·5	...	...	58	79	1	2	...	...	...	...
11·5	...	1	71	90	...	...	...	...	...	...
12·5	...	...	47	72	1	1	...	...	...	...
13·5	...	1	33	52	1	1	...	...	...	...
14·5	...	...	24	28	4	3	...	1	...	...
15·5	...	...	18	18	5	8	...	...	...	...
16·5	...	...	14	14	5	5	...	...	...	...
17·5	...	...	3	8	7	3	1	...	...	...
18·5	...	...	2	3	11	8	...	...	...	...
19·5	...	...	3	2	3	5	...	...	...	...
20·5	...	...	...	1	4	6	...	...	...	...
21·5	...	...	...	...	3	1	...	1	...	...
22·5	...	...	...	1	2	3	...	1	...	...
23·5	...	...	...	...	2	...	...	...	1	...
24·5	...	...	...	...	2	1	...	2	...	...
25·5	...	...	...	...	1	1	...	...	...	...
26·5	...	...	...	...	1	...	1	...	...	...
27·5	...	...	...	...	...	...	...	...	...	...
28·5	...	...	...	...	...	...	...	...	...	...
29·5	...	...	...	...	...	...	1	...	...	...
Totals ...	6	10	318	422	54	48	3	5	1	...

Table IX. Values of the Length-Weight Coefficient K. 1920.

	No.	Nelson Buoy.	No.	North Wales.	No.	Mersey Estuary.	No.	Menai Straits.
June	256	1·020	249	1·000	134	0·960	...	...
July	297	1·059	148	1·015	286	0·973	48	1·020
August	145	1·020	131	1·052	81	1·018	28	0·960
September ...	405	1·079	147	1·047	31	0·998	33	1·034
October	296	1·040	296	1·039	178	0·969	81	0·968
November......	344	1·067	335	1·016	354	0·948	80	0·995
December ...	127	1·200	211	1·034	434	0·941	...	...

BIOMETRIC INVESTIGATIONS ON THE HERRING.

By W. Birtwistle.

Two samples of herrings, taken by drift-nets off the South-west of the Isle of Man, one in the third week in June and the other in the first week in September, were sent to the University of Liverpool for detailed examination. It was not possible to deal with the whole of each sample in the fresh condition, so they were kept in cold storage, and examined when circumstances permitted. About 60 fish of each sample were examined fresh. Each sample consisted of nominally 250 fish = $\frac{1}{4}$ cran, and were quite unselected.

The usual characters were examined and recorded, viz. :—

1. Total length from extremity of snout to the vertical line joining the tips of the lobes of the caudal fin in the natural position. [T.]

2. Total length to base of tail. [T.cd.]

3. Length from tip of snout to beginning of dorsal fin. [D.]

4. Length from tip of snout to beginning of pelvic fin. [V.]

5. Length from tip of snout to anus. [A.]

6. Lateral length of head. [l.cp.l.]

7. Number of keeled scales between anus and pelvic fins. [K_2.]

8. Sex recorded.

The condition of gonads was noted and was recorded by Hjort's notation. In addition scales were taken from each fish for the estimation of the age.

There was a marked difference between the two samples. The samples taken in June had a mean length of 203 mm., measured from tip of snout to base of tail [T.cd.]. The fish in this sample had only a moderate amount of fat in the ventral cavity, and, with few exceptions, were virgin fish in the first or second stage of maturity.

The investigation of the sex composition showed the males to predominate by about 16 %. No food could be found in the stomachs.

The examination of the scales showed the sample to consist of 55·8 % of fish with two completed winter rings, 37 % with three, 5·8 % with four, 0·5 % with five, and 1·00 % with six, so that the sample may be regarded as consisting almost entirely of fish, with two or three winter rings on the scales.

The very trying work of scale-reading, including the calculation of the percentage-growth rates was only made tolerable by the help of Miss H. Mabel Lewis, Research Assistant in the Department of Oceanography, and for her amiability and patience I am much indebted.

The September catch, taken about 12 miles W.S.W. of the Calf of Man, had a mean length of 234 mm., and was a good sample of fish with considerable intestinal fat. Practically the whole of this sample was in the fifth stage of maturity. Males predominated by about 7 %. Several specimens were found with the stomachs full of *Meganyctiphanes norvegicus.*

Scale examination revealed the following grouping:—5·9 % with two winter rings, 5·4 % with three, 21·1 % with four, 32·1 % with five, 22·4 % with six, 7·6 % with seven, 5·1 % with eight, 0·4 % with nine.

Comparison by weight of the respective samples.

About 60 fish were taken from each sample and weighed fresh. The results were :—

Mean Length [*T*]	June Sample.		September Sample.	
	Frequency.	Av. Wt.	Frequency.	Av. Wt.
mm.		in grms.		in grms.
205	1	74	...	...
215	10	78	...	...
225	20	88	2	103·5
235	26	97	1	96*
245	7	103	4	148
255	1	130	6	146
265	1	132	1	169
275	...	...	18	198
285	...	...	18	215
295	...	...	7	228
Totals	66	...	57	...

* Spent.

Comparison of stages of maturity.

Sample.	Frequency.	I.	II.	III.	IV.	V.	VI.	VII.	Undetermined.
		%	%	%	%	%	%	%	%
June	214	49·53	39·24	7·47	1·86	0·47	...	...	1·40
September	242	...	...	0·83	0·41	90·41	3·72	4·54	...

Where a fish is between two stages it has been placed under the higher stage.

Sex composition of the two samples.

Sample.	Frequency.	♂	♀	Undetermined.
		%	%	%
June	214	57·00	41·59	1·40
September	242	53·3	46·70	...

In the June sample three fish were noticed in a more advanced state of maturity than the majority of the sample—two in Stage IV and one in Stages IV-V. There is evidence, from size and scale markings, that these fish belong to a group similar to the fish in the September sample at Stage V. This being the case, it would suggest that it has taken approximately ten weeks for the herrings to advance from, say, Stage IV to Stage V. And again in the September sample, two fish show a less advanced stage of maturity than the majority, being in Stage III. Evidence from length and scale markings suggests a possibility of their belonging to a group similar to those in Stage II in June, so that if the assumption were permissable, it would indicate that they had advanced from Stage II to Stage III in approximately ten weeks.

Although the data are small, they at least indicate one of many points which it is hoped will be found possible to investigate during the present year. Another interesting point arises, inasmuch as the fish curers stated that two weeks previous to the September sample, nearly all the fish passing through their hands were Spents (= Stage VII) and taken from the same grounds. Unfortunately we have no data, and nothing can be said in confirmation of this.

They stated, however, that they were similar in size to the September sample, and were uncertain how long this supply of spent fish lasted.

That there are spawning grounds in the vicinity of Isle of Man seems certain when a spent population is replaced by another about to spawn, 3·72 % actually spawning, and 4·54 % finished spawning. Furthermore, conditions are favourable on these grounds where there is abundant *Laminaria*, rough ground and deep water of about 20 fathoms.

Estimation of age by scale examination.

Scales were taken from each fish, cleaned and mounted dry on a glass slide.

The original intention was to count the winter rings only, but later on it was decided to record the width of the respective summer zones on the scales as percentages of the measured part of the scale—i.e., the total distance between the "base line" and the outer edge of the striated portion of the scale. This distance was measured by a micrometer eye-piece in conjunction with a low magnification. In actual practice it was found that the personal error might amount to ± 1 %, so that this error should be kept in mind when examining the summaries. The results of these measurements show that in separate year-groups the completed summer areas show a considerable variation. For example, the two-ring scales of the June sample show a variation in the first summer growth from 38 % to 74 % of the measured part of the scale. By examining the tables the other variations will be seen.

Whenever a doubtful scale occurred it was stained in silver nitrate, and examined under polarised light. This materially assisted in the elimination of false rings.

EXPLANATION OF THE TABLES.

One typical scale belonging to each herring has been measured, and these scales are grouped as "two-rings," "three-rings," and so on. The "f" columns show the numbers of scales measured.

Thus, for the group of 2-ringed scales (June) we have one scale in which d_1 is between 36 and 40 % of the distance T (fig. 1); 3 in which d_1 is between 40 and 44 % of T; 3 scales in which d_2 is from 80 to 84 % of T; 10 in which d_2 is 84 to 88 % of T, and so on. So also with the 3-ringed scales and the higher groups.

The *d's* are thus not absolute measurements but relative ones—being percentages of the *T's* of each scale.

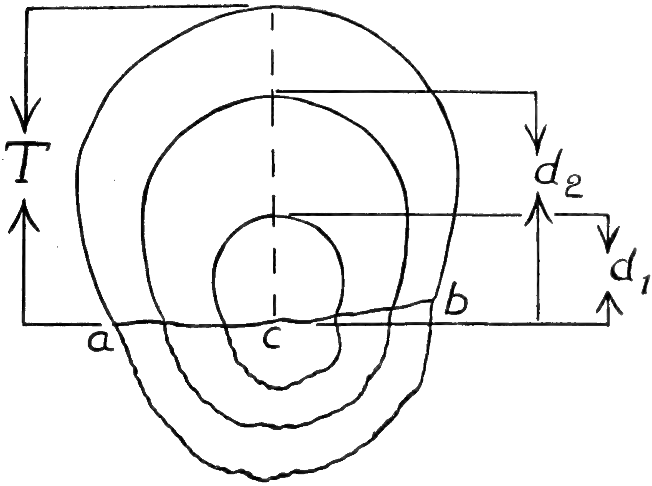

FIG. 1. Diagram of a 2-ringed scale.

Table I. June sample.

2 Ring Scales.				3 Ring Scales.						4 Ring Scales.							
f	d_1	*f*	d_2	*f*	d_1	*f*	d_2	*f*	d_3	*f*	d_1	*f*	d_2	*f*	d_3	*f*	d_4
	%		%		%		%		%		%		%		%		%
1	38	3	82	2	26	1	50	2	86	1	18	1	50	1	78	1	90
3	42	10	86	11	30	2	54	19	90	2	34	1	58	1	82	4	94
11	46	37	90	7	34	4	58	31	94	2	38	1	62	1	86	6	98
4	50	30	94	12	38	6	62	6	98	1	42	1	66	6	90	...	...
12	54	3	98	6	42	9	66	...	...	1	46	1	70	2	94	...	...
14	58	...	...	6	46	9	70	...	...	2	50	2	74	...	...	...	...
18	62	...	...	4	50	7	74	...	...	2	54	2	78	...	...	...	...
14	66	...	...	5	54	10	78	...	...	...	...	2	82	...	...	...	...
5	70	...	...	3	58	6	82	...	...	...	...	...	...	...	...	...	...
1	74	...	...	2	62	3	86	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	1	90	...	...	...	...	...	...	...	...	...	...
83		83		58		58		58		11		11		11		11	
Mean	% 57·76		% 90·96		% 40·9		% 71·1		% 92·8		% 41·6		% 70·4		% 88·5		% 95·8

Table II. September sample.

2 Ring Scales.				3 Ring Scales.						4 Ring Scales.							
f	d_1	*f*	d_2	*f*	d_1	*f*	d_2	*f*	d_3	*f*	d_1	*f*	d_2	*f*	d_3	*f*	d_4
	%		%		%		%		%		%		%		%		%
1	42	1	82	1	30	1	54	2	90	2	34	2	62	1	78	14	94
1	46	6	86	1	34	1	70	9	94	7	38	1	66	2	82	36	97
5	50	3	90	1	42	4	78	1	99	9	42	10	70	10	86	...	...
3	54	2	94	2	46	5	82	...	...	3	46	12	74	27	90	...	...
2	58	1	98	6	54	1	86	...	...	8	50	14	78	10	94	...	...
1	62	...	...	1	70	...	...	...	...	14	54	7	82	...	...	...	...
...	...	...	...	...	...	...	...	...	...	5	58	4	86	...	...	...	...
...	...	...	...	...	...	...	...	...	...	2	62	...	...	...	...	...	...
13		13		12		12		12		50		50		50		50	
Mean	% 52·1		% 88·8		% 49·3		% 78·5		% 93·7		% 49·36		% 75·76		% 89·4		% 96·16

5 Ring Scales.										6 Ring Scales.											
f	d_1	*f*	d_2	*f*	d_3	*f*	d_4	*f*	d_5	*f*	d_1	*f*	d_2	*f*	d_3	*f*	d_4	*f*	d_5	*f*	d_6
	%		%		%		%		%		%		%		%		%		%		%
1	22	1	54	1	74	17	90	1	92	1	22	1	52	1	76	9	88	1	90	2	96
2	26	2	58	3	78	54	94	12	95	1	26	2	60	11	80	11	90	1	92	19	97
4	30	2	62	15	82	2	96	13	96	5	30	9	64	24	84	10	91	2	93	25	98
2	34	4	66	30	86	2	97	20	97	3	34	16	68	12	88	10	92	13	94	6	99
11	38	18	70	25	90	1	98	25	98	9	38	7	72	4	92	4	93	22	95	...	...
11	42	22	74	2	94	...	...	5	99	11	42	9	76	...	...	6	94	9	96	...	...
8	46	17	78	...	...	...	...	...	...	4	46	6	80	...	...	2	95	4	97	...	...
16	50	9	82	...	...	...	...	...	...	6	50	2	88	...	...	...	...	...	...	...	...
11	54	1	86	...	...	...	...	...	...	4	54	...	...	...	...	...	...	...	...	...	...
7	58	...	...	...	...	...	...	...	...	6	58	...	...	...	...	...	...	...	...	...	...
3	62	...	...	...	...	...	...	...	...	1	62	...	...	...	...	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...	...	1	66	...	...	...	...	...	...	...	...	...	...
76		76		76		76		76		52		52		52		52		52		52	
Mean	% 46·00		% 73·63		% 86·26		% 93·3		% 97·1		% 44		% 70·6		% 84·5		% 91·1		% 94·9		% 97·5

Table II. September sample—*continued.*

7 Ring Scales.

f	d_1	f	d_2	f	d_3	f	d_4	f	d_5	f	d_6	f	d_7
	%		%		%		%		%		%		%
2	30	1	54	13	82	3	86	2	91	2	94	1	96
1	34	3	66	4	86	7	89	6	92	6	95	3	97
5	38	8	70	1	90	6	91	3	93	2	96	7	98
3	42	4	74	...	...	2	95	3	94	6	97	7	99
1	46	2	78	...	...	...	...	2	95	2	98	...	...
5	50	...	...	...	...	...	...	2	96	...	...	...	...
1	58	...	...	...	...	...	...	...	...	...	...	...	...
18		18		18		18		18		18		18	
Mean ...	% 42·4		% 70·2		% 83·3		% 89·8		% 93·2		% 96		% 98·1

8 Ring Scales.

f	d_1	f	d_2	f	d_3	f	d_4	f	d_5	f	d_6	f	d_7	f	d_8
	%		%		%		%		%		%		%		%
3	30	1	46	1	74	3	86	2	89	2	92	2	94	2	97
2	38	2	62	6	82	5	89	2	91	1	93	1	95	6	98
2	42	1	66	5	86	3	91	2	92	3	94	3	96	4	99
1	46	2	70	...	...	1	93	3	93	2	95	3	97	...	...
3	54	3	74	...	...	...	...	1	94	2	96	3	98	...	...
1	58	3	78	...	...	...	...	2	95	2	97	...	...	...	...
12		12		12		12		12		12		12		12	
Mean	% 43·0		% 69·3		% 83·0		% 89·1		% 92·2		% 94·6		% 96·3		% 98·2

We shall now summarise Tables I and II—with interesting results.

(*a*) **June sample.**

	No. of Rings in a Scale.		
	2	3	4
d_1	57·8	41·0	41·0
Δ	*33·2*	*30·0*	*29·0*
d_2	91·0	71·0	70·0
Δ	...	*22·0*	*18·5*
d_3	...	93·0	88·5
Δ	...	...	*7·3*
d_4	...	...	95·8

(*b*) **September sample.**

	No. of Rings in a Scale.						
	2	3	4	5	6	7	8
d_1	52·0	49·3	49·4	46·0	44·0	42·4	43
Δ	*36·8*	*29·2*	*26·4*	*27·6*	*26·6*	*27·8*	*26·3*
d_2	88·8	78·5	75·8	73·6	70·6	70·2	69·3
Δ	...	*15·2*	*13·6*	*12·7*	*13·9*	*13·1*	*13·7*
d_3	...	93·7	89·4	86·3	84·5	83·3	83·0
Δ	...	...	*7·4*	*7·0*	*6·6*	*6·5*	*6·1*
d_4	...	...	96·8	93·3	91·1	89·8	89·1
Δ	...	...	...	*3·8*	*3·8*	*3·4*	*3·1*
d_5	...	...	...	97·1	94·9	93·2	92·2
Δ	...	...	...	...	*2·1*	*2·8*	*2·4*
d_6	...	...	...	...	97·0	96·0	94·6
Δ	...	...	...	...	...	*2·1*	*1·7*
d_7	...	...	...	...	...	98·1	96·3
Δ	...	...	...	...	...	...	*1·9*
d_8	...	...	...	...	...	...	98·2

In these summary tables the mean values of the *d's* are collected for scales that have two up to eight rings. The Δ's are the *differences* between these mean values, that is, they are the *mean* widths of the zones of the scales added by growth in each year. Thus, in the June 2-ringed scales 33·2 % of the ringed portion is added on during the interval between the laying down of the 1st and 2nd rings. But that is only the case with the 2-ringed scales: in the 8-ringed ones only 26·3 % of the ringed portion is laid down between the dates of formation of the 1st and 2nd rings. This curious effect can be observed throughout the tables (if one allows for the errors of the means it is quite general). It seems as if the whole scale shrinks up in the older fish and shrinks the more, the older the fish is.

Further, there is an obvious difference between the June and September samples.

These results appear to have important bearings, but it will be advisable that other investigations, which are in progress, be made before a full discussion is attempted.

Table III. Showing Length—Ring frequency.

T.cd. Length.	JUNE SAMPLE.						SEPTEMBER SAMPLE.								
	Rings.						Rings.								
	1	2	3	4	5	6	1	2	3	4	5	6	7	8	9
mm.															
181-190	...	8	7	...	...	...	...	...	...	...	...	...	...	...	...
191-200	...	38	22	2	1	...	...	3	...	...	...	...	...	...	...
201-210	...	45	29	1	...	...	...	2	1	...	...	...	...	...	...
211-220	...	11	11	4	...	...	...	8	4	2	...	1	...	...	...
221-230	...	4	...	4	...	...	...	1	3	18	17	9	2	...	...
231-240	...	...	1	...	...	1	...	...	3	25	38	25	8	6	...
241-250	...	...	...	...	...	1	...	...	2	5	18	17	8	6	1
251-260	...	...	...	...	...	...	...	...	...	...	3	1	...	...	...
	...	106	70	11	1	2	...	14	13	50	76	53	18	12	1

JUNE.	SEPTEMBER.
mm.	mm.
Mean length of fish with 2 ring scales = 202	Mean length of fish with 2 ring scales = 210
„ „ 3 „ = 202	„ „ 3 „ = 226
„ „ 4 „ = 214	„ „ 4 „ = 232
„ „ 5* „ = 225	„ „ 5 „ = 236
„ „ 6* „ = 238	„ „ 6 „ = 237
	„ „ 7 „ = 238
	„ „ 8 „ = 240
	„ „ 9* „ = 245

* 1 example.

ON IRREGULARITIES IN SEA-TEMPERATURE DUE TO TIDAL OSCILLATORY STREAMS.

By R. J. Daniel, B.Sc.

It has been suggested by Professor D'Arcy Thompson* that the annual temperature variation, at a fixed position in the sea, can be represented by a Fourier Series. There ought to be one principal component in such a series, and this ought to account for the greater part of the variation above and below the annual mean temperature. Then there ought to be other components of $\frac{1}{2}, \frac{1}{3}, \frac{1}{4}$, and so on, of a whole year, each of which also accounts for some of the variation from the mean annual value. Some, of course, of these minor components may be expected to have small amplitudes; so small that they may be neglected. An harmonic analysis of the annual temperature fluctuation, at any fixed position, ought, therefore, to give us a series of equations, each of which will represent an harmonic oscillation, and the phase and amplitude of each oscillation would be given by the analysis. If, then, the various components be added algebraically the summation ought to reproduce the observed annual temperature oscillation.

Of course, in making such an analysis, we ought to *assume* the periods of the various components and then evaluate their phases and amplitudes. That supposes a theory (or explanation, rather) of the causes of variation in sea-temperature. Obviously the principal cause is the annual change of declination of the sun. In the case investigated in this paper the other causes are tidal oscillatory streams, by means of which heat is transferred from the sea to the land, or *vice versa*. These oscillations are assumed to have (1) a semilunar period (the neap and spring tides), and (2) a semi-annual period

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* Rept. II Northern area, North Sea Fisheries Investigations, cd. 3358, 1907, p. 185.

(equinoctial tides). An annual sea-temperature oscillation ought, then, to decompose into three component oscillations :—(1) Annual ; (2) Six-monthly ; (3) Fortnightly. On adding, algebraically, these three oscillations there should result one that is very similar to the observed oscillation. There ought, of course, to be a " residue " unaccounted for by the analysis.

The explanation, it has been said, assumes that heat is transferred between the sea-position investigated and the adjacent land by means of tidal oscillatory streams, and it is easy to see that this must be the case. In winter the extensive sand-banks, uncovered by the ebb-tide, lose heat by radiation and evaporation, so that they become colder than the sea-water that flows over them at next flood-tide : therefore, that water is cooled, and when it ebbs out seawards to the sea-position under investigation it dilutes the warmer water there by colder water. A reversal of these conditions occurs in the summer months.

The question presented itself : could the annual temperature oscillation, at a point in mid-channel in the Irish Sea, be subjected to Fourier analysis so as to bring out the three periodic oscillations mentioned above and then leave a residue which might be traced to other periodic or unperiodic causes. It is probable that Fourier analysis is not theoretically justifiable, for the method assumes that the function (the annual sea-temperature oscillation at a fixed station) is periodic—that is, repeats itself exactly from year to year. But it does not ; and there are quite well-marked variations in (1) the dates of maxima, minima and means, and (2) amplitude from year to year. These may, of course, be due to an oscillation, the period of which is a number of years, but about that we do not know yet.

Anyhow, it appears to be worth while to look for the existence of a fortnightly component of sea-temperature oscillation before plunging into Fourier analysis. This is the object of the present investigation. And it is obvious that we must know all the principal causes of variation of sea-temperature before we can, with confidence, say that the difference between one year and another is due to, say, a greater or lesser influx of Atlantic water into the area in question.

A series of readings of daily sea-temperature at certain light vessels in the Irish Sea have been given to us by the Meteorological Office: at present we deal with the period 1907-12, 1914. The temperatures for January, 1915, are also considered, after which month the records cease for the rest of the war period. Chiefly, three light vessels are in question :—

Morecambe Bay : Lat. 53° 54′ N. ; Long. 3° 31′ W.
Bahama Bank : Lat. 54° 20′ N. ; Long. 4° 13′ W.
Carnarvon Bay : Lat. 53° 06′ N. ; Long. 4° 49′ W.

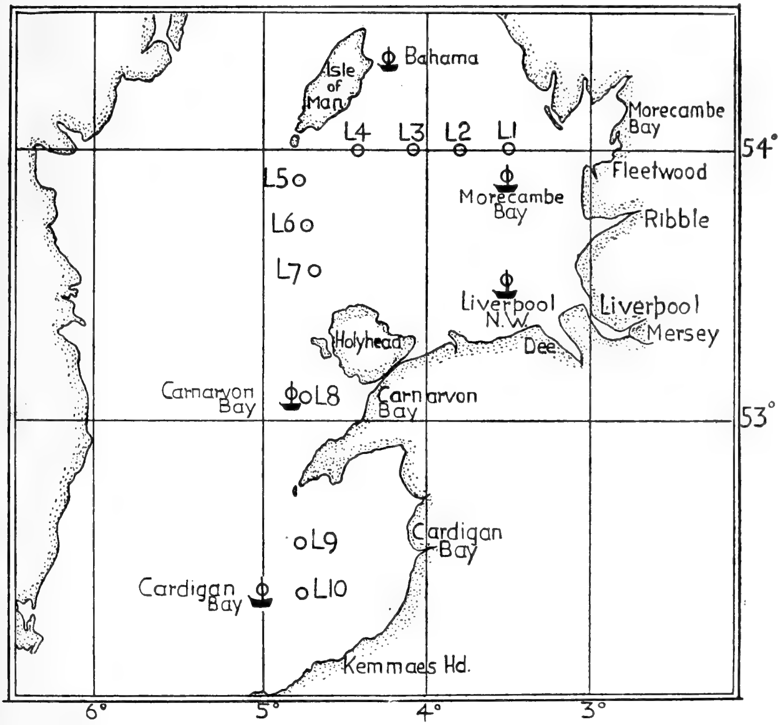

FIG. 2. Lightships and hydrographic stations.

Bahama Bank Ship and Carnarvon Bay Ship I consider to be "open-sea" stations, which are much less under the influence of the land than is Morecambe Bay Lightship. This is about 16 miles distant from the mouth of Morecambe Bay, and the run of the tidal streams is such as to transport water from the Bay to the region between the Bahama Bank and the Morecame Bay light vessels. Therefore, the sea-region about the latter position has a greater range of temperature than at either Bahama Bank or at the middle of Carnarvon Bay. It is to the influence of the land that we look for the explanation of this greater range. Now the greatest differences of temperature between sea and land are experienced during the months January to March and June to September, and so we find it advantageous to use either or both of these periods in making comparisons between the various stations.

Two temperature readings are taken each day at the light vessels—at sunrise and at 4 p.m. It is the latter readings that are taken into consideration here: the fact that they are made at continually varying states of the tide is a condition that may be neglected, as we shall see later. The readings are Fahrenheit ones, but they have been converted into the corresponding Centigrade values.

The daily temperatures for the months January to March are grouped in periods of ten days, and means are calculated. These means are then plotted at the centres of the periods: thus, the mean for January 1st-10th, 1907, is 6·27° C., and this figure is plotted against January 5th. The ten-daily points are then found, and a smoothly-running curve is drawn through or among them. Mean temperatures for any day are found from this curve.

If these smoothed curves are drawn for the first three months of each of the years considerable differences will be found. Thus, in January-March, 1912, there is a comparatively great range, which is about 7° C. at the beginning of January and the end of March, and which is minimal at 4·7°. Such a curve cuts through those of years when the range is less.

When these smoothed curves for Bahama Bank and Morecambe Bay light vessels are compared it is seen that their general appearance, with respect to each other, are the same, on the whole ; and this is so even when the curves from the same one light vessel, in different years, may be very different. The Bahama Ship temperatures are higher throughout all the years considered except 1907. In that year the temperature at Morecambe Bay Ship was minimal (4·54° C.) on Jan. 31st ; but it rose rapidly, and on February 16th it was higher than at Bahama Ship, not only so but it was higher than at Carnarvon Bay Ship, which is more southerly, and is in the core of the water streams moving from south to north, and is less affected by the influence of the land than is either of the other stations.

The general similarity, in shape, of the curves for Morecame Bay and Bahama vessels, and the higher range of the latter are to be expected when one looks at their respective positions. The latter vessel is just north of the line from Maughold Head and Walney Island, along which line the tidal streams that come through St. George's and North Channel meet, and form an area in which there is little oscillatory ebb and flood, but a large, vertical oscillation. It has been found by study of the salinities along the Maughold Head—Walney Line (Hydrographic Stations I-III*) that this area is greatly affected by the tidal streams ebbing out from Morecambe Bay. In its gradual transference across, towards the Manx coast, this water is greatly mixed with that which comes up from St. George's Channel because of the resultant tidal drift from south to north. This mixed water, of course, gradually passes out through the North Channel.†

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* Bassett, "Report on Hydrographic Observations," *Ann. Rept. Lancashire Sea-Fish. Lab.*, 1907-14 ; Johnstone, *ibid.*, 1908, p. 79.

† Knudsen, *Publications de Circonstance,* No. 39, 1907.

While the position of Bahama Bank Vessel does not exclude this effect of the bank water (as shown by a comparison of the temperatures and salinities with those from Stations V-VII, where the conditions are such as to let the Atlantic water become a factor), the effect is much less evident than it is at Morecambe Bay Light Vessel. The cause of the variations from the simple harmonic curve in the graphs of sea-temperature at both Bahama Bank and Morecambe Bay ships may be looked for, therefore, in the local inshore conditions.

One clue to the causes of these variations may be found in the various positions of the minima of sea-temperature. Thus, the differences between the dates of the minima of the smoothed curves for Bahama and Morecambe Bay Ships are shown below :—

	Morecambe Bay.	Bahama Bank.	Difference.
			Days.
1907	January 31	February 20	20
1908	February 14	March 8	23
1909	March 1	March 6	5
1910	January 30	February 3	4
1911	February 9	February 11	2
1912	February 9	February 4	5
1914	January 26	January 22	4

Thus, the difference in the dates at which the minima occur may be from 2 to 23 days. The years 1912 and 1914 are the only ones in which the minimum for Bahama Bank occurs before that for Morecambe Bay. There was a marked deficiency in both the air-temperature and the amount of sunshine until February 10th in 1912 and until January 24th in 1914; and apparently the temperature of the banks in Morecambe Bay, which are laid bare by the tides, cooled the offshore water and delayed the usual rise of sea-temperature in those years. 1907 and 1908 are, however, very exceptional years, for the difference in the dates of occurrence of the minima were 20 and 23 days respectively; and they are also years which show, on the whole, the greatest differences in mean temperature at the two light vessels in question, though the exceptional nature of the conditions is not so strikingly shown as in the dates of the minima. Now it has been suggested that the general weather conditions act on the coastal strip of water between tide marks* to a much greater extent than on the water of the sea; but the change in temperature of the banks then acts on the sea (in some years, in the past, Morecambe Bay has had much ice on the banks in the winter months). This effect of the banks on the coastal sea-water is also shown by the rapid rise in sea-temperature in 1907, during February and March, when there was abundant sunshine and an air-temperature higher than the normal for this time of year.

There are, however, many factors which are bound to affect the temperature of the sea in such an area as Morecambe Bay. These conditions must be very complex, and it can only be during spells of exceptional weather, when one or a few factors predominate, that it is possible to trace out connections such as we are anxious to elucidate.

The heating and cooling of the sea-water in the Morecambe Bay area must, however, be largely influenced by the flowing and ebbing of the tides over about 100 square miles of sand, uncovered every twelve hours. Now, since the spring tides cover and uncover a larger area of sand-banks than do the neaps, it was thought possible that there might be a correlation between the deviations from the mean sea-temperature (as based on the ten-daily averages) and the succession of neaps and springs. Morecambe Bay Light Vessel is about 16 miles distant from the mouth of the Bay, and its position is such that it is not far from the main course of the floods and ebbs. (The tide from the north part of the Bay, however, streams north and south along Walney, and does not pass close to the ship.) There is a mass of water, however, flowing past the ship, for nine

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* Which is, of course, enormous in Morecambe Bay.

miles at springs and six miles at neaps, and this water has been mixed with that which has been in contact with the sand-banks. That this is so (that the influence of the tide streaming off the sand-banks is indirect at the ship) is shown by the fact that there is no evident connection between the sea-temperature at the ship and the state of the tide, whether flowing or ebbing. There would be such a connection if the influence of the banks on the ship were immediate and direct. So one can use the daily, 4 p.m., observations of temperature, even though the latter are taken at all states of the tide.

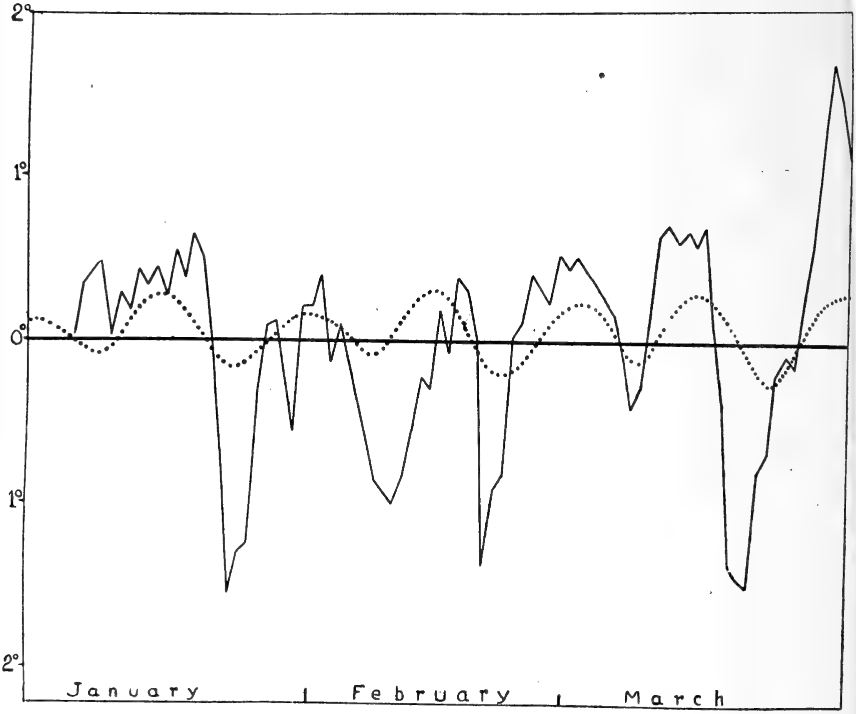

Fig. 3. **Temperature and tidal variations in January-March, 1907, Morecambe Bay Light Vessel.**

In applying these suggestions, the period January to

March has been taken, and, first of all, the data for separate years have been considered : we begin with 1907. The heights of the tide at high water at Liverpool—which is the nearest standard port—are plotted for the p.m. tides of each day, thus we obtain a curve, the maxima of which represent springs and the minima neaps. This curve is drawn as the dotted line in Fig. 3 and the straight line marked 0° C. may be taken as representing mean sea-level at high water for the period in question. To compare the deviations from the mean level at high water with the temperature variations we have next to find the smoothed ten-daily temperature, and it is assumed that in taking the means of overlapping groups of ten days the smaller deviations of temperature, due to tidal causes, are smoothed out. The straight line, " 0° C." in Fig. 3, then represents the temperature graph as deduced from the ten-daily smoothed averages, only it is straightened out, so to speak, because all that we want to find is the deviations of temperature from this smoothed value.

The smoothed temperature values are read off directly from a graph, and then the differences between these and the actually-observed daily temperatures are taken. These actual daily temperatures run rather irregularly, and so I have taken three daily averages : this gets rid of some of the more violent irregularities, but ought not to hide the variations due to the influence of the tides. Thus, the value for January 2nd, for instance, is taken as the mean of three days January 1st to 3rd, and it is plotted against the date January 2nd.

The difference between the smoothed mean ten-daily temperature and the mean three-daily temperature can now be found by adding or subtracting, as the case may be. The former series is represented by a straight line and the latter is represented by a graph, which runs above and sinks below this straight line. It will be seen that there is a rather striking similarity between the fluctuations of temperature and the fluctuations in the height of high water at Liverpool*: the former range between about 0·5° C. above and 1·33° C. below the mean line. This is extraordinary when one assumes that the differences are due, apparently, to the different areas of banks covered by the tides at neaps and springs. One thing, however, must be noticed: for approximately the first half of the period the mean temperature for Morecambe Bay Lightship is below that at Bahama Bank. The foreshore in Morecambe Bay must therefore be exercising a cooling effect since the influence of the sand-banks must be greater at the former position than at the latter. We should expect, then, that each high-water maximum would be opposed by a temperature minimum, whereas the reverse condition is shown by the graph. There is bound, however, to be a lag in the change of temperature, because it will take some time for the effect produced inshore to be felt at the lightship. The second part of the smoothed curves show that the foreshore is now warming the water offshore, and the temperature fluctuations produced by the tides and disclosed by the three-daily averages now correspond directly to the curve of high-water levels—so there is apparently no lag. That is, there is a complete reversal of the relative position of the fluctuations at the two lightships, and yet the periodicity of rhythm of the three-daily temperature fluctuations is apparently undisturbed. In spite of this apparent anomaly we must, however, correlate the changes in tidal level with the temperature fluctuations, though we must not expect a very high degree of correlation since the rate at which heat is transferred to and from the foreshore must depend on other conditions, such as the winds.

If the temperatures for January to March, 1908, be treated in the same way a similar rhythmic fluctuation is shown. But this is not so regular as in the case of 1907. The maxima

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* The difference between the times of high water at Liverpool and Morecambe Bay is only about ten minutes.

and minima follow each other as before, the former lagging from three to seven days behind the maxima of high water of the same year. The correlation breaks down at one place: the maximum high water of January 20th is opposed by the lowest minimum temperature of the whole series and is succeeded by a maximum which holds till January 26th. The weather reports disclose nothing that explains this anomaly; but if the temperatures for January are compared with those of the same month at Bahama Lightship it is seen that there is a sudden and remarkable increase in the difference between the two stations, which rapidly disappears and suggests that some abnormal condition affected the Morecambe Bay temperatures.

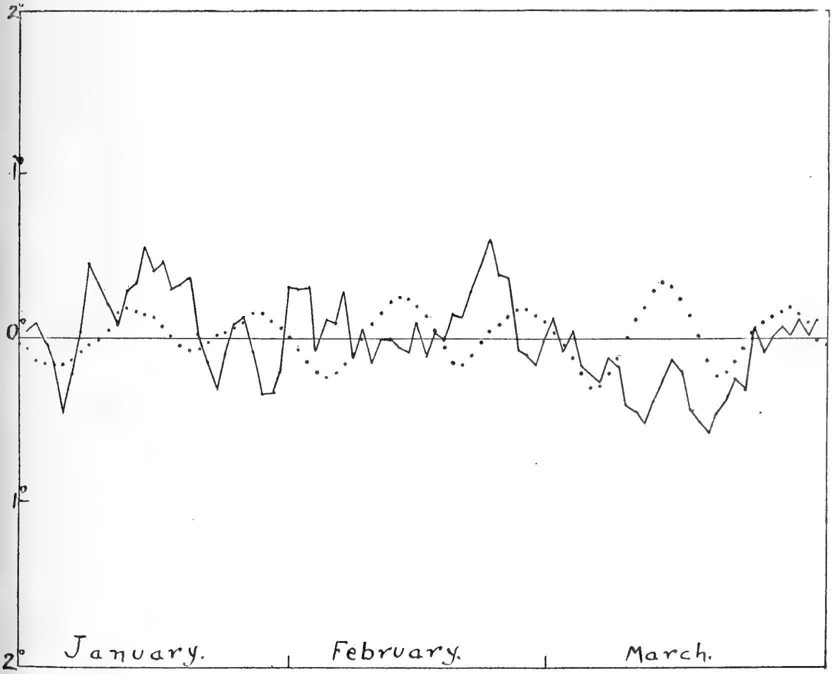

FIG. 4. Temperature and tidal variations January-March, 1910, Morecambe Bay Light Vessel.

The curve for 1909 shows fluctuations which disturb the rhythm, and when that of 1910 was examined it differed so markedly from 1907 and 1908 that it appears proper to reproduce it here (Fig. 4). The fluctuations have a range of about 0·28° C. above and below the mean, and they are irregular so that they fit in badly with the tidal curve of the same year: thus, opposite the tidal maximum of February 12th the temperature fluctuation nearly disappears. Weather conditions have been discussed above, particularly in connection with the rapid and unusual rise of temperature during March, 1907, at Morecambe Bay Ship. The mildness of the early months of 1910, particularly February, are indicated in the smoothness of the ten-day average curve, which contrasts strongly with the steeper curve for the Bahama region. In examining the temperature changes from day to day, however, we are not only dealing with general conditions, but also with the particular conditions for each day. In discussing the smoothed ten-daily curves it was found that in their early months 1907 and 1908 were " strong " years. Whatever were the conditions on the Lancashire coast they were such that they not only caused large differences between the temperatures, day by day, at the two lightships, but they actually altered the shapes of the two curves. It is during these years, therefore, that one might expect the general conditions prevailing over the great sand-banks to impress themselves on the temperature of the water offshore from the Bay and make minor differences. In 1910, however, the inshore conditions may not have been so marked as to do this so far out as the lightships. It is quite impossible, of course, to give due weight to all the factors concerned, but some that undoubtedly operate can be mentioned, just to show the conditions that may hide the tidal effects. The direction of the wind, for instance, will have much influence. The winds themselves warm or chill the banks. They may cut the tide or hold it back. They may raise the tide to more than its normal height: thus a stiff south-west breeze south of Holyhead may cause the water on the Dock Sill at Barrow to be a foot higher than the predicted tide, and a north-east wind in the same southerly area cuts the tide in Morecambe Bay even when, in the Bay itself, light westerly breezes may be blowing. The amount of fresh water which enters the Bay is also large: thus it is estimated* that the rivers there carry down fresh water from about 1,080 square miles of the wettest part of the British Islands. The quantity of water that enters the Bay after heavy rains must alter the temperature of the adjacent sea, especially after a time of melting snow, and the volume of water setting out from the Bay must also vary from this cause. These factors may become more prominent ones in a " weak " year.

These minor conditions are, to a great extent, incalculable ones, and if a long series of years were considered, and combined in some way, the irregularities that disturb the tidal rhythm ought to " cancel out." With this idea in mind all the data available have been treated in the following way :— One tidal graph must be made from all the years. Now the times of high water vary from year to year, but we can take the graph of high waters for 1907 and superpose the similar graphs for the other years upon this by shifting the latter backwards or forwards until the maxima and minima nearly coincide. Unfortunately, the method is complicated by the fact that springs and neaps do not occur with the same intervals in different years, and it is therefore necessary to compare the dates of the highest springs and the lowest neaps throughout, say, January to March for every year in order to find the actual difference in days between the maxima and minima of 1907 and those of other years. If the average of these differences is obtained then one can make the closest fit for the high-water curve of each year with that of 1907.

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* Report of British Rainfall Organisation for 1910.

The fit will not be exact, but the difference will not usually exceed one or two days. The following precautions are necessary in regard to the temperatures before the composite high-water curve can be used. By comparing the daily readings taken from the ten-daily curves the average daily rate of change of temperature can be found. Thus, corrections can be made.

Suppose that it is required to apply the graph of high waters for 1908 to that of 1907. It was found that, in order to get the best fit, the whole graph for 1908 had to be moved forward by four days: thus, January 6th of 1908 will coincide with January 2nd of 1907. Then we see, from the ten-daily average charts that the average temperature for seven years, for January 2nd, is higher than that for January 6th by 0·33° C., and so this amount has to be added to the value taken for January 6th, 1908. Each daily temperature must, of course, be altered likewise before 1908 can be compared with 1907 and its tidal graph. The same method was applied to each of the years, and the daily corrections were applied to the particular readings. The corrected values for each day were then added up and daily average fluctuations were thus obtained for the years 1907-12 and 1914. These were smoothed by taking three-daily averages, and the results were applied to the high-water graph just as in the case of the individual years. The result seems to be satisfactory, though the effect of the resultant fluctuations is toned down, so to speak, and the greater part of the range is no more than 0·28° C. above or below the mean line. But in outline the graph of composite fluctuations follows that of 1907 so closely that one must look on it with some suspicion. If the year 1907 is omitted and the combination of all the others is tried the result is very different. This curve for 1908-12 and 1914 shows little variation from January 1st-5th. In February and March there are signs of the same regular succession of maxima and minima that are shown by 1907, but the general effect is not convincing. What the graph suggests is a possibility rather than a complete demonstration. If the one poor year, 1910, is taken out there is still no essential alteration. Therefore we see that 1907 exhibits so remarkable and characteristic a succession of maxima and minima as to impress itself on the combined temperature curves of the six following years.

The daily fluctuations in temperature for the months June to September for the same years have also been examined. The smoothed curve plotted from the ten-daily averages for the summer of 1907 (the year in which the January-March tidal periodicity of temperature is so plain) rises sharply from 11·17° C. to a maximum of 17·44° C. on July 27-28th, and it falls again as rapidly. The slope of the corresponding curve for 1910 is less, and the maximum is 15·6° C. on August 4th.

If the daily temperatures for the summer 1907 at Morecambe Bay Ship be treated in the same way as in the case of the earlier months there is, it is true, a marked fluctuation above and below the mean line. Minor and irregular fluctuations are more noticeable in the summer months, as might be expected since, at this period, the air-temperature and solar radiation act with greater effect on the surface water and so bring about bigger fluctuations.*

The curve, made as before, shows tidal maxima on June 11th, August 10th, September 8th and September 22nd. These are opposed to minima of temperature, which is the condition one expects. The spring-tide maxima on June 26th, July 11th and August 23rd, however, occur against parts of the temperature curve, which are equivocal as regards the occurrence of maxima or minima. The summer of the year 1907, then, does not fulfil the promise of its spring.

The whole series of years 1907-12 and 1914 were next

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* See Robertson, "Observations of North Sea Surface Temperatures and Salinities, 1904-5," *North Sea Fisheries Investigations Committee* Rept. II (Northern Area), cd. 3358, 1907, p. 155.

thrown together in the same way, as has been indicated above, for the period January-March. The temperature fluctuations so obtained are not so well marked as they are in single years, but the maxima and minima fit much better to the tidal fluctuations with the exception of the period about August 24th, when there is no very evident maximum to correspond to the spring tides of that date. There are indications that this summer rhythm is not due to any one particular year, as in the case of the spring series of data.

TABLE I.

Average Temperatures C.° for Ten-Day Periods. Morecambe Bay Lightship 4 p.m. Surface Observations, January-March, 1907-12, 1914.

	January			February			March		
	1-10	11-20	21-30	31-9	10-19	20-1	2-11	12-21	22-31
1907...............	6·27	5·88	4·38	4·59	5·22	6·11	7·28	7·88	8·99
1908...............	5·45	4·76	4·59	5·17	4·86	5·06	4·76	5·28	5·34
1909...............	6·77	5·66	4·54	4·70	4·38	4·10	3·54	4·65	5·28
1910...............	5·34	5·12	4·32	4·65	4·70	5·22	5·28	5·66	6·77
1911...............	6·32	5·55	5·72	5·00	5·34	6·05	6·38	5·82	6·05
1912...............	6 67	6·61	5·93	4·70	4·70	5·51	5·99	7·00	7·11
1914...............	6·05	5·34	5·00	6·05	6·38	6·32	6·43	6·61	7·06
1915...............	7·28	6·38	5·22	...	...	...	...	...	...
Total	50·15	45·30	39·70	34·86	35 58	38·37	39·66	42·90	46·60
Average	6·27	5·66	4·96	4·98	5·08	5·48	5·67	6·13	6·66

Average Temperatures C.° for Ten-Day Periods. Morecambe Bay Lightship 4 p.m. Surface Observations, June-September, 1907-12, 1914.

	June			July		
	1-10	11-20	21-30	1-10	11-20	21-30
1907.........	11·22	13·12	13·23	14·44	15·94	17·89
1908.........	13·06	12·66	15·43	16·26	15·43	15·66
1909.........	11·50	12·16	13·18	14·32	14·21	14·04
1910.........	11·67	13·33	14·26	14·32	15·60	15·32
1911.........	14·82	14·09	13·60	15·00	16·32	17·73
1912.........	13·38	13·60	13·83	15·43	16·38	16·11
1914.........	11·55	13·99	15·00	15·77	16·77	16·05
Total	87·20	92·95	98·53	105·54	110·65	112·80
Average ...	12·46	13·28	14·08	15·08	15·81	16·11

	August			September		
	31-9	10-19	20-29	30-8	9-18	19-28
1907.........	16·72	16·61	15·16	14·65	15·00	15·38
1908.........	16·11	15·88	15·60	14·60	14·09	13·99
1909.........	15·43	15·94	15·55	14·65	14·26	13·49
1910.........	15·55	16·11	15·55	14·94	14·88	14·49
1911.........	17·89	19·00	17 83	17·56	16·94	15·32
1912.........	15·10	14·71	14·54	14·15	13·55	13·28
1914.........	16·16	17·28	17·22	17·94	16·16	14·60
Total	112·96	115·53	111·45	108·49	104·88	100·55
Average ...	16·14	16·50	15·92	15·50	14·98	14·36

TABLE II.

Number of days that are to be added to, or subtracted from, the dates on which spring and neap tides occur at Liverpool in order that the years 1908-14 *may be superposable on* 1907 (*January-March*).

High water.	1907.	1908.		1909.		1910.		1911.	
	Date.	Date.	Diff. from 1907.	Date.	Diff. from 1907.	Date.	Diff. from 1907.	Date.	Diff. from 1907
			Days.		Days.		Days.		Days
Max.	Jan. 2	Jan. 5	3	Jan. 8	6	Dec. 28	5	Jan. 3	1
Min.	,, 8	,, 13	5	,, 16-17	8·5	Jan. 5-6	2·5	,, 9	1
Max.	,, 15-16	,, 20	4·5	,, 24	8·5	,, 13	2·5	,, 16	0·5
Min.	,, 23-24	,, 28	4·5	,, 31	7·5	,, 20	3·5	,, 25	1·5
Max.	Feb. 1	Feb. 4	3	Feb. 7	6	,, 27	5	Feb. 2	1
Min.	,, 7	,, 11	4	,, 15	8	Feb. 4	3	,, 8	1
Max.	,, 14	,, 19-20	5·5	,, 22	8	,, 12	2	,, 15	1
Min.	,, 22	,, 26	4	Mar. 1	7	,, 19	3	,, 23	1
Max.	Mar. 2	Mar. 4	2	,, 8	6	,, 25	5	Mar. 3	1
Min.	,, 8-9	,, 11	2·5	,, 16	7·5	Mar. 5	3·5	,, 9	0·5
Max.	,, 15-16	,, 19-20	4	,, 23	7·5	,, 13	2·5	,, 16	0·5
Min.	,, 23	,, 26	3	,, 30	7	,, 19	4	,, 24	1
Av. Diff. from 1907 ...		3·75 days		7·3 days		3·45 days		0·9 days	
Av. Diff. from 1907 in nearest whole days		4 days		7 days		3 days		1 day	

High water.	1907.	1912.		1914.		1915.	
	Date.	Date.	Diff. from 1907.	Date.	Diff. from 1907.	Date.	Diff. from 1907.
			Days.		Days.		Days.
Max.	Jan. 2	Jan. 6	4	Dec. 29	4	Jan. 5	3
Min.	,, 8	,, 14-15	5·5	Jan. 6	2	,, 11	3
Max.	,, 15·16	,, 21-22	6·5	,, 15	1	,, 17	1·5
Min.	,, 23-24	,, 29	5·5	,, 21	2·5	,, 26	2·5
Max.	Feb. 1	Feb. 5	4	,, 29	3	Feb. 3	2
Min.	,, 7	,, 12	5	Feb. 5	2	,, 9	2
Max.	,, 14	,, 20-21	6·5	,, 13	1	,, 16	2
Min.	,, 22	,, 27	5	,, 19	3	,, 24	2
Max.	Mar. 2	Mar. 5	3	,, 27	3	Mar. 4	2
Min.	,, 8-9	,, 12	3·5	Mar. 7	1·5	,, 10	1·5
Max.	,, 15-16	,, 21	5·5	,, 14	1·5	,, 17	1·5
Min.	,, 23	,, 27	4	,, 20	3	,, 25	2
Av. Diff. from 1907		4·8 days		2·3 days		2·1 days	
Av. Diff. from 1907 in nearest whole days		5 days		2 days		2 days	

TABLE III.

Number of days that are to be added to, or subtracted from, the dates on which spring and neap tides occur at Liverpool in order that the years 1908-14 may be superposable on 1907 (June-September).

High water.	1907.	1908.		1909.		1910.	
	Date.	Date.	Diff. from 1907.	Date.	Diff. from 1907.	Date.	Diff. from 1907.
			Days.		Days.		Days.
Min.	June 4	June 7	3	May 28	7	June 1	3
Max.	,, 11	,, 15	4	June 4	7	,, 8	3
Min.	,, 19	,, 22	3	,, 11	8	,, 15	4
Max.	,, 26	,, 29	3	,, 18	8	,, 23	3
Min.	July 4	July 8	4	,, 26	8	,, 30	4
Max.	,, 11	,, 14	3	July 3	8	July 7	4
Min.	,, 19	,, 22	3	,, 11	8	,, 16	3
Max.	,, 25	,, 28	3	,, 17	8	,, 22	3
Min.	Aug. 2	Aug. 6	4	,, 26	7	,, 30	3
Max.	,, 11	,, 12	1	Aug. 2	9	Aug. 5	6
Min.	,, 18	,, 20	2	,, 10	8	,, 14	4
Max.	,, 23	,, 27	4	,, 16	7	,, 21	2
Min.	Sept. 1	Sept. 5	4	,, 25	7	,, 29	3
Max.	,, 8	,, 10	2	,, 31	8	Sept. 4	4
Min.	,, 16	,, 18	2	Sept. 8	8	,, 13	3
Max.	,, 22	,, 26	4	,, 15	7	,, 19	3
Av. Diff. from 1907		3·06 days		7·7 days		3·44 days	
Av. Diff. from 1907 in nearest whole days ...		3 days		8 days		3 days	

High water.	1907.	1911.		1912.		1914.	
	Date.	Date.	Diff. from 1907.	Date.	Diff. from 1907.	Date.	Diff. from 1907.
			Days.		Days.		Days.
Min.	June 4	June 4	0	June 8	4	June 1	3
Max.	,, 11	,, 12	1	,, 17	6	,, 8	3
Min.	,, 19	,, 20	1	,, 23	4	,, 16	3
Max.	,, 26	,, 27	1	,, 29	3	,, 27	−1
Min.	July 4	July 5	1	July 9	5	July 2	2
Max.	,, 11	,, 11	0	,, 17	6	,, 9	2
Min.	,, 19	,, 20	1	,, 23	4	,, 18	1
Max.	,, 25	,, 26	1	,, 29	4	,, 27	−2
Min.	Aug. 2	Aug. 4	2	Aug. 7	5	Aug. 1	1
Max.	,, 11	,, 10	−1	,, 13	2	,, 9	2
Min.	,, 18	,, 19	1	,, 22	4	,, 16	2
Max.	,, 23	,, 24	1	,, 28	5	,, 22	1
Min.	Sept. 1	Sept. 2	1	Sept. 5	4	,, 30	2
Max.	,, 8	,, 9	1	,, 11	3	Sept. 7	1
Min.	,, 16	,, 17	1	,, 19	3	,, 14	2
Max.	,, 22	,, 23	1	,, 27	5	,, 22	0
Av. Diff. from 1907		1·0 days		4·2 days		...	
Av. Diff. from 1907 in nearest whole days ...		1 day		4 days		1 day	

SEASONAL CHANGES IN THE CHEMICAL COMPOSITION OF THE MUSSEL (*MYTILUS EDULIS*).

By R. J. Daniel, B.Sc.

Introduction.

The paper is a preliminary notice of an investigation, at present incomplete, into the seasonal variations in the composition of flesh of the common mussel (*Mytilus edulis*) from samples obtained on the mussel-beds of Morecambe, Lancashire. Since the methods of dealing with the samples obtained are all-important in such work, it is this aspect which is dealt with below. It is intended in the full report to include also an account of the structure of the mussel. Although much work has been done in this direction, notably by Sabatier* on *Mytilus edulis* itself, and by List† on closely-allied species, there seems room for a further description of this mollusc.

The positions of the Morecambe mussel-beds are well shown in Chart II, Report of the Lancashire Sea-Fisheries Laboratory, 1912, as they were then. With one exception the samples have been obtained from an area surrounding the two " gunnels," or channels, which connect the Grange Channel with Heysham Lake ; it is mainly from these skears that mussels are consigned for food, several of the samples dealt with being taken from bags already packed for sale.

The importance of this fishery at Morecambe may be shown by the fact that during the years 1900-1904, 7,838 tons of mussels were removed from the beds, the value yielded in any one year amounting to as much as £2,000.

The first sample was received on May 21st, 1920, and since then other samples have been forwarded at intervals of approximately three weeks, by Mr. Edward Gardner, Honorary Bailiff to the Lancashire and Western Sea-Fisheries Committee, to whose kindly assistance I am greatly indebted. The samples vary from 16-39 mussels, and are always

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* Sabatier, *Annales des Sciences Naturelles*, 1877, Series 6, v., page 1.

† List, " Die Mytiliden " *Fauna und Flora des Golfes von Neapel*, xxvii, 1902.

despatched to Liverpool the same way, through the post in tins. They usually arrive in good condition, with the valves of the shells tightly closed.

Method of dealing with samples.

The outsides of the mussel-shells are first freed from barnacles and any foreign matter, washed under the tap, and dried with a towel. The mussels are prised open with a pair of forceps, and a small wooden peg placed between the valves to prevent them from reclosing. After shaking to get rid of any water which may be lodged in the mantle cavity, the mussels are reared up in small racks, with the posterior end of the shell resting on a sheet of blotting paper; the latter absorbs any mucus or excreta that may drain away. It is necessary to open the shells carefully, because if the flesh is punctured, blood and liquid flows from the animal itself. The draining is continued until a dry glaze begins to show on the surface of the flesh, a process which generally takes a little over two hours.

Six mussels are then chosen at random and placed on one side for special examination. The remaining mussels in the sample, with their shells, are weighed in bulk, and after the soft parts are removed, the shells alone are weighed. The difference, of course, gives the wet weight of the soft parts. In all cases the byssus threads are weighed in with the shells. It is from this latter part of the sample that mussels are obtained for sectioning to show the distribution of fat in the tissue.

The six mussels taken from the sample are each weighed in their shells separately on a balance. The soft contents are then scraped with care, by means of a scalpel, into a small porcelain dish which has been previously dried and weighed.

The cleaned shell with any byssus threads are also weighed separately, and it is then possible, by subtracting such weights from those of the mussels with shells, to obtain the wet weight of the flesh in the basin. This gives a more accurate result than weighing the basin and flesh direct, because the removal of the beasts from their shells takes time, and evaporation is constantly going on. The basin and its contents are then placed in an electric oven at 105° C. and dried until a constant weight is obtained. It is probable that all the water is not removed by this method, since the mussels become covered with a hard, impermeable skin.

From the differences of wet and dry weights the amount of water in the tissue is obtained. The dried mussels are powdered in a mortar and stored in small bottles. It is from this powder that the percentages of fat and protein are calculated, two or three samples being run through together.

The following example is given to show the method of tabulating the observations :—

OCTOBER 29TH, 1920.

Sample of 19 mussels taken from the Little Out Skear, close to the Gunnel through into Heysham Lake.

No.	Length.	Total weight with shell.	Weight of shell.	Weight of flesh.
	cm.	grammes.	grammes.	grammes.
1	6·55	20·300	10·790	9·510
2	6·00	15·997	9·206	6·791
3	6·80	18·598	9·821	8·777
4	5·95	16·721	8·557	8·164
5	6·15	15·044	7·746	7·298
6	6·80 Av. 6·375	19·035	10·487	8·548
7	6·20	Totals 105·695	56·607	49·088
8	6·30	Averages 17·616	9·435	8·181
9	6·55			
10	6·80			
11	6·25			
12	6·15			
13	6·40	Weight 7-19 ... 245·04	124·575	120·465
14	6·95			
15	6·35	Average ... ... 18·850	9·580	9·270
16	6·70			
17	5·95	Difference in averages 1·234	0·145	1·089
18	5·90			
19	6·25 Av. 6·365			

The difference in the averages of 1-6 and 7 to 19 in this case are extreme when compared with most of the other samples.

The Shell.

The length of each shell is found in cms., the measurement being from the umbo to the extreme rounded portion of the posterior edge. The shell is composed mainly of carbonate of lime ; there is no trace of phosphate of lime. Iron is present and seems to be connected with the blue colour of the shell. This colour in mussel-shells is not uncommonly segregated into stripes and bands, the remainder of the shell in such cases being practically colourless. Pieces of shell with little colour give feeble reactions when tested for iron, whereas the coloured portions give very decided reactions. The shell also gives the destructive flame reaction for strontium, and since this suggests one of the ultimate destinations of strontium brought down by rivers and streams, it will be interesting to examine other mollusc shells, and calcareous algæ, to ascertain whether its presence in these is general.

Shells with the periostracum have been taken from each sample and powdered in an iron pestle and mortar. After obtaining the water content by weighing powder before and after drying, the samples have been stored, and now await quantitative estimation of carbonate of lime and iron to see if there are any significant changes in the percentages throughout the samples.

Estimation of Fats.

In the estimation of fats, 0·5 to 1 gramme of the powdered mussel-flesh was taken from each sample and the extraction carried out in a Soxhlet apparatus, carbon tetrachloride being used as solvent. Whatman's fat-free extraction thimbles were used, and these were cut down, so that when fitted into a numbered weighing bottle, the lid of the latter could be replaced in position. By excluding air as much as possible in this way, subsequent weighings were done with greater ease and accuracy.

The weighing bottle containing a cut-down thimble, a plug of cotton wool, and also a Swedish filter paper, was first dried and weighed, the date of the sample having been written in pencil on the thimble to avoid confusion. Mussel powder was wrapped carefully in the filter paper and placed in the thimble, the latter being then plugged by the cotton wool. It was found in practice that this method prevented a passing over of the powder itself during the extraction. The weighing bottle, with its contents, was placed in the oven, and once a constant weight was obtained the amount of powder in the thimble was ascertained by subtracting the original weight of the bottle, etc.

To ensure as complete an extraction as possible, the Soxhlet apparatus was kept working for three or four hours, although the solvent appeared clear after the third or fourth siphoning. The thimble, with its residue, was then placed back into the weighing bottle and dried in the oven. The weight of the residue was a check upon the accuracy of the extraction, since its weight plus that of the carbon tetrachloride extract should equal the original dry weight of the powder taken for the experiment. The error generally fell to within 0·5 %, and where differences were greater, the extraction was carried out again.

This system of fat extraction is not without error; other substances besides fats are probably extracted from the tissues. Moreover, there will be oxidation of some of the fat present in the powder during the heating and drying process. The propriety of estimating fats in such a manner, instead of estimating them as fatty acids, has been discussed by several writers*.

The results from the above methods, however, if not strictly accurate are all obtained under the same standard conditions; and since this work is one of comparison rather than intensive quantitative estimation, it is sufficient for the

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* For papers see Hartley, *J. of Physiology*, 1907-8; Mottram, *ibid.*, 1909-10; Kumagawa and Suto, *Bio-chemical Zs.*, 1908; Tamura, *ibid.*, 1913.

purpose. Fastidious method is beside the point in an investigation such as this, where the errors of sampling may be very appreciable.

Proteid Estimations.

Kjeldhal's method was used in estimating proteid. The amount of dried mussel powder taken was 0·5 grammes. This was placed in a long-necked flask, with 20 c.c. of strong sulphuric acid and a little sand added to stop bumping. The flask was then heated cautiously until the frothing of the material subsided. After cooling, a teaspoonful of sodium sulphate was added to increase the temperature of boiling, and a small piece of copper sulphate to assist in the oxidation. The flask was then heated vigorously for an hour or more until the contained liquid became a clear green. After diluting the liquid with distilled water, it was added to an excess of caustic soda and distilled, the ammonia evolved being collected in 75 c.c. of decinormal sulphuric acid. The titration was carried out with decinormal sodium hydrate, cochineal being used as an indicator.

Two or three samples were estimated at one time, a blank experiment having first been made to calculate the error.

In order to obtain the percentages of proteid given below the Kjeldhal nitrogen values have been multiplied by the factor 6·25. This number has been used quite provisionally. There is evidence from experiment that the factor ought to be higher so far as the mussel is concerned, but since this part of the work is incomplete, the more commonly accepted factor has been used in the meantime. The proteid values given at any rate show the tendency of the changes throughout the season.

Estimation of Carbohydrates.

The large quantities of glycogen found in the mussel render it highly desirable to obtain some method of estimation which will give a sufficient degree of accuracy.

Unfortunately, direct method of estimation of glycogen, such as Pfluger's well-known short method, or Fraenkel's extraction with trichloracetic acid, are hardly applicable in this case. Results thus obtained would be untrustworthy, because the mussels have to travel under adverse conditions for twelve hours or more, and probably during this period some of the glycogen is converted into glucose by enzyme action. Mussels required for sectioning and staining for glycogen have been obtained by having them placed into absolute alcohol immediately upon gathering from the beds, but this system could not be extended very well to the estimation of amounts of glycogen, because the original weight of the flesh treated would not be known. Inverting the whole of the glycogen into glucose by keeping mussels several days in chloroform vapour, and estimating the glucose by reduction of Fehling's solution has also been tried. It is dangerous, however, to adopt any method which has not been thoroughly tested, and to do this one requires to work near the mussel-beds and thus obtain fresh material. Since circumstances up to the present have not allowed of such a procedure, the carbohydrates in the meantime have been given as the difference on the other percentages.

One point of interest which arose from the above work is the small amount of trouble with which comparatively large quantities of glycogen may be got from mussels, and it is suggested as an easy and profitable source for obtaining the substance for use in laboratories. The following experiment is given in some detail to show the manner in which mussels were dealt with for this purpose.

A number of mussels in poor condition, and therefore likely to give minimal returns, were procured from the Wallasey beds in the River Mersey on January 25th, 1921.

Thirty-three of the mussels were dealt with an hour or two after gathering. The shells were wedged open, and after shaking to get rid of any sea-water, the posterior adductor, or large muscle, was cut, and the flesh scraped into a weighed 1,000 c.c. flask, through a glass funnel. While passing slowly through the funnel the mussels were minced up with the blade of a scalpel. The wet weight of this mass was found to be 337·9 grammes. Two hundred and thirty-two c.c. of 60 % caustic potash was introduced into the flask, a reflux condenser fitted, and the whole heated on a water bath for three hours. At the end of this time the tissue was broken down in a most thorough manner. After cooling, the contents of the 1,000 c.c. flask was transferred to a tall measuring glass and touched the 560 c.c. mark. The mixture was then diluted with water until the total amount of liquid and tissue came to 1,400 c.c. After stirring well with a glass rod, the mouth of the measuring glass was covered with a petrie dish and the sediment left to settle. This took place in about twenty-four hours, the residue at the bottom measuring up to 170 c.c.

A siphon tube was then placed under the soapy film which had formed on the surface of the liquid, and the clear part of the latter siphoned off from above the sediment into a tall, glass vessel capable of holding 3,000 c.c. This method of siphoning, while allowing a small quantity of glycogen to remain behind in the measuring glass, saves a good deal of trouble in the subsequent filterings.

The glycogen was precipitated from the liquid thus obtained by adding twice its volume of 95 % alcohol. The precipitate was allowed to settle and the liquid then decanted off through a filter paper, contained in a glass funnel, and fitted with a supporting metal cone. The filtration was hastened by the use of a filter pump. The glycogen was then washed by shaking with a little fresh alcohol and run on to the same filter paper. To cleanse the glycogen more thoroughly, it was dissolved by running boiling water through the paper, and the opalescent liquid thus formed received into a fresh flask. The bulk of water was reduced by heating on the water bath, cooled, and the glycogen again precipitated with alcohol and filtered on to a fresh weighed filter paper. It only remained to give a final washing with ether, and dry the glycogen on the paper at 100° C. The quantity of alcohol used is large, but easily recoverable in a still. The subsequent weighing gave a yield of six grammes of glycogen. The actual amount of time taken during the operation was not great, since the periods required for the sediment and glycogen to settle may be employed in other work. The manner in which the mussel tissue breaks down helps the process considerably, and the haste required in obtaining glycogen for instance from mammalian livers, where inversion takes place immediately after death, is not necessary.

The only supply of mussels available for many laboratories, however, will be those obtained from local shops, where they may have languished for two or three days. Therefore, in order to effect a comparison with the fresh sample, a second lot of thirty-three mussels were kept until midday of January 29th or 4 days. By this time most of the shells were gaping, and the animals contained had a flaccid appearance although still able to show some little signs of movement. The weight of flesh was less than in the first sample owing to the slow evaporation of the water contents. The same procedure was gone through as in the fresh mussels, and the amount of glycogen obtained was 4·422 grammes, approximately two-thirds of the first amount, but still in sufficient quantities to show that as a cheap and easily-handled source of glycogen, the common mussel is worthy of consideration.

Estimation of Ash.

To obtain the non-volatile mineral matter, about 0·5 grammes of dried powder was incinerated in a silica crucible. After half an hour of heating to a dull red, the substance was cooled and one or two drops of strong nitric acid added. The heating was then continued over a fierce flame until a white ash was produced. This residue, besides containing inorganic matter from the tissue itself probably also includes a certain amount of salt, deposited on the surface of the flesh by the sea-water during the drying process, and also the sand and mud lying in the gut of the animals. Since the amount of the latter depends upon the vigour with which the animal was feeding when caught, it is a variable quantity which is independent of the actual body metabolism. The percentages have therefore been reckoned on the wet ash free substance. This does not make much difference so far as the fat and proteid percentages are concerned, but alters the carbohydrate values in some cases, since these are obtained by difference.

The percentage results are given below without comment since the work is still proceeding :—

Morecambe Mussels.

Percentages based on Wet Ash Free Substance.

Date.	Water %.	Oil %.	Proteid % N × 6·25.	Carbohydrate % (by difference).
May 21*.........	86·610	0·629	8·261	4·499
June 10	86·440	0·525	8·647	4·388
July 7	85·884	0·867	8·791	4·458
,, 26	81·321	1·267	10·960	6·452
Aug. 20	79·103	1·484	11·859	7·554
Sept. 13	77·867	1·516	12·681	7·936
Oct. 8	81·797	1·277	9·939	6·987
,, 29	80·534	1·454	11·228	6·784
Nov. 25	81·878	1·678	10·960	5·484
Dec. 17	83·926	1·160	9·286	5·628

* In this sample the wet weight was obtained from the flesh after removal from shell into dish, and not by difference of total weight—weight of shell. The water contents therefore should be higher, and other percentages are affected accordingly.

From the September sample onwards, transverse sections have been cut through the region of the liver, with a view to ascertaining the position of fat and glycogen in the tissues, and tracing any changes which may occur.

The following technique has been adopted :—

Fat : (*a*) Tissue fixed in 4 % Formaline ; frozen sections cut and stained with Sudan III ; mounted in glycerine jelly.

(*b*) Fixative 10 % potassium bichromate and glacial acetic ; paraffin sections stained with Sudan III and Delafield's haematoxylin.*

Glycogen : Fixative absolute alcohol ; wax sections stained with Lugol's solution and mounted in xylol balsam.

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* See Bell, *J. of Pathology*, No. 1, XIX, 1914

AN INTENSIVE STUDY OF THE MARINE PLANKTON AROUND THE SOUTH END OF THE ISLE OF MAN.—PART XIII.

By W. A. Herdman, F.R.S., Andrew Scott, A.L.S., and H. Mabel Lewis, B.A.

Once again, from the pressure of other work, it has been found impossible to undertake that general summary of our accumulated data and re-consideration of our previous reports which was promised. We can deal now, as before, only with the observations and results of the past year—and these, moreover, only in brief form in deference to the demand for economy in printing.

The work during 1920 was carried on in exactly the same manner as in previous years, and 573 samples of plankton were collected in the neighbourhood of Port Erin, and have since been worked up in detail. These bring the total number of samples for the 14 years' work, since 1907, up to 7,071.

In addition to an average of six gatherings per week throughout the year in Port Erin Bay, in the specially important months of March, April, July, August and September special hauls were taken both in the bay and outside in the open sea from the motor-boat "Redwing." The results have been treated in the usual way, and the forms, lists, tables and graphs are stored available for future reference in the Oceanographic Department of the University; where also the accumulated collections of plankton catches are housed. A special investigation undertaken by one of us (W.A.H.) from the "Redwing" on the variation observed in successive vertical hauls is dealt with as a separate paper in this Report (p. 161). The following is only to be regarded as a summary of the outstanding facts of the year 1920.

The vernal plankton maximum was again in May, and the largest individual catch was 101·7 c.c. on May 17th. The monthly average catch rises from 3·8 c.c. in January, through 9·8 c.c. in April, to 45·3 c.c. in May, and then falls to 31·6 in June, 12·2 c.c. in August, 19·6 c.c. in September (due to the Copepod maximum) down to the winter minimum 2·4 c.c. in December. The Diatoms taken by themselves form the usual double crested curve with a greater maximum in May, a summer minimum in August, a second lower maximum in September and the winter minimum in December. The monthly average for May was over 21 millions (much greater than in 1919) and in September nearly 1½ millions. The largest single catch of Diatoms was 66,168,350 on May 24th. These numbers are more like those of 1918 than of 1919, when the Diatom catches were unusually small.

The Dinoflagellate maximum was in June, when the monthly average was 184,000. It had risen from about 5,000 in January, and fell to a minimum of 1,463 in October. There was no marked second rise. The largest single haul of Dinoflagellates was 617,900 on June 3rd, mainly composed of *Ceratium tripos*, but the largest haul of *Peridinium* (152,000) was also on the same date—much earlier than in 1919.

The highest monthly average for the Copepoda (both Nauplii and adults) was in September (74,328 adults and 86,956 Nauplii)—much later than last year—and the largest individual catch was 192,510 on September 27th. The monthly maxima are this year in their normal order—Diatoms first, then Dinoflagellates and lastly Copepoda. The great spring increase in Diatoms was late in appearing, but once it did appear was in abundance.

Taking our usual seven dominant genera of Diatoms in detail we find from the monthly averages that, as last year, *Biddulphia* and *Coscinodiscus* have their spring maxima in March, while *Rhizosolenia* is earlier than usual with its maximum in May along with *Chaetoceras*, *Thalassiosira* and *Lauderia*.

The greatest Diatom catches are as follows :—

Coscinodiscus = 225,630 on March 22nd.
Biddulphia = 580,000 on April 20th.
Lauderia = 1,140,000 on May 11th.
Thalassiosira = 1,890,000 on May 17th.
Chaetoceras = 10,741,000 on May 17th (5,967,000 on September 23rd).
Rhizosolenia = 64,295,000 on May 24th.
Guinardia = 1,036,000 on June 14th.

In all cases this year the autumn increase is much smaller than the spring maximum.

Reviewing the records of the six most abundant Copepoda shows that most of them have their maxima late this year—*Acartia* in June, *Temora* in July, *Calanus* and *Oithona* in August, *Pseudocalanus* in September and *Paracalanus* in November. The largest individual haul was 122,000 *Pseudocalanus elongatus* on September 27th. There were about 98,000 *Oithona* on November 11th and over 10,000 *Paracalanus* on the same date. On the whole Copepoda were abundant later in the year than in 1919.

Noctiluca was present from August on to the end of the year, but only reached about 10,000 in a haul—in contrast to over 26,000 in July last year.

Echinoderm larvae were fairly abundant, up to over 9,000, at various dates from March to September. *Sagitta* was most abundant in June and July, rare in other months, though a few are always present. Polychaet larvae were present throughout the year, but most abundant in the early months, up to 56,000 on March 4th. Molluscan larvae, both Gastropod and Lamellibranch, have also much the same distribution, but only reach the thousands in early spring and again in late autumn. *Oikopleura* was present throughout the year, being most abundant in the warmer months and reaching 12,000 in May and 17,000 at the end of September. In most months there were a few hundred in a haul. Rockling and other fish eggs were present from January to October and began to appear again at the end of December. On the whole these distributions corroborate more or less the experience of previous years.

When the special hauls taken during the Easter and summer vacations in the open sea outside are compared with those taken across the bay at the corresponding seasons, it is found that in all groups the numbers per haul are usually higher out at sea. The Copepods were in force outside rather earlier than in the bay, the maximum for the adult Copepoda being in August at sea and in September inside the bay. In other groups there is no great difference in time.

Finally, it may be remarked in connection with the point discussed in our report last year as to the degree of correspondence in time between the hatching of larval fish such as plaice and the appearance in the sea of phytoplankton in abundance, that 1920 may have been a year when microscopic food for the first hatched young fish was scanty in amount. The fish-hatching at Port Erin was unusually early (February) and the Diatoms at least were not present in great abundance until later than usual. It must be remembered, however, that in addition to *Biddulphia* and *Coscinodiscus*, which reach their maxima in March, various larval forms of Invertebrata such as Polychaets and Mollusca are present in considerable abundance in the early spring months and may serve in part, along with the phytoplankton, as food for the young fishes.

VARIATION IN SUCCESSIVE VERTICAL PLANKTON HAULS AT PORT ERIN.*

By W. A. Herdman, C.B.E., F.R.S.

(Emeritus-Professor of Natural History in the University of Liverpool.)

The degree of uniformity in the distribution of the plankton through the water of a sea-area which is under what seem uniform physical conditions is still a vexed question. We are still uncertain as to the degree of validity of our samples, and as to how far they represent more than some proportion of the contents of the actual water which was sampled.

The Sargasso Sea, surrounded by the North Atlantic Gulf Stream circulation, and of relatively high temperature throughout, is probably the largest area of apparently uniform conditions that is known, and the results of the German Plankton Expedition of 1889 show that the twenty-four plankton catches obtained in that area were all small in quantity compared with those from further North and further South in the Atlantic. Schütt, who reports upon these results, shows that the average volume of the twenty-four catches was 3·3 c.c., but the individual catches ranged from 1·5 c.c. to 6·5 c.c. and the greatest divergence from the average was therefore + 3·2 c.c., the divergence in the other direction being − 1·8 c.c. After somewhat arbitrarily deducting 20 per cent. of this divergence as due to errors of the experiment, he estimates the mean variation of the plankton in the area investigated at about 16 per cent. above or below the average of the hauls. Even this reduced figure does not, however, indicate a very high degree of uniformity of distribution such

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* I wish to acknowledge, with thanks, the help I have received in this investigation from Mr. Andrew Scott, A.L.S., and Miss H. M. Lewis, B.A.—from Mr. Scott in the examination and estimation of the catches, and from Miss Lewis in making the calculations. I alone am responsible for the work at sea

as might have been expected in the most "halistatic" known area of the ocean.

These hauls were taken miles apart at considerable intervals of time; the question next arises whether simultaneous or almost simultaneous hauls taken through closely adjacent bodies of water would show a greater degree of uniformity. Hensen made a series of experiments, also discussed by Schütt, in which he hauled the same net twice in rapid succession in as nearly as possible the same body of water, on forty occasions, and eight times in succession once, and found that the average error was about 13 per cent.

In all such work at sea it is obvious that much depends upon the weather, the conditions under which the ship is working and the care taken in the experiment. With the view of getting further evidence from a new series of data, taken with all possible care under favourable conditions, I carried out a number of similar experiments at Port Erin during several months in spring, summer and autumn of 1920. They consisted of a series of four to six "successive" (that is, as nearly as possible simultaneous) vertical hauls taken with the Nansen net of No. 20 silk. On each of the seven occasions (four in April and one each in May, August and September) a day was selected when the weather was favourable and a time when it was known that the tide would not prevent the motor-boat "Redwing" from maintaining her position on the marks during the twenty to thirty minutes that the experiment occupied. Two localities were used, the one just at the mouth of Port Erin Bay with a depth of 8 fathoms, and the other a good deal further out with a depth of 20 fathoms. The boat was kept approximately stationary in the water, the hauls taken as plumb as possible, and the rate of hauling up was fairly constant at two minutes to 20 fathoms. The catches were emptied from the brass bucket of the net direct into bottles of 5 per cent. formaline, in which they remained until examined microscopically in the laboratory—so no loss of material was possible through straining or transferring from one vessel to another.

The first four series (six in each) were taken in April during the time of the ordinary mixed early spring plankton before the phytoplankton maximum; the next series, in May (four hauls), was just at the time of the *Rhizosolenia* maximum and shows a typical phytoplankton; the August series (four hauls) shows a scanty summer zooplankton; and the last series, in September (four hauls), shows again an abundant phytoplankton of autumn Diatoms and Dinoflagellates.

Two out of the thirty-six bottles were unfortunately broken in transit from the Isle of Man, so that the total number examined and now reported on is thirty-four, as follows:—

	Fathoms.	Hauls.	Average.
April 3	8	6	0·20 c.c., mixed plankton.
,, 6	20	5	0·56 c.c., ,, ,,
,, 8	20	6	0·52 c.c., ,, ,,
,, 13	8	5	0·48 c.c., ,, ,,
May 25	20	4	16·125 c.c., phytoplankton.
Aug. 7	20	4	0·50 c.c., zooplankton.
Sept. 16	20	4	6·10 c.c., phytoplankton, etc.

The nature of the plankton in each series was more or less what was to be expected in the locality at that time of year, and the volumes of the catches were also fairly characteristic of the season. The apparent uniformity in the successive catches of each series was obvious at the time of collecting. It seemed to the eye to be the same catch that was emptied from the Nansen-bucket into the bottle of formaline time after time throughout a series. And this apparent uniformity of volume is in most cases confirmed by the careful measurement made afterwards in the laboratory—for example, the six successive hauls from 8 fathoms on April 3rd all measure 0·2 c.c., four out of five of those from 20 fathoms on April 6th are 0·6 c.c., and all four on August 7th from 20 fathoms measure 0·5 c.c. The remaining four series show some variation, but the percentage deviation from the average of each series is in no case great. The volumes of these series are as follows :—

		Average.
April 8—	0·6, 0·6, 0·5, 0·5, 0·4, 0·5. ...	0·52 c.c.
„ 13—	0·4, 0·6, 0·5, 0·4, 0·5	0·48 c.c.
May 25—	19·5, 15·0, 15·5, 14·5	16·125 c.c.
Sept. 16—	6·2, 7·5, 4·5, 6·2	6·10 c.c.

If, however, we examine the detailed results of the microscopic investigation of the catches, we find that even in the same series similar volumes of catches may be made up rather differently, and may in some cases show surprising differences in the numbers of a species in successive hauls, such as 10 and 100, 40 and 800, 4,000 and 18,000. The same organisms are present for the most part in each haul of a series, and the chief groups of organisms are present in much the same proportion. For example, in a series where the Copepoda average about 100, the Dinoflagellates average about 300 and the Diatoms about 8,000. On another occasion we find Copepoda about 1,000, Dinoflagellates about 4,000 and Diatoms about 100,000. These are in mixed catches ; in a phytoplankton (May 25th) the Copepoda may be in hundreds, the Dinoflagellates in tens of thousands and the Diatoms in the millions. But notwithstanding this appearance of similarity between the hauls of a series, there is a considerable percentage deviation in the case of some hauls from the average of their series—not infrequently about plus or minus 50 per cent., in several cases about 70 and in one case plus 129. The following table gives the percentage deviations in the case of the volumes, and of the estimated numbers of the four chief groups of organisms present, viz., Diatoms, Dinoflagellates, Copepoda and the Nauplii of Copepoda.

In all there are about 50 species of organisms that occur with fair regularity throughout the series: 24 species of Diatoms, 4 of Dinoflagellates, 8 of Copepoda and about 14 other organisms or groups of organisms which are not of so much

Date and Depth.	No. of hauls.	Vol. in c.c. average.	Greatest per cent. deviation from average.	Diatoms ditto.	Dinoflagellates ditto.	Copepoda ditto.	Copepod Nauplii. ditto.
April 3— 8 fathoms	6	0·2	0	−52 +24	−42 +24	−14 +21	−19 +39
April 6— 20 fathoms	5	0·58	−14 + 3	−51 +41	−53 +56	−50 +42	−44 +41
April 8— 20 fathoms	6	0·52	−23 +15	−24 +17	−20 +15	−40 +22	−39 +22
April 13— 8 fathoms	5	0·48	−17 +25	−41 +73	−65 +44	−22 +33	−57 +129
May 25— 20 fathoms	4	16·125	−10 +21	−21 +15	−22 +23	−72 +60	−33 +56
August 7— 20 fathoms	4	0·5	0	−70 +59	−27 +17	−13 +32	−21 +10
September 16— 20 fathoms	4	6·1	−26 +23	−36 +30	−22 +36	−36 +53	−31 +37

importance and may be omitted. Of the 24 species of Diatoms as a general rule if a species occurs in one of the hauls of a series it occurs in all, and in many cases in much the same proportions in all; that is, there may be two or three or even more times as many individual cells in one haul as in another, but all will be in the tens, or in the hundreds, or the thousands, or millions. The following are a few examples:—

April 3—

Biddulphia mobiliensis, 1,800, 1,800, 3,800, 4,000, 4,400, 5,400;
Coscinodiscus radiatus, 1,600, 2,600, 2,600, 2,800, 2,800, 2,200;
Lauderia borealis, 10, 20, 50, 40, 40, 20;
Streptotheca thamensis, 40, 30, 30, 40, 40, 60;

April 8—

Asterionella bleakeleyi, 12,000, 20,000, 16,000, 36,000, 28,000, 40,000;
Lauderia borealis, 200, 200, 240, 200, 120, 200;
Rhizosolenia setigera, 40, 40, 80, 80, 40, 40;

May 25—
Guinardia flaccida, 60,000, 62,000, 63,000, 54,000;
Rhizosolenia semispina, 1,620,000, 1,120,000, 1,600,000, 1,460,000;
Streptotheca thamensis, 300, 100, 400, 200.

Many other similar examples might be given. On the other hand in the case of other species or on other occasions there was more variation, and such cases as 60 and 800 in adjacent hauls can be found.

It is much the same with the four common species of Dinoflagellates recorded. There again we find cases of considerable constancy in the hauls of a series, such as :—

May 25—*Peridinium divergens*, 46,000, 62,000, 50,000, 44,000:

and other cases of more variation—even in the same series, such as :—

May 25—*Ceratium furca*, 6,000, 2,000, 8,000, 1,000.

Are we entitled from this to conclude that the Peridinium is very evenly distributed through the water and the Ceratium much less so? I doubt it.

The Copepoda, occurring in much smaller numbers, seem also to indicate in many cases a fairly even distribution. Sometimes they occur only in units, and yet each haul of the series shows a few :—

April 3—*Oithona similis*, 8, 4, 3, 3, 5, 11;
,, 3—*Pseudocalanus elongatus*, 10, 85, 130, 110, 79, 80;
,, 13—*Temora longicornis*, 10, 5, 10, 10, 10;
,, 13—*Oithona similis*, 20, 20, 20, 20, 20.

Other cases again seem to indicate considerable variation in adjacent hauls. Which of these contradictory impressions received from an inspection of the results of the hauls is true to Nature? If the Oithonas on April 13th had been quite irregularly scattered through the water, is it likely that we could catch exactly 20 in each of five successive hauls? On the other hand, if they were evenly distributed, how can we account for one haul (April 6th) catching 40 and the next 140, or for the series on May 25th—20, 80, 460, 290 in the four successive hauls?

Some of the other common organisms outside the above main groups show equally contradictory evidence. The pelagic worm, *Sagitta bipunctata*, is present in nearly every haul in numbers varying from one to twenty-seven, but in some series one or two specimens are present in every haul, while in another case successive hauls in one series varied from one to eleven. Other similar examples might be given from some of the larval forms present. The impression one receives from an inspection of the lists and numbers as they stand is that if on each occasion one haul only in place of four or six had been taken and one had used the results of that haul to estimate the abundance of any one organism or group of organisms in that sea-area one might have arrived at conclusions about 50 per cent. (or in some cases a great deal more) wrong in either direction.

Is such a vague result of any value as a basis for calculations as to the population of the sea? And is it possible that such irregular numbers are compatible with the hypothesis of an even distribution of the plankton throughout a sea-area of constant character? The answer to such questions depends to some extent upon the possible range of error under the conditions of the experiment, and upon the possibility of allowing for that experimental error, and of reducing it by more refined methods of collecting. It may be justifiable to claim, as the result of a good deal of work at sea, that the conditions of these experimental hauls at Port Erin were as free from liability to error as any similar vertical hauls from a boat in the open sea are likely to be. The occasions were chosen so that the weather and state of the tide might be favourable, and every care was taken to have the conditions of the successive hauls in each series as much alike as possible. I feel confident that the possibility of error in the collecting was reduced to a minimum. There is also the possibility of error in the microscopic examination and estimation of the contents of the catch. This only applies in the case of the more minute organisms which were present in great abundance, such as the Diatoms and Dinoflagellates, where samples of the catch have to be taken for counting, and estimations made. In the case of the Copepoda and Sagitta and other larger organisms this source of possible error is excluded, as these forms were picked out directly from the entire preserved catch with the eye or a hand lens and were all counted. Sampling and estimation were not applied to the macroplankton, and yet the irregularity is as great there as in the case of the estimated microplankton.

The experimental error to be expected in the case of the chief groups of organisms, and also in the case of a typical common species of each, has been calculated with the following results.

The total number of Diatoms on April 3rd varied in the six hauls from 3,880 to 10,020, the mean or average being 8,055. Two of the hauls are below the average and four above. The smallest haul is as much as 52 per cent. below the average and the largest haul is 24 per cent. above. The question is—do these variations in the catch come within the limits of the probable error of the experiment?

If we assume that the estimation of the number of Diatoms in each haul is correct, then the possible errors are those inseparable from all such collecting at sea—slight movements of the boat, unknown currents in the water, irregularities in the verticality of the line, etc. In this case of the Diatoms on April 3rd the "probable error" is found to be = 1,458, and the "range" is the mean ± the probable error, that is from 6,600 to 9,500.* Comparing this range with the estimated

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* Obtained as follows:—We may assume that the small unavoidable causes of error are not correlated, and that no single one has much greater effect than any other; also that they tend to make the individual catches more than the mean as often and as much as they tend to make them less

results of the hauls, we find that three of the series are within the range and three are outside it, and two of the latter (3,880 and 10,020) are very considerably beyond the limits of the probable error of the experiment.

The Diatoms for the other hauls give much the same result when treated in the same manner—that is, roughly 50 per cent., or rather more, of the observed variation in the catches is not covered by the calculated range of error of the experiment.

In the following tables the three principal groups of the plankton, Diatoms, Dinoflagellates and Copepoda, and also three prominent organisms—one from each of these groups—are shown for all seven series of hauls treated as in the case of the Diatoms of April 3rd discussed above, and giving in each case the figures necessary to make a comparison between the range of variation in the catches and the calculated range of error :—

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than the mean. Then the first process is to find the "standard deviation." Take, for example, the six successive hauls on April 3rd :—

No. of organisms.	Frequency.	Deviation from Mean.	Δ^2
3,880	1	−4,175	17,430,580
6,670	1	−1,385	1,918,225
8,770	1	+ 715	511,225
9,220	1	+1,165	1,357,224
9,770	1	+1,715	2,941,224
10,020	1	+1,965	3,861,225
48,330 Mean = 8,055	6	0	28,019,703

Find $\sqrt{\frac{\Sigma \Delta^2}{6}} = 2{,}161$ = standard deviation.

Next find 0·6745 × standard deviation = probable error = 1,458.

The range of error = mean ± probable error = 8,055 ± 1,458
= 6,600 to 9,500 (approximately).

The convention is to regard this as the catch, that is the variations between 6,600 and 9,500 are not of any significance—any number between these limits is equally permissible, that amount of variation being possibly due to the unavoidable errors of the experiment.

I. TABLE OF DIATOMS.

Date	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or –	Range of error.	Number of variations beyond range of error.
April 3	6	3,880 to 10,020	8,055	–52 to +24	1,458	6,600 to 9,500	3 out of 6
,, 6	5	36,390 to 104,920	74,340	–51 to +41	14,902	59,440 to 99,240	2 out of 5
,, 8	6	49,320 to 75,720	64,852	–24 to +17	5,979	58,870 to 70,832	3 out of 6
,, 13	5	11,950 to 35,005	20,231	–41 to +73	5,231	15,000 to 25,460	4 out of 5
May 25	4	1,373,500 to 2,008,180	1,744,164	–21 to +15	159,740	1,584,420 to 1,903,900	2 out of 4
Aug. 7	4	230 to 1,220	769	–70 to +59	252	517 to 1,021	2 out of 4
Sept. 16	4	450,230 to 920,550	706,340	–36 to +30	113,255	593,085 to 819,595	2 out of 4

which shows that rather more than 50 per cent. of the observed variations cannot be accounted for by the calculated range of error of the experiment.

II. TABLE OF DINOFLAGELLATES.

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or –	Range of error.	Number of variations beyond range of error.
April 3	6	180 to 380	307	–42 to +24	51	256 to 358	5 out of 6
,, 6	5	1,320 to 4,400	2,824	–53 to +56	741	2,083 to 3,565	4 out of 5
,, 8	6	2,180 to 3,120	2,723	–20 to +15	224	2,500 to 2,950	4 out of 6
,, 13	5	240 to 980	680	–65 to +44	175	505 to 855	2 out of 5
May 25	4	57,600 to 90,200	73,450	–22 to +23	7,839	63,610 to 81,290	2 out of 4
Aug. 7	4	2,170 to 3,500	3,002	–27 to +17	352	2,650 to 3,354	3 out of 4
Sept. 16	4	6,600 to 11,600	8,550	–23 to +36	1,686	6,864 to 10,236	2 out of 4

This shows even a greater range in variation than in the case of the Diatoms, as a good deal more than half the observed variations (22 out of 34) are not covered by the range of error.

III. TABLE OF COPEPODA.

III. Table of Copepoda.

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or −	Range of error.	Number of variations beyond range of error.
April 3...........	6	106 to 149	123	−14 to +21	9	114 to 132	3 out of 6
,, 6...........	5	530 to 1,510	1,062	−50 to +42	233	830 to 1,295	3 out of 5
,, 8...........	6	550 to 1,110	912	−40 to +22	123	790 to 1,035	3 out of 6
,, 13...........	5	340 to 580	436	−22 to +33	61	375 to 495	4 out of 5
May 25...........	4	460 to 2,612	1,631	−72 to +60	636	995 to 2,267	4 out of 4 (all)
Aug. 7...........	4	1,300 to 1,963	1,489	−13 to +31	186	1,303 to 1,675	2 out of 4
Sept. 16...........	4	1,234 to 2,943	1,929	−36 to +53	426	1,503 to 2,355	2 out of 4

Here again over 50 per cent. (21 out of 34) of the variations of the catch are outside the range of error.

IV. Tables of Three Typical Organisms—*Coscinodiscus radiatus.*

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or −	Range of error.	Number of variations beyond range of error.
April 3...........	6	1,600 to 2,800	2,433	−34 to +15	265	2,168 to 2,698	3 out of 6
,, 6...........	5	13,000 to 64,000	43,400	−70 to +47	11,250	32,150 to 54,650	2 out of 5
,, 8...........	6	16,000 to 48,000	27,267	−41 to +76	6,862	20,405 to 34,130	3 out of 6
,, 13...........	5	2,300 to 4,600	3,580	−36 to +28	579	3,000 to 4,160	3 out of 5
May 25...........	4	200 to 800	362	−45 to +121	171	191 to 533	1 out of 4
Aug. 7...........	4	10 to 60	35	−71 to +71	14	20 to 50	2 out of 4
Sept. 16...........	4	70 to 200	130	−46 to +54	33	97 to 163	2 out of 4

This single species of Diatom taken by itself shows much the same proportion between the range of variations and the range of error that is shown by the Diatoms as a whole (Table I)—in this case rather less than 50 per cent.

V. TABLES OF THREE TYPICAL ORGANISMS—*Ceratium tripos.*

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or –	Range of error.	Number of variations beyond range of error.
April 3...........	6	160 to 280	207	–23 to +35	26	181 to 233	3 out of 6
,, 6...........	5	800 to 1,600	1,200	–33 to +33	241	960 to 1,440	4 out of 5
,, 8...........	6	1,100 to 2,200	1,530	–28 to +44	244	1,286 to 1,774	3 out of 6
,, 13...........	5	140 to 520	340	–59 to +53	95	245 to 435	3 out of 5
May 25...........	4	12.000 to 26,000	18,150	–34 to +43	3,437	14,713 to 21,587	2 out of 4
Aug. 7...........	4	1,180 to 1,780	1,520	–22 to +17	169	1,350 to 1,690	3 out of 4
Sept. 16...........	4	800 to 1,800	1,100	–27 to +64	278	822 to 1,378	3 out of 4

Here again this single typical Dinoflagellate taken by itself shows a large proportion of the observed variations (21 out of 34) to be outside the range of error.

VI. TABLES OF THREE TYPICAL ORGANISMS—*Pseudocalanus elongatus.*

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or –	Range of error.	Number of variations beyond range of error.
April 3...........	6	79 to 130	98	–19 to +33	12	85 to 110	3 out of 6
,, 6...........	5	420 to 1,160	800	–48 to +45	175	625 to 975	3 out of 5
,, 8...........	6	420 to 860	697	–40 to +23	97	600 to 794	3 out of 6
,, 13...........	5	290 to 540	384	–24 to +41	65	320 to 450	3 out of 5
May 25...........	4	150 to 1,000	640	–77 to +56	248	392 to 888	3 out of 4
Aug. 7...........	4	240 to 600	377	–36 to +59	90	287 to 467	2 out of 4
Sept. 16...........	4	510 to 1,000	682	–25 to +47	134	548 to 816	3 out of 4

In the case of this prominent Copepod also a large proportion (20 out of 34) of the variations are outside the range of error.

To the question what light does a series of four to six successive hauls throw upon the validity of a single haul, say the first of that series, the answer seems to be that as regards mere size (volume) and general nature (such as phytoplankton, zooplankton or mixed) of the catch the series confirms the representative nature of the single haul in a general way and within limits. For example, in two out of the seven series all the catches (six and four respectively) were alike in volume, the additional hauls taken exactly confirming the evidence of the first. In the remaining five series there was some divergence from the average amounting in the most extreme case to + 23 and − 26 per cent.; so that as far as this experiment shows if a single haul had been taken, in place of a series, it might have given a result about 25 per cent. different in either direction (either above or below the average of the series).

Then again, in regard to the nature of the plankton, without going into the exact statistics of the species or even of the groups of species, it is evident to the eye at the time of collecting, and this is confirmed by the microscopical examination, that any one haul is very fairly representative of its series. If one shows a phytoplankton catch, the others do also.

But if one next proceeds to deal quantitatively with the groups of species that make up the catches, it is found that the individual hauls in a series may differ widely. The preceding tables show that both in the main groups of the plankton and in those species which have been taken out as examples fully 50 per cent. of the variations from the mean of the series extend beyond the range of error, and are therefore not due to possible imperfections in the experiment. Thus more than half the differences between the hauls of a series remains unaccounted for, and may naturally be interpreted as evidence of an unequal distribution of the plankton in closely adjacent areas of water, or in the same area in successive periods of time.

Whether our present methods of collecting and of estimating are sufficiently accurate to enable us to determine the amount of this inequality in the distribution, so as to be able to put probable upper and lower limits to the number of each organism per unit volume of water may be doubtful. But even if the data are not yet sufficiently numerous and reliable, we must still work on in the hope that improvements in method and accumulation of evidence may in time enable us to make some approximation to an estimate of the population of various sea-areas.

I would go further and say that even if we had no hope of attaining to greater accuracy, our present planktonic results are of some value. Although estimates which may be 25 or even 50 per cent. wrong in either direction may not justify us in calculating exactly the number of organisms and of potential food present per area or volume of water, they do give us a useful approximation. Even if 100 per cent. out, doubling or halving the estimated number is a relatively small variation compared with the much larger increases and reductions amounting to, it may be, ten thousand times in the case of Diatoms, ten to fifty times in Dinoflagellates and five to twenty times in Copepoda, which we find between adjacent months, and even greater differences if we take groups of months, in a survey of the seasonal variations of the plankton in European seas.

ON MEASUREMENTS OF SOLES MADE IN 1920.

By James Johnstone, D.Sc.

In June of 1920 a system of observations on board smacks and steam-trawlers, working in the Irish Sea, was put in operation by the Ministry of Agriculture and Fisheries. Two "fish measurers," Commander A. E. Ruxton and Mr. W. C. Smith, were stationed at the ports of Fleetwood and Whitehaven, and, later on, a postgraduate student of the Zoology Department at Liverpool University, Mr. G. F. Sleggs, B.Sc., was engaged on similar work. The object of the observations was to obtain data with regard to the sizes and general distribution of the plaice caught by the first-class trawling vessels on the offshore grounds of the Irish Sea. The measurers usually worked on smacks sailing out from Fleetwood and Liverpool, and, though their specific work was to observe the catches of plaice made, they also measured all the soles caught. The results are very interesting and are also quite novel, for there were, previously, no measurements of the soles trawled on these offshore grounds. Since these fish were the principal objects of the fishing of the smacks the region where they occur was pretty well worked and nearly 6,000 soles were measured. Unfortunately it was impossible to arrange for the work to be commenced earlier than the last day in May, so the spawning period of the fish was not fully covered.

The grounds trawled over are shown on the sketch chart (Fig. 5). The irregularly-marked regions represent, rather roughly, the parts of the sea worked on the various voyages of the smacks with which the measurers went. The Roman numeral gives the month and the suffix gives the number of hours during which trawling went on.

The principal sole-fishing ground is well shown : it extends N.W. from Morecambe Bay Light Vessel up towards Maughold

Head and then over towards the coast of Cumberland. Further South-west there was also a good deal of trawling, and some catches made in Carnarvon Bay are recorded. June was the best month on the whole, and then the two smacks, with which the measurers went, caught about 14 soles per hour's trawling. In July the number was 9, and it was 7 in August and 6 in September.

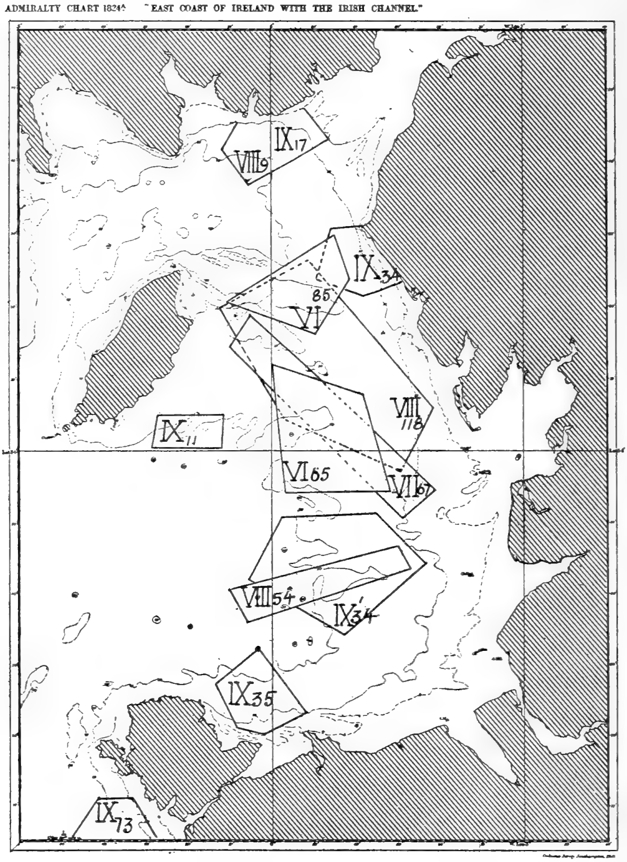

FIG. 5. Grounds from which the measurements of Soles were made.

The sizes are shown in the table below. There is little change, with relation to the months, for the "shortest-half-ranges," that is, the most prevalent sizes of soles caught are:— June, July, August, September. So far, then, as one can judge there is not much indication of a rapid period of growth, as in the case of plaice caught in the same regions, during the summer and early autumn.

Measurements of Soles caught in the Irish Sea, 1920.

Mean length.	June.		July.	August.			September.					
	VI.$_{85}$	VI.$_{65}$	VII.$_{67}$	VIII.$_{9}$	VIII.$_{118}$	VIII.$_{54}$	IX.$_{17}$	IX.$_{34}$	IX.$_{11}$	IX′.$_{34}$	IX.$_{35}$	IX.$_{78}$
19·5	...	...	...	...	...	1	...	4	...	...	...	...
20·5	1	1	...	...	...	1	2	1	...	3	...	2
21·5	7	5	1	...	1	...	...	1	...	1	...	...
22·5	11	1	...	...	1	2	2	2	...	3	...	6
23·5	23	20	1	2	5	2	2	5	...	7	...	8
24·5	46	37	2	...	12	2	...	3	...	11	...	32
25·5	83	42	13	...	28	7	1	13	1	16	10	41
26·5	92	57	27	1	59	22	3	11	1	26	5	49
27·5	94	68	42	1	82	21	5	13	3	26	8	54
28·5	113	85	47	1	81	37	7	11	2	38	6	75
29·5	102	62	47	3	108	44	8	18	...	28	8	83
30·5	85	91	77	3	114	46	9	13	2	48	4	76
31·5	110	73	58	2	109	46	17	17	1	40	11	61
32·5	108	67	81	...	135	44	18	13	1	29	6	52
33·5	85	72	58	1	97	45	6	16	...	35	8	45
34·5	58	49	60	1	87	38	5	8	1	14	6	29
35·5	55	27	46	1	80	23	11	10	1	17	...	21
36·5	42	25	18	1	51	19	4	3	...	6	5	16
37·5	23	11	12	...	38	18	5	2	2	8	2	7
38·5	24	10	13	1	20	20	4	1	...	3	2	4
39.5	18	7	3	...	13	4	...	1	...	1	...	3
40·5	10	7	9	1	7	5	5	2	1	...	...	3
41·5	5	4	2	1	5	2	5	...	...	...	1	1
42·5	6	...	2	2	3	3	...	...	...	...	1	...
43·5	4	...	...	...	1	2	1	...	...	1	...	1
44·5	2	...	...	...	...	...	...	...	...	...	1	...
45·5	2	...	...	5	...	...	1	...	...	...	...	2
46·5	1	...	...	...	...	...	...	...	...	...	...	...
47·5	1	...	...	1	...	...	...	...	...	...	...	...
48·5	...	...	...	...	...	...	...	...	...	...	...	...
Totals ...	1,211	821	619	28	1,137	454	121	168	16	361	84	671
Catch per hour	14	13	9	3	10	8	7	5	1	11	2	9

ON BLACK LITTORAL SANDS IN LANCASHIRE.

By James Johnstone, D.Sc.

On most places in the littoral zone on the coast of Lancashire the sand below the surface is more or less black. On the Formby shore, for instance, on the landward side of the channel between the shore and Taylor's Bank there is (or used to be) a cockle-bed, but below the upper two or three inches of clean, yellow sand the substratum is very black. At Piel (in Barrow) there is a dense bed of lugworms on the west side of the railway embankment, and here also the sand beneath the surface is black to grey in colour, the superficial layer being yellow. Close to the embankment there are little gutters containing a few inches of water, and on the sides of these the upper, yellow layer of sand is only about an inch in depth, while below that, and as deep down as one can dig with a spade, at all events, the sand is dense black. Further out towards the low-water mark the upper, yellow layer becomes thicker and the sand underneath becomes grey in colour, and the greyness becomes rather lighter as one goes out away from the shore.

The dense, black sand close inshore smells offensively of decaying seaweed and sulphuretted hydrogen when it is turned over. When I first collected a sample I dried it in a steam oven and was, for the moment, surprised to find that the colour had disappeared long before the sand became dry. Even in the cold it disappears rather quickly, a mass of the black substance becoming light yellow in about an hour. But underneath the upper layer of a quarter of an inch in thickness the dense, black colouration was persistent. It was evident that one has to do here with a deposit of moist ferrous sulphide which rapidly oxidises.

Samples of the black sand were put into tall, narrow glass tubes and covered with salt-water, fresh water, 5 % formaline and 70 % methylated spirit. In all cases the same thing happened: the upper 5 mm. or so of sand bleached rapidly to the normal, light yellow colour and then the action slackened. Very slowly the discolourised layer thickened, but after some six months it was little over about 5 mm. in thickness. Some of the black substance was put into a 12 × 3 cm. tube, the latter being filled to within an inch of the top. The water in the sand was drained off for about ten minutes and then the upper part of the tube was dried and filled with melted paraffin wax, the latter being coated over the outer edge so as to make an air-tight seal. After eight months the sand remained perfectly black and there was no trace of bleaching. A little white substance, rather like a bacterial growth, formed on the surface, but this was not bleached sand: it has not yet been examined.

Another, and similar, tube was filled in the same way, but was sealed with an ordinary, unluted cork. The sand gradually dried, but it did so unequally in such a way that air was able to penetrate along irregularly dried paths. These paths bleached to the usual light yellow colour while the other parts remained black. Gradually, however, the whole became grey or yellow, but on the margins of the "paths" an ochreous substance, evidently ferric oxide (Fe_2O_3), began to appear. After eight months the whole contents of this tube had not completely bleached, or reddened.

A little of the blackest sand was placed in a glass tube of 2 cms. bore and about 12 cms. long. Hydrogen was generated from zinc and sulphuric acid, washed in strong H_2SO_4, bubbled through a strong alkaline solution of pyrogallic acid, again passed through strong H_2SO_4, and finally dried in a calcium chloride U-tube. The tube containing the black sand was gently heated and the O-free, dry gas was passed through it until the sand was quite dry. It was then dark grey in colour. When shaken out on to a sheet of paper it rapidly bleached to the normal colour. It even bleached when kept in a desiccator.

When examined under a microscope the sand is seen to contain black granules adhering to, and mixed among, the grains, but the latter are not "coated." When it is treated with dilute HCl it bleaches at once and SH_2 is evolved. The solution, when filtered, gives all the tests for iron. When the sand is ignited strongly it also bleaches, but the iron is not then so easily dissolved out, though it can be, of course.

The blackening and subsequent bleaching are easily imitated. Some very clean, white sand was ignited, cooled, and then put into an evaporating basin and covered with a 0·5 % solution of ferrous sulphate. A little ammonium chloride and ammonium hydrate were added, and SH_2 was bubbled through the wet sand. The latter rapidly blackened. It was then quickly washed in boiled-out water and put into a tall glass tube with a little overlying water. In a few hours the upper layer bleached and the result resembled that obtained from the naturally discoloured sand. Just the same effects were produced when the mixture of clean sand and dilute solution of ferrous sulphate was treated with ammonium sulphide. The bleaching occurred in much the same way, but the decolourised, upper layer was yellow because of the presence of sulphur. Evidently, then, these littoral, black sands are the result of the formation of ferrous sulphide. Everywhere on this coast (and especially in the North Lonsdale region) the sea-water in the interstices of the sand contains soluble iron salts. Everywhere there are organisms (lugworms and cockles, for instances) which form excretal substances, and in any case they die in the sand sometime or other. The putrefactive process gives rise to SH_2 and some ammonia salts, and then the trace of iron present in the water is precipitated as ferrous sulphide. So one often finds a dead cockle-shell in clean sand with some black sand in the shell cavity. Wet ferrous sulphide very easily oxidises, of course, and therefore the upper layers of sand are always clean. But the black stuff underneath exists under conditions that are nearly anaerobic and so the oxidation is confined to the upper layer. Near the shore there is a continual access of organic matter, in the form of land drainage, which penetrates into the sand and renders the process of formation of ferrous sulphide a continuous one. Further out, over the littoral zone, there is not so much of the organic matter for it is the more easily distributed by the tide, and so the bleached layer is thicker and the underlying discoloured stratum is not so black.

The same process, as was pointed out by J. Y. Buchanan,* occurs on the sea-bottom in deep water and is responsible for the formation of blue and black muds. Such sulphide-containing muds and sands do not (or, at least, need not) be found among sedimentary strata, for oxidation would generally have led to the bleaching. But, in such strata, the presence of much iron in the form of Fe_2O_3 may usually indicate that the sediments from which they have been formed have been the seats of putrefactive processes.

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* See "Accounts Rendered," Cambridge University Press, 1919, pp. 133-158.

results of the hauls, we find that three of the series are within the range and three are outside it, and two of the latter (3,880 and 10,020) are very considerably beyond the limits of the probable error of the experiment.

The Diatoms for the other hauls give much the same result when treated in the same manner—that is, roughly 50 per cent., or rather more, of the observed variation in the catches is not covered by the calculated range of error of the experiment.

In the following tables the three principal groups of the plankton, Diatoms, Dinoflagellates and Copepoda, and also three prominent organisms—one from each of these groups—are shown for all seven series of hauls treated as in the case of the Diatoms of April 3rd discussed above, and giving in each case the figures necessary to make a comparison between the range of variation in the catches and the calculated range of error :—

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than the mean. Then the first process is to find the "standard deviation." Take, for example, the six successive hauls on April 3rd :—

No. of organisms.	Frequency.	Deviation from Mean.	Δ^2
3,880	1	−4,175	17,430,580
6,670	1	−1,385	1,918,225
8,770	1	+ 715	511,225
9,220	1	+1,165	1,357,224
9,770	1	+1,715	2,941,224
10,020	1	+1,965	3,861,225
48,330 Mean = 8,055	6	0	28,019,703

Find $\sqrt{\frac{\Sigma\,\Delta^2}{6}} = 2,161$ = standard deviation.

Next find 0·6745 × standard deviation = probable error = 1,458.

The range of error = mean ± probable error = 8,055 ± 1,458
= 6,600 to 9,500 (approximately).

The convention is to regard this as the catch, that is the variations between 6,600 and 9,500 are not of any significance—any number between these limits is equally permissible, that amount of variation being possibly due to the unavoidable errors of the experiment.

L

I. TABLE OF DIATOMS.

Date	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or –	Range of error.	Number of variations beyond range of error.
April 3	6	3,880 to 10,020	8,055	–52 to +24	1,458	6,600 to 9,500	3 out of 6
,, 6	5	36,390 to 104,920	74,340	–51 to +41	14,902	59,440 to 99,240	2 out of 5
,, 8	6	49,320 to 75,720	64,852	–24 to +17	5,979	58,870 to 70,832	3 out of 6
,, 13	5	11,950 to 35,005	20,231	–41 to +73	5,231	15,000 to 25,460	4 out of 5
May 25	4	1,373,500 to 2,008,180	1,744,164	–21 to +15	159,740	1,584,420 to 1,903,900	2 out of 4
Aug. 7	4	230 to 1,220	769	–70 to +59	252	517 to 1,021	2 out of 4
Sept. 16	4	450,230 to 920,550	706,340	–36 to +30	113,255	593,085 to 819,595	2 out of 4

which shows that rather more than 50 per cent. of the observed variations cannot be accounted for by the calculated range of error of the experiment.

II. TABLE OF DINOFLAGELLATES.

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or –	Range of error.	Number of variations beyond range of error.
April 3	6	180 to 380	307	–42 to +24	51	256 to 358	5 out of 6
,, 6	5	1,320 to 4,400	2,824	–53 to +56	741	2,083 to 3,565	4 out of 5
,, 8	6	2,180 to 3,120	2,723	–20 to +15	224	2,500 to 2,950	4 out of 6
,, 13	5	240 to 980	680	–65 to +44	175	505 to 855	2 out of 5
May 25	4	57,600 to 90,200	73,450	–22 to +23	7,839	63,610 to 81,290	2 out of 4
Aug. 7	4	2,170 to 3,500	3,002	–27 to +17	352	2,650 to 3,354	3 out of 4
Sept. 16	4	6,600 to 11,600	8,550	–23 to +36	1,686	6,864 to 10,236	2 out of 4

This shows even a greater range in variation than in the case of the Diatoms, as a good deal more than half the observed variations (22 out of 34) are not covered by the range of error.

III. TABLE OF COPEPODA.

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or −	Range of error.	Number of variations beyond range of error.
April 3...........	6	106 to 149	123	−14 to +21	9	114 to 132	3 out of 6
,, 6...........	5	530 to 1,510	1,062	−50 to +42	233	830 to 1,295	3 out of 5
,, 8...........	6	550 to 1,110	912	−40 to +22	123	790 to 1,035	3 out of 6
,, 13...........	5	340 to 580	436	−22 to +33	61	375 to 495	4 out of 5
May 25...........	4	460 to 2,612	1,631	−72 to +60	636	995 to 2,267	4 out of 4 (all)
Aug. 7...........	4	1,300 to 1,963	1,489	−13 to +31	186	1,303 to 1,675	2 out of 4
Sept. 16...........	4	1,234 to 2,943	1,929	−36 to +53	426	1,503 to 2,355	2 out of 4

Here again over 50 per cent. (21 out of 34) of the variations of the catch are outside the range of error.

IV. TABLES OF THREE TYPICAL ORGANISMS—*Coscinodiscus radiatus.*

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or −	Range of error.	Number of variations beyond range of error.
April 3...........	6	1,600 to 2,800	2,433	−34 to +15	265	2,168 to 2,698	3 out of 6
,, 6...........	5	13,000 to 64,000	43,400	−70 to +47	11,250	32,150 to 54,650	2 out of 5
,, 8...........	6	16,000 to 48,000	27,267	−41 to +76	6,862	20,405 to 34,130	3 out of 6
,, 13...........	5	2,300 to 4,600	3,580	−36 to +28	579	3,000 to 4,160	3 out of 5
May 25...........	4	200 to 800	362	−45 to +121	171	191 to 533	1 out of 4
Aug. 7...........	4	10 to 60	35	−71 to +71	14	20 to 50	2 out of 4
Sept. 16...........	4	70 to 200	130	−46 to +54	33	97 to 163	2 out of 4

This single species of Diatom taken by itself shows much the same proportion between the range of variations and the range of error that is shown by the Diatoms as a whole (Table I)—in this case rather less than 50 per cent.

V. TABLES OF THREE TYPICAL ORGANISMS—*Ceratium tripos.*

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or −	Range of error.	Number of variations beyond range of error.
April 3..........	6	160 to 280	207	−23 to +35	26	181 to 233	3 out of 6
,, 6..........	5	800 to 1,600	1,200	−33 to +33	241	960 to 1,440	4 out of 5
,, 8..........	6	1,100 to 2,200	1,530	−28 to +44	244	1.286 to 1,774	3 out of 6
,, 13..........	5	140 to 520	340	−59 to +53	95	245 to 435	3 out of 5
May 25..........	4	12.000 to 26,000	18,150	−34 to +43	3,437	14,713 to 21,587	2 out of 4
Aug. 7..........	4	1,180 to 1,780	1,520	−22 to +17	169	1,350 to 1,690	3 out of 4
Sept. 16..........	4	800 to 1,800	1,100	−27 to +64	278	822 to 1,378	3 out of 4

Here again this single typical Dinoflagellate taken by itself shows a large proportion of the observed variations (21 out of 34) to be outside the range of error.

VI. TABLES OF THREE TYPICAL ORGANISMS—*Pseudocalanus elongatus.*

Date.	Hauls.	Range of variation.	Mean.	Per cent. deviation.	Probable error + or −	Range of error.	Number of variations beyond range of error.
April 3..........	6	79 to 130	98	−19 to +33	12	85 to 110	3 out of 6
,, 6..........	5	420 to 1,160	800	−48 to +45	175	625 to 975	3 out of 5
,, 8..........	6	420 to 860	697	−40 to +23	97	600 to 794	3 out of 6
,, 13..........	5	290 to 540	384	−24 to +41	65	320 to 450	3 out of 5
May 25..........	4	150 to 1,000	640	−77 to +56	248	392 to 888	3 out of 4
Aug. 7..........	4	240 to 600	377	−36 to +59	90	287 to 467	2 out of 4
Sept. 16..........	4	510 to 1,000	682	−25 to +47	134	548 to 816	3 out of 4

In the case of this prominent Copepod also a large proportion (20 out of 34) of the variations are outside the range of error.

To the question what light does a series of four to six successive hauls throw upon the validity of a single haul, say the first of that series, the answer seems to be that as regards mere size (volume) and general nature (such as phytoplankton, zooplankton or mixed) of the catch the series confirms the representative nature of the single haul in a general way and within limits. For example, in two out of the seven series all the catches (six and four respectively) were alike in volume, the additional hauls taken exactly confirming the evidence of the first. In the remaining five series there was some divergence from the average amounting in the most extreme case to + 23 and − 26 per cent.; so that as far as this experiment shows if a single haul had been taken, in place of a series, it might have given a result about 25 per cent. different in either direction (either above or below the average of the series).

Then again, in regard to the nature of the plankton, without going into the exact statistics of the species or even of the groups of species, it is evident to the eye at the time of collecting, and this is confirmed by the microscopical examination, that any one haul is very fairly representative of its series. If one shows a phytoplankton catch, the others do also.

But if one next proceeds to deal quantitatively with the groups of species that make up the catches, it is found that the individual hauls in a series may differ widely. The preceding tables show that both in the main groups of the plankton and in those species which have been taken out as examples fully 50 per cent. of the variations from the mean of the series extend beyond the range of error, and are therefore not due to possible imperfections in the experiment. Thus more than half the differences between the hauls of a series remains unaccounted for, and may naturally be interpreted as evidence of an unequal distribution of the plankton in closely adjacent areas of water, or in the same area in successive periods of time.

Whether our present methods of collecting and of estimating are sufficiently accurate to enable us to determine the amount of this inequality in the distribution, so as to be able to put probable upper and lower limits to the number of each organism per unit volume of water may be doubtful. But even if the data are not yet sufficiently numerous and reliable, we must still work on in the hope that improvements in method and accumulation of evidence may in time enable us to make some approximation to an estimate of the population of various sea-areas.

I would go further and say that even if we had no hope of attaining to greater accuracy, our present planktonic results are of some value. Although estimates which may be 25 or even 50 per cent. wrong in either direction may not justify us in calculating exactly the number of organisms and of potential food present per area or volume of water, they do give us a useful approximation. Even if 100 per cent. out, doubling or halving the estimated number is a relatively small variation compared with the much larger increases and reductions amounting to, it may be, ten thousand times in the case of Diatoms, ten to fifty times in Dinoflagellates and five to twenty times in Copepoda, which we find between adjacent months, and even greater differences if we take groups of months, in a survey of the seasonal variations of the plankton in European seas.

ON MEASUREMENTS OF SOLES MADE IN 1920.

By James Johnstone, D.Sc.

In June of 1920 a system of observations on board smacks and steam-trawlers, working in the Irish Sea, was put in operation by the Ministry of Agriculture and Fisheries. Two "fish measurers," Commander A. E. Ruxton and Mr. W. C. Smith, were stationed at the ports of Fleetwood and Whitehaven, and, later on, a postgraduate student of the Zoology Department at Liverpool University, Mr. G. F. Sleggs, B.Sc., was engaged on similar work. The object of the observations was to obtain data with regard to the sizes and general distribution of the plaice caught by the first-class trawling vessels on the offshore grounds of the Irish Sea. The measurers usually worked on smacks sailing out from Fleetwood and Liverpool, and, though their specific work was to observe the catches of plaice made, they also measured all the soles caught. The results are very interesting and are also quite novel, for there were, previously, no measurements of the soles trawled on these offshore grounds. Since these fish were the principal objects of the fishing of the smacks the region where they occur was pretty well worked and nearly 6,000 soles were measured. Unfortunately it was impossible to arrange for the work to be commenced earlier than the last day in May, so the spawning period of the fish was not fully covered.

The grounds trawled over are shown on the sketch chart (Fig. 5). The irregularly-marked regions represent, rather roughly, the parts of the sea worked on the various voyages of the smacks with which the measurers went. The Roman numeral gives the month and the suffix gives the number of hours during which trawling went on.

The principal sole-fishing ground is well shown: it extends N.W. from Morecambe Bay Light Vessel up towards Maughold

Head and then over towards the coast of Cumberland. Further South-west there was also a good deal of trawling, and some catches made in Carnarvon Bay are recorded. June was the best month on the whole, and then the two smacks, with which the measurers went, caught about 14 soles per hour's trawling. In July the number was 9, and it was 7 in August and 6 in September.

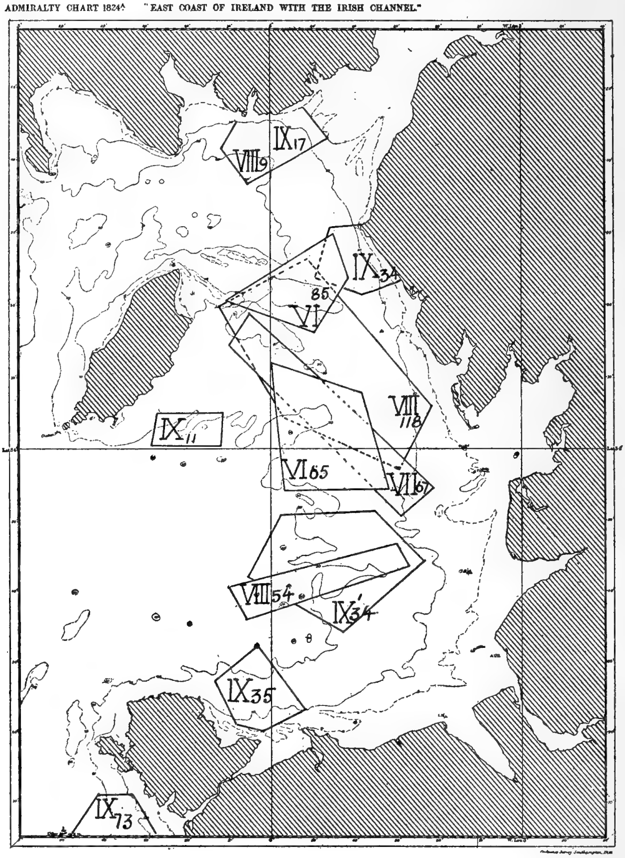

FIG. 5. Grounds from which the measurements of Soles were made.

The sizes are shown in the table below. There is little change, with relation to the months, for the "shortest-half-ranges," that is, the most prevalent sizes of soles caught are :—June, July, August, September. So far, then, as one can judge there is not much indication of a rapid period of growth, as in the case of plaice caught in the same regions, during the summer and early autumn.

Measurements of Soles caught in the Irish Sea, 1920.

Mean length.	June.		July.	August.			September.					
	VI.$_{85}$	VI.$_{65}$	VII.$_{67}$	VIII.$_{9}$	VIII.$_{118}$	VIII.$_{54}$	IX.$_{17}$	IX.$_{34}$	IX.$_{11}$	IX′.$_{34}$	IX.$_{35}$	IX.$_{78}$
19·5	...	...	...	...	...	1	...	4	...	...	...	...
20·5	1	1	...	...	...	1	2	1	...	3	...	2
21·5	7	5	1	...	1	...	...	1	...	1	...	...
22·5	11	1	...	...	1	2	2	2	...	3	...	6
23·5	23	20	1	2	5	2	2	5	...	7	...	8
24·5	46	37	2	...	12	2	...	3	...	11	...	32
25·5	83	42	13	...	28	7	1	13	1	16	10	41
26·5	92	57	27	1	59	22	3	11	1	26	5	49
27·5	94	68	42	1	82	21	5	13	3	26	8	54
28·5	113	85	47	1	81	37	7	11	2	38	6	75
29·5	102	62	47	3	108	44	8	18	...	28	8	83
30·5	85	91	77	3	114	46	9	13	2	48	4	76
31·5	110	73	58	2	109	46	17	17	1	40	11	61
32·5	108	67	81	...	135	44	18	13	1	29	6	52
33·5	85	72	58	1	97	45	6	16	...	35	8	45
34·5	58	49	60	1	87	38	5	8	1	14	6	29
35·5	55	27	46	1	80	23	11	10	1	17	...	21
36·5	42	25	18	1	51	19	4	3	...	6	5	16
37·5	23	11	12	...	38	18	5	2	2	8	2	7
38·5	24	10	13	1	20	20	4	1	...	3	2	4
39.5	18	7	3	...	13	4	...	1	...	1	...	3
40·5	10	7	9	1	7	5	5	2	1	...	...	3
41·5	5	4	2	1	5	2	5	...	...	...	1	1
42·5	6	...	2	2	3	3	...	...	...	...	1	...
43·5	4	...	...	...	1	2	1	...	...	1	...	1
44·5	2	...	...	...	...	...	...	...	...	...	1	...
45·5	2	...	...	5	...	...	1	...	...	...	...	2
46·5	1	...	...	...	...	...	...	...	...	...	...	...
47·5	1	...	...	1	...	...	...	...	...	...	...	...
48·5	...	...	...	...	...	...	...	...	...	...	...	...
Totals ...	1,211	821	619	28	1,137	454	121	168	16	361	84	671
Catch per hour	14	13	9	3	10	8	7	5	1	11	2	9

ON BLACK LITTORAL SANDS IN LANCASHIRE.

By James Johnstone, D.Sc.

On most places in the littoral zone on the coast of Lancashire the sand below the surface is more or less black. On the Formby shore, for instance, on the landward side of the channel between the shore and Taylor's Bank there is (or used to be) a cockle-bed, but below the upper two or three inches of clean, yellow sand the substratum is very black. At Piel (in Barrow) there is a dense bed of lugworms on the west side of the railway embankment, and here also the sand beneath the surface is black to grey in colour, the superficial layer being yellow. Close to the embankment there are little gutters containing a few inches of water, and on the sides of these the upper, yellow layer of sand is only about an inch in depth, while below that, and as deep down as one can dig with a spade, at all events, the sand is dense black. Further out towards the low-water mark the upper, yellow layer becomes thicker and the sand underneath becomes grey in colour, and the greyness becomes rather lighter as one goes out away from the shore.

The dense, black sand close inshore smells offensively of decaying seaweed and sulphuretted hydrogen when it is turned over. When I first collected a sample I dried it in a steam oven and was, for the moment, surprised to find that the colour had disappeared long before the sand became dry. Even in the cold it disappears rather quickly, a mass of the black substance becoming light yellow in about an hour. But underneath the upper layer of a quarter of an inch in thickness the dense, black colouration was persistent. It was evident that one has to do here with a deposit of moist ferrous sulphide which rapidly oxidises.

Samples of the black sand were put into tall, narrow glass tubes and covered with salt-water, fresh water, 5 % formaline and 70 % methylated spirit. In all cases the same thing happened: the upper 5 mm. or so of sand bleached rapidly to the normal, light yellow colour and then the action slackened. Very slowly the discolourised layer thickened, but after some six months it was little over about 5 mm. in thickness. Some of the black substance was put into a 12 × 3 cm. tube, the latter being filled to within an inch of the top. The water in the sand was drained off for about ten minutes and then the upper part of the tube was dried and filled with melted paraffin wax, the latter being coated over the outer edge so as to make an air-tight seal. After eight months the sand remained perfectly black and there was no trace of bleaching. A little white substance, rather like a bacterial growth, formed on the surface, but this was not bleached sand: it has not yet been examined.

Another, and similar, tube was filled in the same way, but was sealed with an ordinary, unluted cork. The sand gradually dried, but it did so unequally in such a way that air was able to penetrate along irregularly dried paths. These paths bleached to the usual light yellow colour while the other parts remained black. Gradually, however, the whole became grey or yellow, but on the margins of the " paths " an ochreous substance, evidently ferric oxide (Fe_2O_3), began to appear. After eight months the whole contents of this tube had not completely bleached, or reddened.

A little of the blackest sand was placed in a glass tube of 2 cms. bore and about 12 cms. long. Hydrogen was generated from zinc and sulphuric acid, washed in strong H_2SO_4, bubbled through a strong alkaline solution of pyrogallic acid, again passed through strong H_2SO_4, and finally dried in a calcium chloride U-tube. The tube containing the black sand was gently heated and the O-free, dry gas was passed through it until the sand was quite dry. It was then dark grey in colour. When shaken out on to a sheet of paper it rapidly bleached to the normal colour. It even bleached when kept in a desiccator.

When examined under a microscope the sand is seen to contain black granules adhering to, and mixed among, the grains, but the latter are not "coated." When it is treated with dilute HCl it bleaches at once and SH_2 is evolved. The solution, when filtered, gives all the tests for iron. When the sand is ignited strongly it also bleaches, but the iron is not then so easily dissolved out, though it can be, of course.

The blackening and subsequent bleaching are easily imitated. Some very clean, white sand was ignited, cooled, and then put into an evaporating basin and covered with a 0·5 % solution of ferrous sulphate. A little ammonium chloride and ammonium hydrate were added, and SH_2 was bubbled through the wet sand. The latter rapidly blackened. It was then quickly washed in boiled-out water and put into a tall glass tube with a little overlying water. In a few hours the upper layer bleached and the result resembled that obtained from the naturally discoloured sand. Just the same effects were produced when the mixture of clean sand and dilute solution of ferrous sulphate was treated with ammonium sulphide. The bleaching occurred in much the same way, but the decolourised, upper layer was yellow because of the presence of sulphur. Evidently, then, these littoral, black sands are the result of the formation of ferrous sulphide. Everywhere on this coast (and especially in the North Lonsdale region) the sea-water in the interstices of the sand contains soluble iron salts. Everywhere there are organisms (lugworms and cockles, for instances) which form excretal substances, and in any case they die in the sand sometime or other. The putrefactive process gives rise to SH_2 and some ammonia salts, and then the trace of iron present in the water is precipitated as ferrous sulphide. So one often finds a dead cockle-shell in clean sand with some black sand in the shell cavity. Wet ferrous sulphide very easily oxidises, of course, and therefore the upper layers of sand are always clean. But the black stuff underneath exists under conditions that are nearly anaerobic and so the oxidation is confined to the upper layer. Near the shore there is a continual access of organic matter, in the form of land drainage, which penetrates into the sand and renders the process of formation of ferrous sulphide a continuous one. Further out, over the littoral zone, there is not so much of the organic matter for it is the more easily distributed by the tide, and so the bleached layer is thicker and the underlying discoloured stratum is not so black.

The same process, as was pointed out by J. Y. Buchanan,* occurs on the sea-bottom in deep water and is responsible for the formation of blue and black muds. Such sulphide-containing muds and sands do not (or, at least, need not) be found among sedimentary strata, for oxidation would generally have led to the bleaching. But, in such strata, the presence of much iron in the form of Fe_2O_3 may usually indicate that the sediments from which they have been formed have been the seats of putrefactive processes.

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* See "Accounts Rendered," Cambridge University Press, 1919, pp. 133-158.

L.M.B.C. MEMOIRS

No. XXIV. APLYSIA

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CONTENTS.

INTRODUCTION.

The Mollusc of which the present Memoir is the subject belongs to the Euthyneura, a sub-class of the Gastropoda. The Euthyneura are hermaphrodite, and usually, except in primitive forms, have undergone detorsion so that the visceral nerve cords are uncrossed. In many cases a secondary external symmetry has been acquired. The Euthyneura are divided into two orders, Opisthobranchiata, including *Aplysia*, and Pulmonata, including land forms such as the Snail. In Opisthobranchiata the ctenidium is situated posterior to the heart, and there is usually a widely-open pallial cavity. The ctenidium is covered by the overhanging mantle in the sub-order Tectibranchiata, containing *Aplysia*, but this mantle skirt is absent in the Nudibranchiata.

The family Aplysiidae has six genera, viz. :—*Aplysia*, *Dolabella*, *Dolabrifer*, *Aplysiella*, *Phyllaplysia*, and *Notarchus*. Of these only *Aplysia* is British, and of the three best known European species, *Aplysia limacina*, *A. depilans*, and *A. punctata*, only the last named inhabits the waters round our shores.*

The popular name for *Aplysia* is the Sea-hare; it has been called this since the days of Pliny owing to its resemblance to a sitting hare when contracted, and to the similarity between the auriculate tentacles and the ears of the hare. The name *Aplysia*† was first given to the Sea-hare in the 13th edition of the "Systema Naturae" of Linnaeus (1791), though the 12th

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* It was formerly supposed that the large Aplysiae, taken in Torbay by Major Hunt in 1875 ("Trans. Devonsh. Nat. Assoc.," 1877), were specimens of *A. depilans*, but the characters of the species were not then sufficiently well defined to determine this with certainty. Major Hunt later (1904) considered them unusually large specimens of *A. punctata*, and for many years only this species has been known on British coasts. Similarly the very small rose red species of Thompson has been shown to be the young stage of *A. punctata*.

† The *Aplysia* mentioned by Aristotle is not a Mollusc, but a Sponge. The word means "that which cannot be washed" or possibly "washed with."

edition (1767) has *Laplysia*, an obvious misprint for *L'Aplysia*. In the 10th edition, the animal is called *Tethys limacina*, but the name *Tethys* now belongs to a genus of Nudibranchs.

As a type for dissection *Aplysia* is of considerable value. Not only is it the largest British Gastropod, but it exhibits intermediate characters between the primitive and more highly specialised forms. Thus, though it has partially acquired a secondary external symmetry, its internal organs are still markedly asymmetrical and afford numerous links in the chain of evidence that detorsion has taken place. The pallio-visceral nerve cords, long but uncrossed, resemble the Streptoneura in the first character and the Euthyneura in the second. There is as yet no indication of the concentration of the nervous system which is so marked a feature of the more specialised Tectibranchs and Nudibranchs, although other members of the family (e.g., *Phyllaplysia*, *Notarchus*) show it. Further, the tendency towards disappearance of the shell and mantle cavity can be understood after a study of this form.

HISTORY.

Aplysia has been known from very early times, the first authentic description of it being that of Pliny in the first century A.D. By the ancients it was generally regarded with abhorrence, due, no doubt, to its grotesque appearance and the nauseating odour of the large Mediterranean species. Whatever the cause, this entirely innocuous creature became invested with poisonous and magical properties, and only one writer of early times (Nicander, c. 150 A.D.) says a good word for it, quoting it as a specific in certain diseases.

Pliny,* who called it Lepus marinus, the Sea-hare, gives an account of the popular superstitions regarding it. He

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* Pliny describes three species, two in the Mediterranean and one in the Indian Ocean. Of these the last is probably a *Dolabella*.

describes it as being poisonous to the touch, producing vomiting and subsequent death, unless the antidote of "asses' milk and asses' bones ground and boiled" be given to the victim. Other observers thought the "onely aspect and sight thereof" was poisonous, while another version of this superstition was that if a human being touched an *Aplysia*, that person died. Others said that the Sea-hare died, "which latter," says Johnston, "would be the more probable result."

Johnston, in his "Introduction to Conchology," quoting from Cuvier's "Histoire des Mollusques," claims that the celebrated Locusta used *Aplysia* "to destroy such as were inimical to Nero; it entered into the fatal potion which she prepared for the tyrant himself, and which he had not the resolution to swallow; and Domitian was accused of having given it to his brother Titus." There is, however, no foundation for this story, which was probably quoted by Cuvier from the 1550 edition of the "Antiquarium lectionum" of Coelius Rhodiginus, and does not occur in the original (1516) edition.*

Apuleius, one of the first to investigate the internal anatomy of *Aplysia*, was accused of magic and poisoning, and the principal point of evidence brought forward at his trial was that he had induced two fishermen to procure a Sea-hare. To him belongs the earliest description of the teeth of the first triturating stomach. He says they are "similar to the ossicles or ankle bones of the hog, connected and joined." Aelian says *Aplysia* "resembles a snail from which the shell has been taken," but Dioscorides found the shell under the mantle folds and compared *Aplysia* with a Cuttle-fish.

In 1554, Rondelet, in his "De Piscibus Marinis," gave two fairly good figures of *Aplysia* under the name *Lepus marinus*.

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* I am indebted to Dr. Charles Singer for unravelling this difficulty. In the 1550 edition, produced by Camillio Ricchieri (Rhodiginus), the statement about Locusta appeared for the first time, and was evolved, Dr. Singer says, "out of his inner consciousness by putting together the ideas of poison by *Aplysia* in Pliny and the exploits of Locusta." Bechmann, in his "Beitrage zur Geschichte der Erfindungen," Leipzig, 1786-1805, quotes also from the 1550 edition of Rhodiginus and copies the same errors.

He explains that it should not be confused with other fishes, because " it is very poisonous and would be fatal to anyone who ate it." Rondelet makes the mistake of putting the genital groove on the left side of the body instead of on the right side. This mistake was copied by Aldrovandus, but corrected by Gesner, both of whom reproduce Rondelet's figures. Gesner removes *Aplysia* from the fishes and places it amongst the soft-bodied animals.

In 1684, Redi made the first recorded investigations of the internal anatomy of *Aplysia* since the time of the unfortunate Apuleius. He called it the marine Slug from its resemblance to the terrestrial *Limax*, and described the internal anatomy of both animals. Nearly a century after Redi, Bohadsch, a Bohemian fugitive who took up his residence in Naples, wrote a book on marine animals, published in 1761. In this book he describes two species of *Aplysia*, which he calls *Lernaea*, gives good figures of them both, and a long and fairly accurate description of the internal anatomy. He studied their habits and observed the exudation of a milky as well as a purple fluid. The opaline gland, which secretes the milky fluid, has since been called by his name. He dissected the alimentary canal, nervous system and sexual organs, and came to the conclusion that *Aplysia* was related to the land snail.

The first authentic mention of *Aplysia* in British literature is in Pennant's " British Zoology," Vol. 4, published in 1777. He figures a small specimen and classifies it amongst the Worms. It is true that Borlase, in his " Natural History of Cornwall " (Oxford, 1758), says that he was brought a Sea-slug on March 24th, 1752. He states that the animal had eyes on its antennae and exuded a purple dye. He thought it was a Holothurian and compared it with the undoubted Holothurian in Rondelet, Part 2, p. 125. The purple suggests *Aplysia*, but it is strange that if his specimen was a Sea-hare he did not know of Rondelet's description of it. Sowerby, in 1806, recorded *Aplysia* from St. Michael's Bay, Cornwall, and investigated its purple dye.

In 1767, Linnaeus, in his "Systema Naturae," adopted the name given to *Aplysia* by Bohadsch, viz.: *Lernaea.* (Editions 8 and 9.) In the tenth edition he revised its nomenclature and called it *Tethys*, in the 12th edition *Laplysia*,* and in the 13th edition *Aplysia.* To one species of *Aplysia* he gave the name *Aplysia depilans.*

Lamarck, in 1812, attempted a classification of Invertebrate animals and recognised the affinities between the Bullidae and Aplysiidae. In 1817, Macri, a Neapolitan, disposed once and for all of the fables concerning *Aplysia*, and stated in most emphatic language that it was quite harmless.

In 1817 appeared Cuvier's "Mémoires pour servir à l'histoire et à l'anatomie des Mollusques," containing "Mémoire sur le genre *Laplysia*" (first published in 1803). This Memoir contains a full account of the Mollusc with good figures. Cuvier made the first chemical investigation of the purple, though he made the bad mistake of supposing that it was the gland now known to be the kidney, which exuded that fluid.

From 1820 onward *Aplysia* has been studied from every standpoint by many observers, so that a fairly complete knowledge of its anatomy, histology, and embryology (excluding the metamorphosis) has been obtained. The literature, however, contains many inaccuracies, copied without verification by different writers, and no reliable monograph, with the exception of that by Mazzarelli, has appeared.

The most important works on the anatomy of *Aplysia* during the nineteenth century are those of Delle Chiaje, Sander

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* *Laplysia* appears to be a printer's error for *L'Aplysia,* and was corrected by Gmelin in the thirteenth edition. *Aplysia* means "that which one cannot wash." It has no meaning for the Mollusc which now bears it, and was chosen quite arbitrarily by Linnaeus. The *Aplysia* of Aristotle is a sponge which could not be freed from gritty and dirty matter. Aristotle does not mention the Sea-hare.

Rang, Milne Edwards, Spengel, Blochmann, Cunningham, Vayssière, Lacaze Duthiers, Mazzarelli, Guiart, and Blatin. Very little work has been done in this country; nearly all these authors investigated the larger Mediterranean species. Milne Edwards (1847) and Blatin and Vles (1906) contributed to our knowledge of the circulation, Cunningham (1883) worked out the relations of the kidney and the pericardium, to Spengel (1881), Lacaze Duthiers (1888), and Guiart (1901) we owe a comprehensive account of the nervous system, and Mazzarelli's important monograph, published in 1893, has already been noticed.

The first observations on the development of *Aplysia* were due to van Beneden, who, in 1841, described the veliger larva* with its nautiloid shell. In 1874, Lankester published a paper on the development of *Aplysia*, and eight years later Manfredi summarised the information on the subject. Blochmann also worked on the embryology. Mazzarelli published several papers on the development, and corrected Lacaze Duthier's curious mistake in supposing the primitive kidney to be an anal eye. More recently, Georgevitch (1900) and Carazzi (1900) studied the embryology, and the latter, in 1905, worked out the cell lineage in the early stages. Carr Saunders and Margaret Poole, in 1910, made a careful investigation of the work of previous authors. The metamorphosis of the larva into the adult condition is not yet known.

The large size of the Mediterranean species of *Aplysia* has made them suitable for histological and physiological study. The histology of the mantle glands was investigated by Blochmann in 1883; in 1888, Robert studied the microscopic structure of the hermaphrodite gland; and Cuénot, in 1890, described the blood and lymphatic glands. Mazzarelli has written several papers on the histology and physiology of *Aplysia*, the chief being on the reproductive system and the

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* Sars, however, had discovered this larva.

pallial glands. Botazzi worked on the physiology of the nervous system and muscles, Jordan on the physiology of movement, MacMunn, Moseley, and Briot on the "purple," and Ariola on digestion.

HABITAT.

Aplysia punctata inhabits the shallow-water zone of the sea down to a depth of about forty fathoms (Lo Bianco). Its range extends from the Mediterranean to the Arctic Circle. It is, however, extremely susceptible to the effect of foul or badly aerated water, so that it occurs most abundantly on those parts of the coast where the tide runs rapidly and the water is uncontaminated by sewage or decaying matter. The best place to look for it is on the beds of *Zostera* at very low tides. Its appearance is often sporadic, and whereas it may be very abundant in a certain year at a definite spot, the same place may not yield a single specimen when searched again the following year. The same applies to the collection of specimens with the dredge. At different places along the coast remarkable incursions of *Aplysia* have occurred at intervals, as described by Major Hunt in Torbay, and by other observers on the Welsh and Manx coasts. Such an incursion was recorded by Chadwick at Port Erin in July, 1916, when, after a severe storm, hundreds of Aplysiae were thrown up on a small area of shore within Port Erin Bay. They were in poor condition and lay amongst pieces of decaying weed. Most of them disappeared after a few days.*

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* The cause of the sudden appearance of Aplysiae in such numbers is not known. It is probable that many die after breeding, but on this occasion Chadwick saw no cordons of eggs. Possibly the stormy weather tore off masses of weed, on which the animals were feeding, from the rocks in deep water, and the Aplysiae were thrown up with the weed. Compare also similar incursions of *Aphroditе*.

FOOD.

The food of *Aplysia* consists of seaweeds of various kinds. When full grown it lives on green and brown weeds such as *Ulva lactuca*, species of *Fucus*, etc., and the colour and markings of its skin bear a close resemblance to the weed (*vide* External Characters). The animal can adapt itself to its surroundings, and undergoes remarkable colour changes which very quickly enable it to imitate the particular weed on which it is feeding at the time. Thus very small specimens feed on red weed like *Delesseria* and are coloured rosy red, larger specimens feeding on weed from the *Laminaria* zone are brown, while those feeding on *Fucus* are olive brown. (*Vide* Life History.)

If the contents of the crop be examined, Foraminifera, little Ophíuroids, and small Gastropods may sometimes be found, but these have probably been consumed accidentally along with the weed and do not form the bulk of the food as Cuvier implied in his account of the Sea-hare.*

LIFE-HISTORY.

During the spring the Aplysiae come up into shallow waters to deposit their cordons of eggs amongst the weeds between tide marks. From the eggs hatch, in about a fortnight, free-swimming veliger larvae, which lead a pelagic existence. The metamorphosis into the adult form is not known. The youngest Aplysiae found are about a quarter of an inch in length, and are brought up in the dredge attached to red weed. These young forms are of a deep rose-red colour and feed upon the weeds which they so closely resemble. Apart from the differences in the shape of the tentacles they are in external form like the adult, though differing from them so markedly in colour. These small red specimens were

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* Cuvier, G. "Mémoires pour servir à l'histoire et à 'anatomie des Mollusques." Paris, 1817.

formerly regarded as a distinct species (*A. rosea* of Rathke, *A. nexa* of Thompson). Garstang,* however, showed that they were the young stage of *A. punctata*, and that when kept in a tank and fed on different weed they changed colour and became first brown and finally olive green, the inference being that these colour changes represent the protective colouration exhibited by the animal as it passes through the *Laminaria* and *Fucus* zones respectively, during its migration from deep water to its breeding grounds, as it becomes mature.

After the period of oviposition in the spring it is not known what happens to *Aplysia*. Mediterranean fishermen assert that it becomes full grown in one season, lays its eggs, and dies. Confirmation of this statement is indicated by observations made at the Plymouth Laboratory. Dr. Orton thinks that *Aplysia* is probably an annual, and that it attains the length of 6-8 inches in a single season. Dr. Orton's records also point to an early and a late brood of young, the first reaching the red stage about July, and the second about September at Plymouth. Thus the wintering forms spawn in the spring, and the young produced may reach maturity and spawn in the autumn. It is also possible that the same individual can produce two broods during its life-time.

There are, therefore, the following stages in the life-history :—

1. Pelagic veliger (larval) stage hatching from shore-laid eggs.
2. Metamorphosis (unknown).
3. Rose-red stage in red alga zone on sea bottom.
4. Brown stage in *Laminaria zone.*
5. Olive green stage in *Fucus* zone. This is the mature stage when spawn is produced.
6. If the individual survives egg-laying it may return to deeper water.

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* Garstang. "Journ. Mar. Biol. Assoc." 1889-1890.

ENEMIES.

Despite the ancient fables concerning them (*vide* History), Aplysiae are absolutely harmless and appear to possess few enemies. No other animals are known to attack them,* and they are singularly free from parasites or epizoic organisms. There is no record of any parasite, but on young specimens in the " red " stage, small colonies of *Obelia* and *Pedicellina*, etc., are occasionally found attached to the mantle.

In all stages *Aplysia* is protectively coloured, and the resemblance to the weed on which it is feeding is so close that detection may be difficult except when it is moving. If attacked it has two means of defence.† It can exude a rich purple dye, which forms an effective screen under cover of which it can escape, from glands situated on the under side of the mantle, and an acrid fluid from the sub-pallial opaline or poison gland. It might be supposed that the dye would have been employed by the ancients, to whom *Aplysia* was well known, but there is no evidence that they utilised this particular animal. The unstable character of the dye coupled with abhorrence of the creature that produced it were quite sufficient to prevent its use.

FOSSIL REMAINS.

There are no authentic fossil remains of *Aplysia*, whose soft body and delicate shell do not lend themselves to preservation. The supposed fossil shells of *Aplysia* from the Pliocene are probably flakes from Pelecypod shells. (Zittel, Text-book of Palaeontology, Vol. 1, p. 568.)

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* Rondelet states that the Mullet eats the Sea-hare. As, however, he also says that *Aplysia* feeds on " water, mud, and filth," he cannot have investigated very thoroughly either its habits or its anatomy.

† As Sir Charles Eliot says of the Nudibranch : " It cannot fight and it cannot run away."

EXTERNAL CHARACTERS.

(Figs. 1-7.)

If possible, *Aplysia* should be examined alive before any attempt is made to dissect it. No one who has seen only the preserved animal can have an adequate idea of the appearance of the living animal, for not only does it lose its colour and the velvety nature of the skin, but it dies in a contracted condition, rarely measuring more than a third of its length when alive. When preserved it assumes the " sitting-hare " position, but it seldom does so during life. Then it resembles a large slug with a face like that of a rhinoceros of grotesque and solemn aspect. The body is relatively broader and the visceral hump higher than in the Slug.

The colour of the full-grown animal varies, but it usually resembles very closely the particular weed on which the specimen is found. In many it is a rich olive green or brown, with small black spots and irregular greyish flecks. A black spot is due to granules of pigment in the skin, a white or greyish mark to absence of pigment, whereas the green or brown colour is caused by colouring matter dissolved in the cells of the epidermis and underlying layers. Preservative, especially methylated spirit, quickly extracts the soluble pigment, and to a lesser extent also the granular pigment. Hence the grey appearance of preserved specimens. Gautier and Villard* have shown that the soluble colouring matter possesses the same spectrum as chlorophyll, and that it can be traced back to the chlorophyll extracted from the food by the liver cells. If this is so, *Aplysia* can be said to imitate the weed by making use of the pigments extracted from the weed.

Not only, however, does *Aplysia* imitate the colour of the weed, but also its shape. For example, a specimen feeding

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* Gautier and Villard. " Recherches sur le pigment vert jaune du tegument des Aplisies." C. R. Soc. Biol., Paris, T. LVI, p. 1037-1039, 1904.

upon frilled *Chondrus crispus* possessed frilled parapodia like the fronds of the weed. The resemblance was so perfect that unless the *Aplysia* was moving, it was impossible to distinguish it from its surroundings.

The greyish flecks on the skin differ in shape and size at different ages and in different specimens. When first they appear they are spots, few and far between. After a time ovate flecks arise, arranged radially round the original spot, like the zooids of a compound Ascidian. The radial spots finally fuse with one another and with the first spot to form an irregular patch. These spots bear a close and unmistakable resemblance to the irregular colonies of Polyzoa found growing on the weed.

The body is soft and slimy to the touch owing to the mucus which is secreted abundantly by the epithelial glands of the skin.

Externally the animal appears bilaterally symmetrical, but the symmetry is superficial and does not extend to the internal organs. It has been acquired by detorsion of a spirally coiled type. The body may be divided, for purposes of description, into three regions :—

(1) Cephalic region.
(2) Foot and its appendages.
(3) Mantle and Visceral Hump.

1. *Cephalic region.* The anterior portion of the body, consisting of the head and neck, is very highly contractile. This region is frequently bent ventralwards when *Aplysia* is moving sluggishly over the weeds. (Fig. 2.) The head bears the mouth, two pairs of auriculate tentacles, a pair of sessile eyes and the male copulatory organ. The tentacles are contractile, but not, as in the snail or slug, invaginable. The anterior pair are short, with an open groove on the outer side formed by the curling of the edge. At the base they are stout, and confluent with paired labial expansions which form

a kind of "buccal veil," shaped like two quadrants of a circle, and sloping slightly inwards to the mouth aperture, which is a vertical slit lying between them. This buccal veil can be thrust out, partly invaginated, or flattened to form a shield. (Fig. 3.) The anterior tentacles are tactile organs.

The posterior tentacles or rhinophores (Fig. 4, *rh.*) are longer and less fleshy than the anterior pair. Like these, they are grooved along their outer edges, but the grooves are closed proximally so that they bear a certain resemblance to hare's ears. When the animal is moving they are directed forwards and outwards, when at rest they stand almost upright. They function as olfactory organs.

Immediately anterior and slightly lateral to the base of the rhinophores lie the paired eyes. Each eye is a bluish black speck situated on a circular patch of white (unpigmented) skin. The eye is so small that it often cannot be found in a much contracted specimen. It is usually flush with the surface of the head, but in a well expanded *Aplysia* it may be elevated on a small papilla. (Fig. 3.)

On the right side of the body at the outer side of the base of the right anterior tentacle is the aperture through which the male copulatory organ or penis is protruded. This aperture is connected, by means of a shallow open groove, the spermatic groove (Fig. 4, *sem. gr.*), with the common genital aperture. The groove is unpigmented. On pressing it open with forceps the groove is seen to consist of two projections from the body wall which meet but do not fuse. Along the tube so formed the spermatic fluid passes forwards from the common genital duct to the penis during copulation.

The neck is long in *Aplysia punctata*, and is of the same diameter as the head.

2. *The Foot.* The foot or pedal sole is the organ of locomotion. It is an elongated, flattened, muscular structure which occupies the whole of the ventral surface of the animal,

extending forwards in front of the buccal veil and backwards as a projection or " tail " posterior to the visceral mass. Its anterior end is almost rectangular, the posterior pointed. There is no division into regions as in many Gastropods. Anteriorly the foot is separated from the body by a backwardly directed gutter (Figs. 2 and 22, *gt.*), which makes a cleft about half an inch deep between the foot and the buccal veil. The vertical slit-like mouth is continuous ventrally with this gutter, but behind the mouth the gutter narrows and ends blindly. (*Vide* glands of the foot.)

From the postero-lateral portion of the foot, in the region of the visceral hump, arise a pair of upwardly directed outgrowths, the parapodia or swimming lobes. These are mobile fleshy structures and cover the visceral hump when the animal is at rest. Anteriorly the flaps are free, their bases being about an inch apart, but posteriorly they are fused completely in this species. The line of attachment is thus a horseshoe, with the open ends directed forwards. (Fig. 4, *para.*; Fig. 7, *para. b.*)

The foot is much narrower than in the land snail, and the whole of it is rarely used for creeping. Usually one portion of it is flattened and the remainder has the edges curled towards one another. When *Aplysia* crawls up the stalks of seaweeds only the anterior part of the foot is flat, the posterior portion curls itself round the stalk by approximation of the lateral edges. (Figs. 21-23.) The narrowness and elongation of the foot are well adapted for this purpose. (Compare the broad flat foot of a *Doris*.) It is stated by various observers that the foot can also be used for crawling in the inverted position on the surface film as in many Nudibranchs. During creeping and swimming the foot exhibits waves of movement due to muscular contraction. These are not so well shown in *Aplysia* as in the Snail, and different observers give conflicting accounts of the direction of the waves. They appear to pass backwards along the edges of the foot, and the type is called retrograde.

Aplysia can also swim by means of sinuous movements of its parapodia, or can, according to Guiart, jerk itself suddenly backwards like a Cephalopod by rapid closing of the parapodial lobes. This last movement is probably connected with respiration and with the excretion of faecal matter.

3. *Mantle and Visceral Hump.* (See Fig. 7.)

[Hold the parapodia apart with the fingers.]

Between the lobes of the upstanding parapodia and overlying the visceral hump can be seen a mushroom-shaped mass consisting of the mantle enclosing the shell. In the typical Gastropod the mantle encloses the projecting visceral mass, and mantle and visceral mass are permanently lodged within a conical or spirally coiled shell (Cf. *Patella*, *Buccinum*, etc.). Between the mantle and the body is a space, the pallial cavity, which contains the ctenidia, and into which the anus, the kidney, and the genital glands discharge. At first sight the condition in *Aplysia* appears to vary from this type, but is really a modification of it, due to reduction of the mantle and shell and to the reflection of the mantle flaps over the shell. In many Gastropods the mantle edges become either temporarily or permanently reflected dorsalwards over the surface of the shell (e.g., *Cypraea*, *Physa*, etc.). In *Aplysia* this has become permanent by the fusion of the mantle flaps in the mid-dorsal line. The fusion, however, is not quite complete, as a circular aperture (Fig. 7, *sh. ap.*), which varies in size in the different species of *Aplysia*, is left in the centre. In the young individual the space is very much larger than in the adult. (Cf. Fig. 21). Through the mantle aperture can be seen the delicate, transparent, horny shell. As might be expected, the enclosure of the shell is causing its gradual disappearance. In some allied forms it has disappeared altogether. The six genera of Aplysiidae can be arranged in a series on this point, thus :—

Dolabella. Shell with deep anal incision and short spire.
Dolabrifer. Boat-shaped shell.
Aplysiella. Shell slightly covered.
Aplysia. Shell covered, circular aperture in mantle.
Notarchus. Shell much reduced, shell sac closed.
Phyllaplysia. Shell absent.

As the result of the inclusion of the shell by the mantle and of the compression of the visceral hump during the acquisition of secondary symmetry, the mantle cavity, or cavity between the mantle and the body wall, is much reduced.

The mantle, shell, and visceral hump form a projecting shelf, fixed on the left side but free on the right side of the animal. The mantle is uniformly thin dorsally, but at the right postero-lateral corner it becomes thick and fleshy and curves upwards in the form of a spout or siphon known as the anal spout or funnel. This is shaped somewhat like the auriculate tentacle as it is open along its outer side, but it is much thicker. The edges are often frilled. On the posterior wall of this spout lies the anus, which has a radiate appearance due to the sphincter muscle which regulates the opening and closing of the aperture. When the parapodia are closed the anal spout frequently projects between them, but it can be completely withdrawn. (Cf. Figs. 4, 5, *an. f.*)

[Lift the free edge of the mantle shelf.]

Beneath the mantle shelf lies a crescent-shaped space, open dorsally and anteriorly where the parapodia are free, but shut in posteriorly where they are fused. The concave side of this crescent and its floor are formed by the body wall, its outer or convex side is bounded by the right parapodium, and the incomplete roof consists of a glandular projection of the mantle. This space is all that remains of the pallial cavity. It contains the single ctenidium and the osphradium or water-testing organ, and into it discharge the reproductive apparatus, the kidney, the anus, and certain glands to be described later.

The Ctenidium. The ctenidium (Fig. 7, *ct.*), as in most Tectibranchs, is a lobate plume-like structure which is attached by a broad base to the postero-lateral portion of the floor of the pallial cavity. Its free portion projects backwards and slightly outwards into the cavity, but it can be rotated on its axis or even thrust upwards above the edge of the mantle shelf, the last-named position occurring when the water becomes deficient in oxygen. Along the antero-dorsal convex side of the ctenidium runs a mid-rib, formed by the efferent branchial vessel. On each side of it are ranged the pinnules of the gill. The afferent branchial vessel forms a similar mid-rib on the postero-ventral concave side of the ctenidium. (*Vide* Circulation.)

The Osphradium. (Spengel's Olfactory Organ.) Immediately anterior to the attachment of the ctenidium and lying in the body wall is situated an organ whose function is to test the water approaching the ctenidium. This, the osphradium, is visible as a yellow patch in the living animal, but is often difficult to find in a preserved specimen. (*Vide* Sense Organs.)

Genital Aperture. The common genital aperture (Fig. 7, *c. gen. ap.*) is a small crescentic opening situated at the right anterior end of the pallial cavity on its floor, at the level of the anterior limit of the projecting mantle shelf. Its position can be readily determined as it lies at the junction of the pigmented and unpigmented skin of the neck and pallial cavity respectively. Moreover, from it arises the obliquely placed seminal groove which extends forwards to the penis at the base of the right anterior tentacle.

Nephridial Aperture. The nephridial aperture (Fig. 21, *ren. p.*) is situated on the under side of the overhanging roof of the pallial cavity immediately posterior to the point of attachment of the ctenidium. It is a small slit-like aperture, and can be found by gently stroking the surface in this region with the handle of a scalpel.

Glands of the Pallial Cavity. Two sets of glands, both probably defensive in function, open into the pallial cavity. These are the purple gland and the opaline gland.

The purple gland (Fig. 7, *p. gl.*) is situated on the under side of the free edge of the mantle shelf and occupies a clearly defined area. In the resting condition it is yellowish or brown in colour. The numerous ducts of the large unicellular glands give a pitted appearance to this region. If a living *Aplysia* be irritated by forcibly holding up the mantle skirt or by removing the animal from sea-water, a rich, reddish purple dye mixed with abundant mucus issues from the mantle glands. The discharge is not instantaneous, but takes place within a few seconds. The dye mixes very slowly with the sea-water and forms an effective screen under cover of which the soft-bodied and otherwise helpless Mollusc can escape from its foes.

The Opaline Gland (Vayssière), Poison Gland (Cunningham), Grape-shaped Gland (Cuvier), Gland of Bohadsch (Mazzarelli) lies beneath the floor of the anterior part of the pallial cavity, into which it discharges by numerous apertures, which tend to fuse in small groups in some individuals (Fig. 7, *op. gl.*). In well preserved specimens the orifices may be rendered visible by stroking the surface with the handle of a scalpel. In the largest of the European species, *Aplysia limacina*, the ductlets unite and discharge through a single external aperture, and in this species, too, the gland has the appearance of a bunch of grapes. Cuvier's name, grape-shaped gland, is applicable therefore to this species only.

[Reflect the parapodia, insert scissors into the circular aperture in the mantle on the summit of the visceral dome, and make radial cuts towards the edge of the mantle, thus exposing the shell. Cut along the edges of attachment of the mantle and remove the flaps entirely.]

THE SHELL. (Fig. 6.)

Redi describes the shell of *Aplysia* as " most delicate and quite smooth, so that it seems to be polished and looks like transparent talc." The shell in *Aplysia* is in process of disappearing. It is completely hidden from view by the upward growth of the mantle, and in allied forms such as *Phyllaplysia* has disappeared altogether. It has lost the three-layered condition of the shell of most Molluscs, what is called the shell being only its outer horny layer. Beneath this, but separated from it and often broken in pieces, lies all that remains of the calcareous layers.* The shell has become flattened like the visceral hump which it covers, and has lost all trace of the spiral coiling which occurs in the larval stage. The columellar muscle has disappeared though remnants of it still remain, and the shell is held in place by the upgrowing mantle folds.

In shape the shell is depressed, with a rounded growing margin situated anteriorly and a pointed umbo with recurved edge. The umbo and recurved edge form the rostrum (Fig. 6, *ros.*) of some authors. The umbo is posterior, and is directed downwards. The shallow arch of the shell is greatest near the umbo. The shell is slightly asymmetrical owing to the presence of a concavity (*an. in.*) on the right border into which the anal spout fits. This concavity is much deeper in *Dolabella.* Rings of growth are visible on the shell.

[Lift up and remove the shell.]

Beneath the shell lies the thin transparent mantle, through which can be seen the organs of the visceral hump. The latter are moulded to the shape of the shell, a recurved projection of hepatic tissue filling the concavity of the shell near the umbo.

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* The calcareous matter readily dissolves in acid, and will therefore not be found in a specimen preserved in an acid fixative.

A portion of the mantle is marked off by its opacity from the remainder. This portion is in the form of a band about an eighth of an inch wide which closely follows the contour of the shell. It is the shell-forming region of the mantle, and owes its opacity to the greater height of its unciliated columnar cells and to their abundant contents. (See Fig. 21, *sh. f.*)

Through the transparent skin can be seen the kidney, the liver, and the spongy tissue overlying the purple gland. (Cf. Figs. 15, 21.) The kidney is a triangular gland which is asymmetrically placed on the left side of the visceral mass. Its surface is channelled by the blood-vessels belonging to the afferent renal system. On the right of the kidney lies spongy tissue, forming the thickness of the mantle shelf at this point. Between the spongy tissue and the kidney, in the acute angle between the two, a stout band of muscle (Fig. 15, *ret. mant.*) makes its appearance. This band, when traced in sections, is found to arise from the base of the right parapodium. It threads its way between the pericardial cavity and the anterior aorta, and is inserted on the under-side of the mantle beneath the right side of the shell. This muscle probably functions as a retractor of the visceral hump. A similar but much smaller muscle occurs on the left side, arising from the left parapodium. (*Vide* Muscular System.)

Posteriorly the space beneath the mantle is occupied by the liver.

HISTOLOGY OF THE FOOT AND ITS GLANDS.

The pedal epithelium consists of slightly pigmented cells interspersed between which are goblet-shaped mucous gland cells. The pedal sole is ciliated throughout, and there is an abrupt line of division between these cells and the smaller and less compact, strongly pigmented, unciliated cells of the lateral body wall. Beneath the epithelium the cells are very irregular, with abundant lacunae or blood spaces, and numerous muscle bundles. The muscles are arranged longitudinally, as flattened bands bounding the body cavity (haemocoele), and diagonally, as irregular interlacing strands. (Fig. 21, *l. ped. m.*)

The glands of the foot are either diffuse or concentrated glands. To the former class belong the isolated unicellular gland cells, which are distributed over the whole surface of the foot. To the latter class belong three sets of glands.

The unicellular gland cells lie in or just within the ciliated epithelial layer of the foot. (Figs. 21, 23, *ped. gl.*) They resemble those which occur on most parts of the external surface of the animal, but are more crowded in this region. Each consists of an enlarged flask-shaped cell, the neck of the flask forming the duct for the discharge of the fluid secreted by the bulbous portion.

The concentrated, aggregate or compound glands are three in number, viz.: the anterior pedal gland, the supra-pedal gland, and the paired posterior pedal glands. There is no trace of a middle pedal gland or pore. The anterior pedal gland (Figs. 9 and 22, *ant. ped. gl.*) forms a compact and closely packed glandular area at the anterior end of the foot. The gland cells, though derived from epithelial cells, have pushed their way, as in all the compound glands, into the loose tissue lying beneath the epithelium. The cells are still flask-shaped, but the neck of the flask has become much elongated. The anterior pedal gland discharges on the antero-ventral portion of the foot.

Towards the posterior portion of the anterior pedal gland, larger gland cells appear. These gradually separate themselves off from the ventral gland and discharge dorsally into the gutter between the buccal region and the foot. These gland cells constitute the supra-pedal gland. (Fig. 9, *sup. ped. gl.*)

Opening on the posterior end of the foot, about half an inch from the tip in a full-grown specimen, are a pair of posterior pedal glands. These differ from the anterior and supra-pedal glands in that each gland possesses a cellular duct into which the large gland cells discharge. The duct is of wide calibre, and its walls consist of large squarish cells bearing long flagella. (Fig. 24, *post. ped. gl.*)

HISTOLOGY AND PHYSIOLOGY OF THE MANTLE GLANDS.

(*a*) *The Purple Gland.* As has already been described under External Characters, a rich purple dye is secreted by unicellular glands situated on the under side of the free edge of the mantle. Secretion takes place only when the animal is irritated. A large quantity of mucus issues with the dye, which mixes slowly with the sea-water and forms a screen under cover of which *Aplysia* can hide itself or escape.

The dye is not a permanent colour in the form in which it is given off by the animal. It is therefore not adapted for use as is the dye obtained from *Murex*, *Purpura*, etc., though it probably resembles it fairly closely in chemical composition. There is no record in early literature which shows that the ancients either knew of or attempted to use the dye obtained from *Aplysia*. Their feelings of disgust towards this harmless Mollusc probably prevented the discovery of the dye in those species which produced it.*

Under the influence of light the purple changes colour and becomes reddish; acid increases the intensity of colour, alkali does not affect it at first, but on subsequent exposure to light it becomes rose pink. When a piece of cotton or silk material is stained with the dye the colour remains purple for a variable period, but ultimately changes, especially if left in the light, to a dull brown. The same colour change takes place, but much more rapidly, when the purple is mixed with alcohol.

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* *Aplysia punctata* and *A. limacina* exude purple, but *A. depilans* only a milk-white fluid. The last named is a common Mediterranean species, and is probably the one described in the early literature.

(*b*) *The Opaline or Poison Gland.* This gland, situated on the floor of the pallial cavity and discharging into it by numerous apertures, consists of enormous unicellular vesicles, whose contents in stained preparations closely resemble those of the mucous glands of the skin generally. The gland is well developed in specimens not more than a third of an inch in length, occupying a relatively greater area than in full-grown individuals. (See Fig. 21, *op. gl.*) The fluid excreted by the gland is milky and acrid in nature, and in the Mediterranean species possesses a nauseating odour which was well known to the ancients, and was largely responsible for their abhorrence of the Sea-hare. The foetid smell has not been noticed in the British species. While the purple is very readily exuded by *Aplysia* under irritation, the milky secretion of the opaline gland is only rarely discharged, and then less copiously than the purple. The secretion is probably both protective and excretory. Mazzarelli states that the opaline gland may also exude purple, but this has not been confirmed by other observers.

THE DIGESTIVE SYSTEM.

(Figs. 8-12.)

[Cut through the floor of the pallial cavity, being careful not to injure the visceral nerve cords or the paired ganglia which lie immediately beneath. The cut should be made between the common genital aperture and the opaline gland. Continue backwards keeping to the right of the anus. Cut forwards in front of the common genital aperture obliquely towards the middle line between the tentacles. This involves cutting across the external seminal groove. Turn back the flaps of body wall, but do not cut any connections in the abdominal region. The opaline gland now lies on the right of the cut, while on the left, by turning up the sub-pallium, can be seen the reproductive apparatus, the parietal and visceral ganglia, and the anterior aorta. The visceral mass is in the centre. Now cut between the parapodium and the visceral hump, following the course of the horseshoe formed by the base of the parapodia round to the left. By slitting up the connective tissue which holds the visceral mass in place the whole of the latter can be lifted and turned backwards and forwards without disarranging the organs.]

The digestive organs of *Aplysia* consist of a buccal mass bearing an odontophore and receiving the discharge of two salivary glands ; an oesophagus which dilates into an enormous crop ; two " triturating stomachs " ; a small chamber, the true stomach, into which open the ducts of a voluminous digestive gland or " liver " ; a caecum ; intestine and rectum. The mouth is anterior, the anus postero-lateral and on the right side of the body. (*Vide* External Characters.)

Buccal Mass or Pharyngeal Bulb. This is a pear-shaped, highly muscular organ which can be partly thrust out during feeding in order to grasp the weed upon which *Aplysia* browses. At the anterior narrow end lies the mouth, a median vertical slit-like aperture without lips or distinct outline. The opening is beset with from twelve to twenty longitudinal ridges which allow of considerable expansion in this region. (Fig. 9, *buc. f.*) The epithelium of the labial region is ciliated and glandular. The mouth leads into the cavity of the buccal mass. This is shown in section in Fig. 9. Its swollen posterior end forms a cul-de-sac on the ventral side and lodges the odontophore. Dorsally is given off the oesophagus, and the ducts of the salivary glands enter the bulb.

The whole apparatus is held in place by means of stout ligaments whose position and appearance vary with the state of contraction of the animal examined. Some are transverse, some obliquely placed ; all are attached to the body wall round the buccal orifice. They form the extrinsic muscles of the buccal mass. Viewed from the side the buccal mass presents the following groups of intrinsic muscles :—

1. Paired fan-shaped antero-lateral muscles, originating from the mouth region and spreading out to be inserted on the swollen posterior wall of the buccal mass.

2. Paired postero-dorsal muscles, connected dorsally in the middle line and continuous in direction with those of the oesophagus.

3. A single, stout basal mass of muscle situated on the ventral side of the odontophore.

4. A circular band of muscle acting as a sphincter round the buccal orifice.

[Open the buccal mass by a median longitudinal incision along the dorsal side.]

An internal view of the bulb shows that it consists of a thick walled chamber, from the postero-ventral portion of whose floor arises a pulley-like structure, the odontophore. The food entering the mouth is forced upwards over the top of the odontophore and leaves the bulb by the dorsally situated oesophagus, coming under the action of the radula or tooth ribbon as it does so. The interior is divisible into five regions :—

1. The oral region beset with longitudinal ridges as already noted. This part, which is eversible, ends abruptly posteriorly where the sphincter muscle causes a slight constriction and the jaws are fixed.

2. The mandibular region. On the walls of this region are affixed paired flat horny plates, the so-called mandibles. (Fig. 9, *mand.*) Dorsally the plates are connected by semi-cartilaginous tissue so as to appear to be continuous ; ventrally they merge into the epithelium of the mouth. They are composed of dark brown chitinous rods packed side by side, but with one free end curved and projecting slightly into the cavity. The rods have been called "stick cells." The mandibles have no masticatory function, but help to stiffen the buccal orifice and to form a plate against which the radula can work.

3. A region of irregular folds which are more complex dorsally where they form a channel which is gradually cut off from the main cavity by two lateral inwardly projecting folds, thus forming the pharyngeal canal. (Fig. 22, *ph. can.*) The edges of the pharyngeal folds bear a few scattered "stick cells," differing slightly in shape from those of the jaws. (Fig. 22.) This region is abundantly supplied with mucus from the salivary glands which discharge into the cavity of the buccal mass. (Fig. 22, *r. sal. d.*)

4. The odontophore. This arises as a cushion-like projection from the floor of the posterior cul-de-sac of the buccal mass, and has the shape of a pulley fixed on its postero-ventral side. Over the surface of the pulley lies the radula, whose posterior immature end is lodged within a pouch known as the radular sac.

The cushion or rotella is a highly muscular organ supported by paired "cartilages" of a spongy nature and covered with the epithelium of the buccal cavity. It is held in place by muscle bands, which attach it to the wall of the buccal mass and allow the whole apparatus to be thrust forward or withdrawn. The cartilages also can be moved one on the other so as to give a lateral movement, but this is only possible in a very small degree.

Over the posterior, dorsal, and anterior faces of the rotella is stretched the radula or rasping organ. (Fig. 9, *rad.*) This is a broad ribbon consisting of a basal or sub-radular membrane in which are set numerous chitinous teeth arranged in close and regularly placed transverse rows. A delicate protective layer of connective tissue covers the posterior part of the ribbon. The radular teeth are minute denticles whose cusps are directed backwards. The central tooth of each row differs from the lateral teeth, which are all alike. (Fig. 10.) In *Aplysia punctata* there are fifteen lateral teeth on each side so that the radular formula is 15.1.15. The number of laterals, however, may differ in various individuals according to age. The broadest and oldest part of the radula is that spread over the anterior face of the rotella. Here the teeth are dark brown in colour while those further back are paler and softer. The posterior portion of the radula is hidden within the radular sac (Fig. 9, *rad. s.*), where the new rows of teeth are formed to replace those worn out by constant use. This replacement goes on throughout the life of the animal.

5. The pharyngeal canal. Dorsal to the odontophore the cavity of the bulb becomes laterally compressed and an incipient separation of the channel so formed occurs. This is the pharyngeal canal and the ingrowing projections that will later cut it off from the buccal cavity are the pharyngeal crests. (Fig. 22, *ph. can.* and *ph. cr.*) These crests bear groups of " stick cells " similar to those forming the mandibles. The canal passes insensibly into the oesophagus.

Oesophagus and Crop. The oesophagus is the posterior continuation of the pharyngeal canal. (Fig. 8.) At first it is a narrow thin-walled tube which passes through the nerve ring. After emerging from the ring it swells into a voluminous chamber, the crop (Fig. 8, *cr.*), which becomes spirally coiled when the hunchback attitude is assumed by the animal. The walls possess a thin muscular coat, and internally have rugose folds. The lining endothelium is ciliated but not glandular. The crop is called the first stomach by earlier writers. It is capable of great expansion.

The Gizzard. This is sharply marked off from the preceding region by an annular constriction which occurs at the point of junction, and by a pronounced difference in musclature. The gizzard consists of two portions. It is thick walled, possessing a dense coat of circular muscle fibres covering the anterior portion and of longitudinal fibres in the posterior portion. When slit open the two chambers are seen more plainly. These are called by some authors the first and second triturating stomachs (Fig. 8, *ant. giz.* and *p. giz.*), and by those who call the crop the first stomach, the second and third stomachs. The lumen of both chambers is very small, for, in addition to the thickness of the wall, the inner lining is beset with semi-transparent horny teeth. These are probably of little use for grinding purposes, but compress and strain the food so as to prepare it for the action of the digestive juices. In the first triturating stomach are from twelve to twenty teeth. (Fig. 11, *a. b.*) These are large and stout, with diamond-shaped bases set in sockets in the walls. They are readily detachable. Their shape varies; some are almost perfect pyramids, others like the Cap of Liberty, with backwardly directed points. Between the teeth the walls of the gizzard are thrown into folds. In the second portion of the gizzard the teeth are much more slender. (Fig. 11, *c.*) They are long and tapering, with pointed tips and ovoid bases, and are about twelve in number.

Stomach and Caecum. At this point the alimentary canal becomes embedded in the digestive gland. A pair of valves (Fig. 12, *l. stom. v.*), muscular and covered with long vibratile cilia, regulate the passage of the food from the posterior portion of the gizzard into the morphological stomach. Up to the present no change of a digestive nature has taken place in the food, and in sections of the preceding portions of the canal, the histological elements of the weed are plainly visible. Digestion proper is initiated in the stomach (Fig. 8, *stom.*), which forms an ill-defined chamber, the " camera biliare " of Zuccardi. The stomach receives the discharge from the " liver " by a variable number of ducts (usually three on the right side and one on the left). The ducts are almost equal in diameter to the stomach itself. They are strongly ciliated so as to drive the hepatic fluid forwards into the alimentary canal. It is probable that the bile is not only digestive but also excretory. The liver is more properly an hepato-pancreas, but functions also as an accessory kidney.

From the stomach the food is directed by a strongly ciliated fold, which plugs the entrance to the intestine, into the caecum (Fig. 12, *caec.*). This arises as a diverticulum of the stomach. In specimens about twelve millimetres long it is a mere knob on the surface of the latter, but in the full-grown *Aplysia* it reaches from the heart of the liver mass to the surface, its blind end being swollen and slightly bent on itself.* The cavity of the caecum is divided longitudinally by a ciliated glandular fold, which terminates a short distance from the blind end, thus allowing the two portions on each side of the fold to communicate with one another. The fold is known as the typhlosole or caecal valve (Fig. 12, *caec. v.*). The left portion of the fold is continuous with the cavity of the stomach, the right with the intestine. The food, as was shown by Mazzarelli and Zuccardi, after being mixed with the hepatic fluid, passes down the left side of the caecum, up the right side and so into the intestine. The stomach and the caecum "constitute therefore, physiologically, the true stomach of *Aplysia*, but morphologically the true stomach, arising from the larval stomach, is represented by the 'camera biliare' only, and the hepatic caecum represents a new formation."

The Intestine. This receives the food from the caecum and passes forwards through the visceral mass, emerging on its anterior surface. (Fig. 12, *int.*) It then takes a sharp bend to the left, and, still lying on the surface, though sunk in a depression which exactly fits it, passes backwards along the ventral face of the visceral mass, loops back on itself, then bends upwards and to the right along the dorsal side of the visceral mass towards the anus, which is postero-lateral in position. Its diameter narrows gradually, and its walls become thinner and less muscular. It is ciliated throughout.

The Rectum. The terminal portion of the intestine which

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* In dissection this blind end should be looked for and the caecum traced back from it. Otherwise it may be removed with the liver substance and its connection with the stomach wrongly supposed to be another bile duct.

ascends the anal papilla, may be called the rectum, though it is not differentiated from the remainder of the gut. (Fig. 8, *rect.*) Near the anus it becomes more muscular, however, and at the point where it discharges to the exterior, a sphincter muscle, formed by interlacing muscle bands in the surrounding tissue, occurs. Waste products are forcibly expelled by the alternate relaxation and contraction of the anal sphincter, and the ciliary action of the respiratory chamber, aided, if necessary, by sudden approximation of the parapodial lobes, removes the faecal matter from the neighbourhood of the animal.

GLANDS OF THE GUT.

These comprise the salivary glands and the "liver."

Salivary Glands. There are two elongated salivary glands in *Aplysia*, and they discharge, as has already been described, into the buccal cavity. Each gland is attached by connective tissue to the side of the crop and passes forwards, rarely taking part in the spiral coiling of the latter. Just behind the nerve ring the glandular tissue stops, and the flat, thin-walled duct passes through the ring as in all Euthyneura, runs parallel to the oesophagus, and plunging into the muscles on the dorsal side of the buccal mass opens into the buccal cavity. (Figs. 22 and 23.)

In sections the glandular portion shows a simple aggregation of secretory cells round a central duct. The duct is ciliated. The salivary secretion consists largely of mucus, and is not digestive. The nerve supply is drawn from the buccal ganglia (Fig. 17, *r. sal. n.* and *l. sal. oes. n.*), and the blood supply from the gastro-oesophageal artery. (Fig. 13, *g. oes. a.*)

Liver. The liver, digestive gland or hepato-pancreas is a compact, voluminous gland which makes up the greater part of the visceral mass. With the gonad it forms, as it were, a packing for the coils of the alimentary canal. In a specimen which has been long preserved the components of the visceral mass are extremely difficult to separate. In the fresh condition, however, this is possible. The outline of the liver is smooth and rounded. It shows no trace of spiral coiling, but is divided into irregular lobes.

Microscopically the liver (Fig. 21) consists of simple groups of cells lining central spaces, the spaces uniting to form ciliated channels, the bile ducts. The latter are of wide calibre and discharge by four orifices into the stomach. The hepatic cells contain dark brown or greenish granular pigment and frequently drops of oil. The bile fluid is in part digestive and in part excretory.

Mechanism of Digestion.

The food, which consists of seaweeds of various species, is grasped by the protruding lips and jaws and rasped off in small pieces by the action of the radula. To do this the whole odontophore is thrust forwards so that the radular ribbon works against the flat surface of the jaws. The backwardly-directed teeth of the radula scrape off particles of the weed, and the mucous secretion of the salivary glands mixes with the food and moistens it. The food is then stored in the crop. Relaxation of the sphincter muscle between the crop and the gizzard allows the food to pass into the latter in small quantities at a time. Here the horny gizzard teeth squeeze and strain the fragments. The rate of entrance into the stomach proper is regulated by means of the strong flap-like valves which guard the aperture. In this chamber the digestive juice from the liver is poured on the food, which then travels slowly down one side of the caecum, up the other side, and so into the intestine. By this time digestion is practically complete, the digested matter is absorbed, and the waste products, in the form of loose irregular pellets, are expelled through the anus.

BLOOD VASCULAR SYSTEM.

(Figs. 13-15.)

The blood vascular system in *Aplysia* consists of a two-chambered heart, arteries, venous sinuses and lacunae. The heart is enclosed within a pericardial chamber, and is situated on the left side of the animal, ventral to the kidney and overlying the visceral mass somewhat obliquely. It is in close proximity to the ctenidium as in all Molluscs. The pericardium is a portion of the coelom and communicates with the renal cavity, which is also coelomic, by a reno-pericardial aperture. The arteries constitute an asymmetrical system of vessels supplying the tissues with blood from the heart. There is no capillary system, but the arteries discharge into large spaces within the tissues known as lacunae. The lacunae are devoid of epithelial lining, the blood coming into apparent contact with the muscles and connective tissue fibres. From the lacunae the blood travels back to the general body cavity surrounding the gut and other organs. This body cavity is not, therefore, a true coelom, since it contains blood, but a haemocoele. From the haemocoele the blood is collected in wide vessels with definite walls, the venous sinuses. These occur only near the ctenidium and kidney, with which they communicate, and are not to be found in other parts of the body. The blood traverses either the kidney or the ctenidium on its way back to the heart, so that the blood entering the heart is mixed blood, the greater part being oxygenated blood from the ctenidium and a small portion being blood purified from nitrogenous waste, but not oxygenated, from the kidney.

The blood is colourless and contains amoeboid corpuscles. The oxygen carrier is haemocyanin dissolved in the plasma.

It is at first sight difficult to see how a constant circulation can be maintained on account of the great spaces in the body. The blood fills them very rapidly causing sudden turgidity, which was formerly thought to be due to the imbibition of water. The reverse process, viz., the emptying of the spaces, is brought about chiefly by the strong muscular contractions of the animal, the blood being forced out of the tissues by compression.

[DISSECTION. Remove the shell so as to expose the kidney lying on the surface of the flattened visceral hump. Dissect away the left anterior portion of the kidney: the heart is situated directly beneath it. Trace the arteries from the heart. The course of the arteries can best be followed by injecting, drop by drop, a strong aqueous or gelatine solution of Prussian blue into the three main trunks whose apertures can be found by slitting up the large arterial trunk arising from the ventricle of the heart. For a complete injection use Prussian blue gelatine and inject either into the efferent branchial vessel from the ctenidium or into the spongy tissue of the foot.]

The Pericardium (Fig. 14, *pc.*) is a spacious chamber, representing a shut-off portion of the true coelom, which does not contain blood. It communicates with the cavity of the kidney by means of a small reno-pericardial duct situated close to the entrance of the renal vein into the auricle, i.e., on its anterior wall. The walls of the pericardium are supported by tough interlacing fibrous bands. The nerve supply is derived from the parietal ganglion. (Fig. 16, *pc. n.*)

The Heart does not fill the pericardium. It projects from its floor into the cavity and runs obliquely across the body, the ventricle being slightly anterior to the auricle, and both lying anterior to the ctenidium. (Hence the name Opisthobranchiata.)*

The Auricle (Fig. 13, *aur.*), which is on the right, is thin-walled, delicate, and transparent. Fine interlacing strands of muscle and fibrous tissue give it the appearance of beautiful lace. The auricle receives blood from the ctenidium and the kidney by two efferent branchial veins and a renal vein

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* Great contraction may cause the heart to appear almost transverse.

respectively. The ventricle (Fig. 13, *ventr.*) is smaller than the auricle and has thick, opaque muscular walls. There is a constriction between auricle and ventricle, marked internally by two crescentic flaps or valves. (Fig. 14.) Neither auricle nor ventricle possesses an endothelium so that the muscle strands are bathed directly by the blood.

From the antero-ventral portion of the ventricle arises the arterial trunk which supplies the whole body with blood. It runs obliquely across the floor of the pericardium, and is attached to the latter. Auricle and ventricle must be pushed back to expose it. The sides of this aorta are sacculated, and an internal examination shows that the sacculae are divided off from the central cavity by fibrous strands. The function of the sacculations, which form the crista aortae (Fig. 13, *cr. ao.*), is not known. It is supposed by some to be a lymph gland in which the leucocytes of the blood are manufactured: by Grobben it was regarded as a gland for pericardial excretion (Cf. Keber's Organ in Lamellibranchs.). Mazzarelli pointed out that it is not alone in containing leucocytes in its wall, for both auricular and ventricular walls produce them.

On slitting up the crista aortae a semicircular valve is seen guarding the entrance from the ventricle in order to prevent regurgitation of blood into the ventricle. Three apertures or paths of exit for the blood are visible :—

1. An anterior opening lying ventral to the auricle. This leads to the anterior aorta.

2. A smaller aperture at the level of the ventricle and leading to the gastro-oesophageal artery. In some Opisthobranchs this artery arises as a branch from the posterior or abdominal aorta.

3. A posterior aperture leading to the abdominal aorta.

ARTERIES.

The arterial system shows great asymmetry. Three arterial trunks arising from the heart are present, viz.: the anterior aorta, the gastro-oesophageal artery, and the posterior or abdominal aorta. The anterior aorta supplies the mantle, the foot and its appendages, the head and tentacles, the nervous system, the pallial and sub-pallial glands, and the reproductive organs; the gastro-oesophageal artery sends blood to the alimentary canal; the abdominal aorta supplies the liver and those portions of the gut and reproductive organs lying within the visceral mass.

The Anterior Aorta (Fig. 13, *ant. ao.*) leaves the pericardium on its right antero-ventral face immediately posterior to the parietal and visceral ganglia. At this point a sharp bend forwards occurs, and its first branch is given off to the vesicle of Swammerdam (Fig. 13, *spth. a.*). The aorta then passes to the right of the parietal ganglion and ventral to the nerves issuing from that ganglion. An artery runs dorsalwards to supply the mantle (*dors. a.*). From the right side of the aorta arise branches to the opaline gland and genital organs (*gen. a.*). The trunk gradually assumes a more median position, and no more branches occur until the nerve ring is reached. The artery does not, however, as in the Snail, pass through the nerve ring, but runs between the pedal and parapedal commissures, ventral to the former (i.e., outside the ring) and dorsal to the latter (Figs. 13, 23.). Asymmetrical arteries to foot and body wall are given off, and the now median artery runs forward ventral to the buccal mass, which it supplies with blood. Finally it forks and terminates in the labial tentacles and anterior portion of the foot.

It must be remembered that in an animal possessing such a high degree of contractility as *Aplysia* the appearance of the arterial system varies greatly according to the amount of contraction exhibited by the specimen dissected. Thus the aorta at the level of the nerve ring may form a semicircle in a contracted specimen, whereas in an expanded specimen the left pedal artery hooks sharply over the parapedal commissure.

A. *Anterior Aorta.* (Unless otherwise stated the branches are unpaired.)

1. *Artery to the Spermatheca.* (Fig. 13, *spth. a.*) This small artery is easily overlooked, but is demonstrated by injection. It arises from the aorta on its left side just as the latter leaves the pericardium, runs along the duct of the vesicle and branches fanwise over the surface of the spermatheca.

2. *Dorsal Artery.* (Fig. 13, *dors. a.*) This arises from the aorta close to its exit from the pericardium and runs dorsalwards, looping round the retractor muscle of the mantle to supply the mantle and its glands.

3. *Genital Artery* (*gen. a.*). This large artery springs from the right side of the aorta and runs straight backwards dorsal to the branchial nerve (from the parietal ganglion) to supply the genital organs. In some specimens of *Aplysia punctata* it gives off one or more branches to the opaline gland, but in others, and in *A. depilans*, the branch to the gland arises independently from the aorta. The genital artery follows the course of the large hermaphrodite duct in a backward direction and sends branches to it. It then passes through the loop formed by the accessory genital glands, supplying them with blood, and on emerging from the mass runs beside the little hermaphrodite duct, without, as is also the case with the nerve, taking part in the sinuosities of the duct. The artery finally reaches the hermaphrodite gland.

3'. Artery to the opaline gland in specimens where this arises separately from the aorta and not as a branch of the genital artery.

4. *Pedal Arteries* (*ped. a.*). A pair of pedal arteries arise from the aorta at the level of the nerve ring. That on the right is posterior in its origin to that on the left. As already stated the pedal arteries pass backwards ventral to the para-

pedal commissure whereas the aorta is dorsal to it, so that they appear to hook over the commissure. Both pass backwards obliquely towards the foot. Arriving at the surface of the foot at about the level of the crop they plunge immediately into it and branch into anterior and posterior trunks. The former has the shorter course ; the latter can be traced almost the whole length of the foot just under its inner surface. It is not possible to trace the branches by dissection, but in sections of small specimens they are seen to merge gradually into the large and ill-defined lacunae of the foot. A large branch to the parapodium (*para. a*) is given off from the posterior branch of the pedal artery.

5. *Cephalic Arteries* (*ceph. a.*). Cervical of Mazzarelli. The paired cephalic arteries arise, like the pedal, asymmetrically from the aorta. Their distribution is different on right and left sides. As in the case of the pedal arteries the right cephalic artery is posterior to the left in origin. The right artery passes forwards or outwards, according to the degree of contraction of the animal. It sends a small branch to the blood sinus surrounding the ganglia (*ne. a.*). Arrived at the penis it branches into three. The first branch supplies the penis (*pn. a.*) ; the second runs ventral to the penis and beyond it, to the body wall (*b. w. a.*), the rhinophore (*rh. a.*) and the eye (*opt. a.*) ; the third branch sends blood to the spermatic groove (*sem. gr. a.*). The left cephalic artery also runs ventral to the pedal ganglion, sending to it a small artery. It then goes direct to the body wall, rhinophore and eye of its side.

6. *Radular Artery* (*rad. a.*). This small unpaired artery arises from the dorsal side of the aorta and runs directly into the radular sac which lies immediately above it.

7. *Peribuccal or Anterior Tentacular Arteries* (*peribuc. a.*). Paired symmetrical arteries encircle the buccal mass in the region where the muscle is thickest. From each artery arises a branch to the labial tentacle (*ant. tent. a.*).

8. *Anterior Pedal Arteries* (*ant. ped. a.*). Coronary of Blatin and Vles. These paired symmetrical arteries form the anterior termination of the aorta. They curve round the lateral portion of the extreme anterior end of the foot and also supply the anterior pedal gland.

B. *Gastro-oesophageal Artery* (*g. oes. a.*).

This large artery supplies that portion of the gut between the oesophagus and the gizzard. In many forms it springs from the abdominal aorta, but in *Aplysia* it arises independently from the middle of the pericardial portion of the arterial trunk. To trace its branches the main artery should be injected with a coloured solution. On reaching the surface of the crop the artery forks, the two arms of the fork running to right and left of the crop along its surface and branching repeatedly, forming a beautiful raised pattern when injected. A small branch is given off to each salivary gland and runs along its inner side. Backward branches ramify over the gizzard.

C. *Posterior or Abdominal Aorta* (*abd. ao.*).

This emerges from the left postero-ventral portion of the pericardium and passes backwards to supply the organs contained within the visceral hump. The artery runs dorsal to the anterior coil of the intestine and soon gives off on the left side a large branch to the liver. The hepatic artery divides into superficial (*s. hep. a.*) and deep (*d. hep. a.*) branches which ramify within the liver tissue. A second branch, also arising on the left side, has numerous hepatic and intestinal branches (*hep. int. a.*). It supplies the caecum (*caec. a.*), the artery running along the concave side of the curve and giving off branches over the surface of the caecum. The remainder of the posterior aorta supplies the gonad and little hermaphrodite duct (*gen. a.*).

Lacunae and Venous Sinuses.

The lacunae are irregular spaces in the tissues into which the arteries empty themselves, there being neither capillary system nor system of veins. The lacunae are best shown in those parts of the body, such as the foot, the parapodia, the tentacles or the mantle, where the tissues are of a spongy nature. Here there are interlacing bands of fibrous and muscular tissue united by connective tissue. Between the bands are numerous irregular spaces, the lacunae. The only compact tissue in these regions is the surface epithelium. The lacunae are not bounded by any epithelium, so that, as in the case of the walls of the heart, the muscles and connective tissue fibres are apparently bathed by the blood. By means of this lacunar system a rapid flow of blood into the tissues can be effected, causing sudden turgidity and expansion. This was thought to be due, by earlier writers, to the imbibition of water.

In the visceral hump the lacunae are much smaller owing to the compactness of the organs in this region. It is noteworthy, however, that the connective tissue holding the parts of the visceral hump in place is fenestrated so that the blood can pass through.

The course of the blood from the lacunae back to the heart can be traced by injection or by sections of small specimens. If, for example, a few drops of Prussian blue solution be carefully injected by means of a hypodermic syringe into any portion of the foot or lateral body wall, the fluid readily passes through the lacunae and emerges into the general body cavity in the form of little spurts from gaps between the longitudinal muscle bands of the foot and sides of the body. (Fig. 21, *ped. lac.*) It can similarly be shown that the blood from the mantle, the body wall generally, the tentacles, the foot and parapodia is discharged by irregularly-placed apertures into the large body cavity in which lie the gut and its glands, the nervous system and the reproductive organs. This cavity, the apparent body cavity, is therefore not a true coelom, for it contains blood, but a haemocoele. Only the cavities of the pericardium, of the renal sac, and of the hermaphrodite gland are coelomic.

The portion of the haemocoele into which the blood from all parts of the body, with the exception of the kidney and the ctenidium, is discharged is known as the ventral abdominal sinus. Like the lacunae in the tissues this sinus has no bounding epithelium. From this sinus the blood is sent either to the kidney or to the ctenidium on its way back to the heart. To facilitate the propulsion of the blood, venous sinuses with muscular walls collect it from the common sinus and empty themselves into the kidney or the ctenidium. These muscular sinuses are not extensive, but occur only in close connection with the kidney and ctenidium. Their walls are fenestrated. Five of these sinuses constitute the main afferent branchial sinus, the remainder form the renal sinus.

The chief factors of the afferent branchial sinus are :—

1. A small sinus (Fig. 14, *sin.* 1) receiving blood from the left anterior body wall. It runs backwards along the edge of the sub-pallium on the left side of the body, ventral to the kidney and pericardium, and posterior to the ctenidium bends to the right to enter the main sinus.

2. A large sinus (*sin.* 2) opening from the ventral abdominal sinus (anterior part) into the left of the main afferent branchial sinus.

3. A large sinus (*sin.* 3) bringing blood from the posterior part of the ventral abdominal sinus, viz., from the visceral hump. It enters the main sinus on its posterior wall.

4. A small sinus (*sin.* 4) from the right body wall. Through its fenestrated walls it receives also from the ventral abdominal sinus.

5. A small sinus (*sin.* 5) receiving from the right anterior portion of the ventral abdominal sinus.

The union of the sinuses forms the large branchial sinus or afferent branchial vessel (*aff. br.*), which lies immediately beneath the floor of the pallial cavity posterior to the ctenidium. The sinus enters the ctenidium on its outer concave side and extends the whole length of this surface. On slitting up this portion of the sinus, large gaping orifices are seen through which the blood passes to the lamellae of the gill. There is here, as in the tissues generally, no capillary system.

From the ctenidium the blood is collected by two efferent branchial vessels which lie along the inner, convex portion of the gill (*eff. br.*). Like the afferent vessel the efferent vessels communicate with the lamellae by wide openings. The efferent vessels discharge into the auricle of the heart.

All the blood from the ventral abdominal sinus does not enter the ctenidium for purposes of aeration. At the level of the heart there enters the kidney on its dorso-lateral face a short sinus bringing blood from the left portion of the haemocoele. (Fig. 15, *ren. sin.*) A small quantity of blood from the left body wall and the anterior part of the left parapodium also enters the renal sinus, and on the right side of the kidney several small sinuses from the mantle and pericardial roof open. (Fig. 15, *ren. mant. sin.* and *ren. peri. sin.*) The renal sinus discharges into the lamellae of the kidney, from whence the blood is collected by an efferent vessel (Fig. 14, *eff. ren.*) and taken to the heart. There is thus a renal portal system in *Aplysia.* The blood is collected on the ventral side of the kidney, and, purified now from nitrogenous waste matters, leaves by a short efferent renal vessel situated on the right side of the kidney. The efferent vessel opens into the base of the efferent branchial vessel, just as the latter is about to open into the auricle.

RESPIRATORY SYSTEM.

Aeration of the blood is brought about through the medium of the single asymmetrically placed ctenidium, whose position and external structure have already been described under External Characters. For its blood supply and innervation see the sections on Blood Vascular System and Nervous System respectively.

In microscopic preparations the ctenidium shows a regular epithelium, in some parts ciliated, in others, especially near the insertion of the ctenidium, strongly glandular. Beneath the epithelium lies a loose tissue consisting of connective tissue and muscle fibres. The centre of each pinnule is a blood space whose walls are bounded by the tissue just mentioned. There is no capillary system, but the afferent branchial vessel opens by " gaping orifices " into this cavity, and the efferent vessel collects in a similar way.

EXCRETORY SYSTEM.

(Figs. 14, 15, 21.)

The excretory system of *Aplysia* consists of a single asymmetrically placed kidney situated on the left side of the body, overlying the heart and visceral hump, and covered by the shell and mantle. In shape it forms a triangle whose base is directed forwards over the heart, the apex of the triangle curving towards the right posteriorly. It will be noted that the kidney has separated itself from the visceral mass, and lies close under the mantle. In all Euthyneura the single kidney represents the morphologically right (topographically left) member of an original pair of which the fellow has entirely disappeared in *Aplysia.*

The kidney is a coelomic sac lined by a glandular epithelium which is produced inwards in the form of parallel lamellae. The renal sac communicates with the pallial cavity and with the pericardium. The former opening, the renal pore, is the aperture through which the renal excretion is discharged. (Fig. 21, *ren. p.*) It lies in the wall of the pallial cavity at the root of the ctenidium. Its walls are muscular. There is no ureter, but the renal sac empties its excretion directly through the renal pore. The reno-pericardial duct connects the cavities of the renal sac and pericardium, and is thus a means of communication between the renal and pericardial portions of the coelom. It brings about a secondary connection between the pericardium and the exterior. The duct is not visible to the naked eye and is difficult to demonstrate by injection in *Aplysia punctata*, as Cunningham was able to do in the larger Mediterranean species. Sections, however, show that the duct is situated close to the entrance of the efferent branchial vessel into the auricle.

Internally the kidney consists of fairly regular parallel lamellae, which are pendent from its dorsal surface and are held in place by fibrous bands arising from the floor of the renal sac. The lamellae sometimes branch. They run obliquely across the cavity. A single layer of non-ciliated cells forms the wall of each side of the lamella, and between two walls is a blood sinus. Blood enters the kidney by a dorsally placed afferent renal sinus, collecting from the left anterior portion of the ventral abdominal sinus, and to a lesser extent from the left body wall and left parapodium. Small sinuses enter the right anterior border of the gland from the mantle from the part roofing in the kidney. These sinuses branch repeatedly over the surface of the renal sac, lying in channels excavated on its upper surface. The blood passes through the lamellae to collect again in a large sinus, the efferent renal sinus, on the floor of the gland. The efferent renal vessel leaves the ventral side of the kidney on its right side, and discharges into the efferent branchial vessel just as the latter enters the auricle. (*Vide* Blood Vascular System.)

The kidney is innervated from the branchial ganglion. (Fig. 16, *ren. n.*)

The kidney is not the only organ of excretion. The sacculations forming the crista aortae, certain cells of the liver and of the connective tissue, and the opaline gland are probably all concerned with the elimination of waste matter.

The Crista Aortae (Fig. 13, *cr. ao.*) lies on the aorta close to its origin from the ventricle of the heart. Leucocytes occur in its walls and are thence transferred to the blood stream, so that the region is also a lymph gland. It is claimed by Grobben, however, that waste matter from the blood is drawn off here, and that the crista aortae is homologous with the pericardial gland of other Molluscs.

The liver contains two kinds of cells :—(*a*) Protoplasmic cells rich in granules, secreting a digestive ferment, and (*b*) cells poor in protoplasm, but usually full of brown oily globules, excretory in function. The former stain deeply, the latter hardly at all.

The connective tissue surrounds the whole of the body organs as a thin layer and permeates between the coils of convoluted organs, e.g., accessory genital mass, forming a packing for the coils. It also fills the spaces between the muscle fibres of the foot and parapodia, but not completely, for frequent gaps, the lacunae, occur. These lacunae are part of the blood vascular system. In the large haemocoele (ventral abdominal sinus), in addition to the layer covering the gut, nervous system, etc., layers of connective tissue occur between the gut and body wall. (These have been omitted from Figs. 21-23.) In many parts, especially where the organs are compact, as in the visceral hump, the connective tissue is fenestrated to allow of the passage of the blood through it. The tissue consists of colourless corpuscles embedded in a semi-gelatinous matrix. Some of these corpuscles (cells of Leydig) contain concretions of chalky matter, and function as accumulative excretory cells.*

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* Note that in a specimen preserved in acid fixative all traces of these concretions disappear.

MUSCULAR SYSTEM.

The muscles in *Aplysia* are usually arranged in elongated bundles. The individual fibres are tubular, and are not transversely striated. (Fig. 21, *l. ped. m.*) The chief groups are :—

1. The muscles of the gut, extrinsic and intrinsic.
2. The retractor muscles of the mantle, penis, etc.
3. The muscles of the kidney, ctenidium, etc.
4. The muscles of the foot and body wall.

The extrinsic muscles of the gut comprise those holding the buccal mass in place and the sphincter muscles at mouth and anus. The first named consist of numerous straight bands radiating from the buccal mass towards the foot and body wall. The remainder of the gut is held in place by connective tissue only. The whole alimentary canal possesses an intrinsic muscular coat of fibres varying in thickness in the different regions. It is thickest and most complicated in the wall of the buccal mass and gizzard. (*Vide* Alimentary Canal.)

Stout bands of fibres arising from the parapodia act as retractors of the mantle and so of the visceral hump. There are two of these bands on the right side arising from the right parapodium, and one on the left side arising from the left parapodium. The right anterior muscle threads its way between the vesicles of the opaline gland, passes upwards between the pericardium and the left wall of the pallial cavity, through the spongy mantle tissue to the surface of the mantle lying beneath the shell. It arrives at the surface between the kidney on the left and the free edge of the mantle containing the purple glands on the right, spreading out to be inserted directly on the mantle epithelium. (Fig. 15, *ret. mant.*) The posterior right retractor muscle passes upwards from the right parapodium in the region of the anus. The left muscle is smaller than those on the right side, but is similar in distribution and origin. (Fig. 21, *ret. mant.*)

The retractor penis arises from the muscles of the foot. It consists of numerous bands which join up only at the base of the penis sheath to form the stout hollow pillar of muscle which traverses that organ. (Fig. 19, *ret. pn.*) In the kidney and ctenidium small muscular projections arise from the walls to support the lamellae. (Fig. 21.)

The musclature of the foot is very characteristic. On the inner surface bordering on the haemocoele, flat longitudinal bands occur and run the whole length of the foot. (Fig. 21, *l. ped. m.*) Between the bands the haemocoele enters into communication with the lacunar system of the foot. In the spongy tissue of the foot and parapodia the muscle bundles are intricately woven to form a network. The meshes of the network are partly filled with connective tissue of a gelatinous nature, but numerous lacunae occur. The muscles are directly bathed by the blood.

NERVOUS SYSTEM.

(Figs. 16, 17, and 23.)

The nervous system is of great interest from the comparative point of view because it exhibits the intermediate condition between the streptoneurous and euthyneurous types. The Streptoneura possess long visceral cords twisted into a figure of eight, the Euthyneura usually have uncrossed cords, and the majority show a tendency to shortening of the visceral cords and concentration of the chief ganglia around the oesophagus. *Aplysia* has long, untwisted visceral cords, the homology of whose ganglia is at first sight somewhat obscure and has given rise to considerable confusion in the literature on this Mollusc.

The nervous system of the typical Gastropod consists of the following ganglia :—Paired cerebral, paired stomato-gastric, paired pedal, paired pleural, paired parietal, and unpaired visceral ganglia. The cerebral, pleural, and pedal ganglia form a nerve ring surrounding the oesophagus. The two cerebral and two pedal ganglia are united by means of cerebral and pedal commissures respectively, the former dorsal and the latter ventral in position. Connectives link up the cerebral and pedal, cerebral and pleural, and pleural and pedal ganglia. The cerebral ganglia are connected with the ventrally placed stomato-gastric ganglia, which are united by a commissure. The visceral nerve cords originate from the pleural ganglia, and along the course of these cords, which are united posteriorly lie the remaining ganglia, viz., two parietal ganglia and a single visceral or abdominal ganglion. In *Aplysia* all these ganglia, with the exception of the left parietal (the infra-intestinal ganglion of Prosobranchs), are present as distinct ganglia. There is evidence that the left parietal ganglion has fused with the unpaired visceral ganglion. The right parietal (supra-intestinal ganglion of Prosobranchs) and the visceral ganglion form an apparent pair owing to the shortening of the pleuro-visceral connectives along which they lie.

The regions innervated by these ganglia are similar to those in other Gastropods. The cerebral ganglia are the main sensory centres supplying the tentacles (touch, smell, taste), the eyes and the so-called auditory organ. The stomato-gastric ganglia are the seat of the extensive sympathetic system which ramifies over the surface of the gut. The pedal ganglia are motor centres innervating the foot and its appendages. From the pleural ganglia originate the pleuro-visceral connectives (visceral cords), the ganglia along the course of these cords supplying the mantle and its glands, the gill and the osphradium, the genital organs, heart, kidney, etc.

In a fresh specimen the nerves appear yellowish white in colour, and the ganglia are a bright yellow or orange. The whole of the nervous system, both central and peripheral, is surrounded by a sheath of connective tissue between which and the nervous tissue lies a blood sinus. In the anterior regions of the body it is sometimes difficult to distinguish between nerves and the delicate muscle tendons that hold the gut in place. The presence of the blood sinus surrounding the nerve, however, at once distinguishes the latter.

[Dissection. Make a median incision through the body wall between the rhinophores so as to expose the buccal bulb. Extend the cut forwards and backwards until the cerebral ganglia are visible. Find the pleural ganglia and trace the pleuro-visceral cords back to the adjacent parietal and visceral ganglia, which are situated dorsal to the alimentary canal and at the level of the posterior curve of the crop, exactly beneath the anterior wall of the pericardium. This involves making an oblique incision towards the genital aperture. Continue the cut through the floor of the pallial cavity between it and the base of the right parapodium.]

A. *Cerebral Ganglia and Nerves.* (Fig. 16.)

The cerebral ganglia (*c. g.*) lie on the dorsal side of the oesophagus at its point of origin from the buccal mass. So large are the nerve cells in these and the other chief ganglia that the surface possesses a granulated appearance. The antero-lateral surface of each cerebral ganglion is somewhat swollen, and is seen in sections to consist of a distinct ganglion, the optic ganglion of Mazzarelli, which is markedly disproportionate to the minute eye of the animal. The two cerebral ganglia are united by a single cerebral commissure, and are linked up with the pleural, pedal, and stomato-gastric or buccal ganglia by cerebro-pleural, cerebro-pedal, and cerebro-buccal connectives respectively.

From the cerebral ganglia arise the following pairs of nerves, the distribution of right and left sides being similar except in the case of 5 :—

1. A small tegumentary nerve (*teg. n.* 1). This arises from the antero-ventral portion of the ganglion and runs forward to the skin between the tentacles. A branch of the nerve innervates the buccal orifice, and the dorsal side and

muscles of the bulb. A chain of small ganglia occurs along the course of this branch.

2. Anterior tentacular nerve, the nerve of the labial tentacle (*ant. tent. n.*). This arises from the ventral side of the cerebral ganglion, emerges beneath the third nerve, and runs forward as a stout nerve beside the buccal mass. It has two branches. The first or superficial branch is external to the second or deep branch. The superficial branch runs close under the skin of the labial tentacle, forking round the lobes of the tentacle. Knotty thickenings often occur along it, but these do not contain nerve cells. The internal or deep branch divides into three, of which two supply the ventral and lateral portions of the buccal cavity and are ganglionated, while the third runs along the fleshy base of the labial tentacle.

3. Posterior tentacular nerve, the nerve of the rhinophore (*rh. n.*). Its origin is close to that of 1 and 2, but it immediately ascends dorsal to them so that it appears to be the first nerve when the ganglia are exposed. Its course is straight to the rhinophore. When it reaches the body wall a small nerve branches off to supply the inner side of the tentacle. The main nerve is ganglionated at the base of the auriculate portion of the rhinophore, and from this ganglion a single nerve proceeds along the inner or folded side of the tentacle, branching to supply the lobes of the ear-like apex.

4. The optic nerve (*opt. n.*). The presence of a comparatively large optic ganglion, attached to the cerebral ganglion, would suggest a well developed eye and stout optic nerve. Such is not the case, however. The eye is sunk in the skin at the base of the rhinophore, and its nerve is extremely slender. The optic nerve is closely attached to the nerve of the rhinophore.

Nerves 3 and 4 pass dorsal to the penis on the right side.

5. Tegumentary nerve (*teg. n.* 2). It springs from the postero-lateral portion of the cerebral ganglion, and supplies

the skin on the side of the body anterior to the rhinophore. On the right side it sends a branch to the penis.

6. The "auditory" nerve (*aud. n.*). This slender nerve arises from the posterior side of the cerebral ganglion, and passes backwards between the cerebro-pleural and cerebro-pedal connectives to the statocyst, which lies in a shallow pit excavated on the surface of the pedal ganglion.

B. *Pleural Ganglia and Nerves.*

The pleural ganglia (*pl. g.*) are situated laterally to the cerebral ganglia with which they are connected by the short and stout cerebro-pleural connectives. Pleuro-pedal connectives are also present, but there are no pleural commissures. From the pleural ganglia arise the long pleuro-visceral connectives. That on the right side passes straight to the parietal (supra-intestinal) ganglion lateral to the right salivary gland. The left connective dives ventral to both salivary gland and oesophagus, emerging into view again at the posterior end of the crop, where it swells to form the visceral ganglion, lying adjacent but slightly postero-ventral to the parietal ganglion. Both connectives run dorsal to the aorta. The amount of contraction of the animal may cause some variation in the relative positions of the parts in this region. From the pleural ganglion arises a slender nerve to the body wall. In some specimens there are two nerves on the left side and one on the right (*teg. n.* 3 and *teg. n.* 4). The nerve emerges from the anterior portion of the ganglion and passes straight outwards. It has an anastomosis with the posterior tentacular nerve (A3) and with the tegumentary nerve (C5). Although nerves arise from the pleural ganglia in Streptoneura (e.g., *Patella*), their presence is rare in the Euthyneura, where the infra-intestinal ganglion takes on the work of supplying the reduced mantle. The fact that the visceral ganglion supplies both viscera and mantle region is evidence that this ganglion represents infra-intestinal and visceral ganglia, and Guiart claims to have found traces of this fusion in *Aplysia.* Both Guiart and Mazzarelli deny that any nerves arise from the pleural ganglia in *Aplysia.* Pelseneer, however, figures a pleuro-pedal plexus in *Aplysiella petalifera.*

C. *Pedal Ganglia and Nerves.*

Each pedal ganglion (*ped. g.*) lies close to the pleural ganglion of its side. A stout cerebro-pedal connective runs between it and the cerebral ganglion, and a pleuro-pedal connective between it and the pleural ganglion. From it arise the numerous nerves supplying the foot and parapodia. The anterior portion of the ganglion bears a hollow sac, the "otocyst" (Fig. 23, *ot.*), which receives a slender nerve from the cerebral ganglion (nerve A6). The pedal ganglia are united by two commissures, known as the pedal and parapedal commissures respectively. The former is a broad commissure which lies ventral to the oesophagus and thus completes the cerebro-pedal nerve ring. (Fig. 23, *ped. comm.*) The parapedal commissure (*para. ped. comm.*) is long and slender, and is ventral not only to the oesophagus but also to the aorta. The aorta, therefore, passes through the space between the two commissures. The parapedal commissure gives off a small nerve on the left side to the connective tissue in this region.

The pedal nerves may vary in number and distribution in different specimens. Those on the right side are always larger and more numerous than those on the left, since they are distributed to such asymmetrically placed structures as the penis, genital groove, etc.

1. Anterior pedal nerve. This large nerve arises from the ventral side of the pedal ganglion and divides into four branches, all of which supply the foot. The first or deep branch is hidden by the second and third in dissection and runs forward to the anterior portion of the foot.

2. Small tegumentary nerve.

3. Tegumentary nerve. This large nerve supplies the retractor muscles of the head, the skin, and, on the right side, the muscle strands attached to the penis. It anastomoses with the posterior tentacular nerve (A3).

An additional small tegumentary nerve, occurring on the right side only, supplies the skin and penis.

All the above nerves run forwards. The following run in a posterior direction.

4. Parapodial nerve (Fig. 16, *para. n.* 1.). This is a large nerve which arises from the ventro-lateral side of the pedal ganglion and passes straight backwards ventral to the longitudinal muscle bands and somewhat obliquely to innervate the parapodium. It branches on its outer side only.

5. Small tegumentary (*teg. n.* 7). This nerve springs from the inner dorsal side of the ganglion, crosses dorsal to 4, and runs beside the crop. It has three branches, viz., to the body wall anterior to the genital aperture, to the parapodium, and to the sub-pallium. On the right side it has an anastomosis with the vulvar nerve (D1) from the parietal ganglion and also with the nerve from the pleural ganglion (B1).

6. Small parapodial (*para. n.* 2). This goes straight to its destination and does not branch until it reaches the muscles of the parapodium.

7. Middle pedal nerve (*ped. n.* 2). It passes straight backwards, crosses ventral to 8, and plunges into the middle portion of the pedal sole.

8. Posterior pedal (*ped. n.* 3). This large nerve innervates the posterior portion of the foot, branching on the surface of the muscle bands. An additional nerve, distributed to the foot, may be present on the left side.

D. *Parietal Ganglion* (*par. g.*).

The parietal ganglion (supra-intestinal) lies beside, but slightly antero-dorsal to the visceral ganglion, at the level of and dorsal to the posterior curve of the crop. This is the last remains of streptoneury in *Aplysia*. The unpaired nerves arising from the ganglion are liable to variation. The main ones are :—

1. Small vulvar nerve (*vul. n.*), which springs from the antero-lateral portion of the ganglion and runs transversely, branching into two to innervate the sub-pallium and the vulvar orifice. Before branching, however, it has an anastomosis with the small tegumentary nerve (C5) from the pedal ganglion.

2. Branchial nerve (*br. n.*). This arises from the posterior portion of the parietal ganglion. It is a stout nerve which goes to the base of the ctenidium, where it swells into the branchial ganglion. Just before entering the branchial ganglion a nerve passes out to supply the purple gland. From the ganglion are supplied the osphradium, the ctenidium, and the kidney.

3. A small nerve to the floor of the pericardium (*pc. n.*).

4. A small nerve to the spermatheca (*spth. n.*).

E. *Visceral Ganglion* (*visc. g.*).

(Represents the infra-intestinal and visceral ganglia fused.)

The following nerves arise from the ganglion :—

1. A small nerve to the gastro-oesophageal artery (*g. oes. n.*).

2. A stout nerve (*an. n.*) from the outer side of the ganglion whose course is straight to the anal region dorsal to the visceral mass. One branch ascends the anal spout and supplies the muscular walls of the anus and the fleshy siphon, another branch passes ventral to the rectum to the genital duct and accessory glands.

3. Genital nerve. This passes ventral to the duct of the spermatheca, runs parallel to the large hermaphrodite duct, and on the ventral surface of the albumen gland swells into a small ganglion (*gen. g.*). From the ganglion

branches supply the genital duct and accessory genital glands. The largest branch emerges on the dorsal side of the accessory mass, passes dorsal to the rectum and innervates the little hermaphrodite duct and gland.

4. A small nerve to the floor of the mantle cavity.

F. *Stomato-gastric or Buccal Ganglia.* (Fig. 17.)

The buccal ganglia (*buc. g.*) are small ganglia lying on the ventral side of the buccal mass. They are slightly anterior to the cerebral ganglia with which they are connected by cerebro-buccal connectives (*c. buc. conn.*). A buccal commissure is present.

[DISSECTION. After dissecting the nerves from the cerebral, pleural, and pedal ganglia, detach the nerves as near as possible to the organs they innervate. Dissect off the connective tissue from the gut so that it can be pinned back on the left side. Cut through the muscle bands that hold the buccal mass in place and turn the latter over to expose its ventral surface. The buccal ganglia are now visible. *Or* cut through the oesophagus about half an inch from the buccal mass, detach the muscle bands as before, and turn the whole forwards so as to expose the ventral side of the buccal mass. This method, however, involves cutting the visceral nerve cords.]

The following nerves arise from the buccal ganglia :—

1. From the commissure is given off a median radular nerve (*rad. n.*), which runs forward, plunges into the muscles of the buccal mass and enters the radular sac on its ventral side.

2. A small nerve (*buc. n.* 2) which supplies the basal muscles of the buccal mass.

3. A large nerve (*buc. n.* 3) which soon bifurcates to supply the lateral muscles of the buccal mass. In some specimens there appear to be two distinct nerves as the branching occurs at the root. On the posterior side of this nerve

a small artery supplies the sinus in the connective tissue surrounding the nerve. This may at first be mistaken for a branch of the nerve.

4. A large nerve to the salivary gland and oesophagus. This nerve runs inwards. On the right side the nerves to salivary gland (*r. sal. n.*) and alimentary canal (*r. oes. n.*) arise separately as two distinct nerves. The nerve to the gut runs parallel to the oesophagus and branches into two. One branch runs forward again to the pharyngeal crest of the buccal mass, internal to the salivary gland; the other branch runs backwards along the oesophagus, giving off twigs to it. With its fellow nerve it forms an anastomosing network, which, according to Mazzarelli, accompanies the gut to the anus. Nerve rings occur at the level of the gizzard. On the left side the nerve (*l. sal. oes. n.*) branches into three. One branch goes to the salivary gland, another forwards to the pharyngeal crest, and the third backwards along the oesophagus.

SENSE ORGANS.

The sense organs in *Aplysia* consist of paired eyes, paired "otocysts," and a single osphradium. In addition there are scattered sensory cells in the epithelium of various parts of the body, particularly on the two pairs of tentacles. The sense of touch is present over the whole outer surface, but is especially acute in the tentacles. Taste is located in the epithelium lining the entrance to the buccal cavity. The rhinophores are the seat of the olfactory sense, but the osphradium, which tests the water passing over the ctenidium, must also be said to have some appreciation of odours. The "otocysts" function as organs of orientation and the eyes are the organs of sight.

The Epithelial Sense Cells.

On the inner sensory surface of both pairs of tentacles and on the floor of the mantle cavity, roof of the mantle cavity, and lower part of the inner side of the right parapodium (i.e., on the walls of the pallial cavity) occur, amongst the ordinary epithelial cells, cells which give rise to brush-like bunches of stiff but slender processes resembling cilia in appearance. (Fig. 21, *pz.*) These are the " Pinselzellen " of Flemming. The nerves supplying the Pinselzellen penetrate the epithelium and end on the surface in fine fibrils.

EYES.

There are two eyes, one being situated at the base of each rhinophore on its anterior side. During life the eye often appears to be situated on a small elevation, but in a contracted condition may be completely sunk in the skin. Each eye is a bluish black spot and is surrounded by a clear circular patch of unpigmented skin.

The eye consists of a closed vesicle lying just beneath the surface skin, the epithelium covering it forming a transparent cornea. Between the wall of the vesicle and the epithelium lies a small amount of connective tissue, and the vesicle is surrounded internally by tissue of a similar nature, but more closely packed together.

The optic vesicle is an ovoid sac whose walls are formed by a single layer of cells. These cells are not, however, of equal depth. Those in proximity to the cornea, i.e., on the outer side of the organ, are thin and flattened, and form the false cornea. Laterally and internally the cells are of much greater vertical diameter, increasing in height from the false cornea to the internal wall of the vesicle, where they form the retina. There is abundant pigment on the wall abutting on the interior of the vesicle, but not in the cells forming the false cornea. The pigment zone thus forms a rather broad horseshoe, whose open ends reach to the false cornea. The retinal cells are of two kinds, called by Pelseneer the retinulae and retinophora. The former are pigment cells, the latter the sensory cells of the organ of sight.

On the inner portion of the retina is poised a gelatinous non-cellular lens, whose outer margin, facing the cornea, is smooth and evenly convex, but whose inner edge, abutting on the retina, is ill-defined. Hair-like processes, known as "Stiftchen," project from the retina to hold the lens in place.

Blood lacunae surround the eye, and blood is brought to it by a branch of the cephalic artery. (Fig. 13, *opt. a.*) It is innervated by a small optic nerve (Fig. 16, *opt. n.*) which arises from a comparatively large optic ganglion attached to the cerebral ganglion.

THE STATOCYST.

The statocysts or otocysts (Fig. 23, *ot.*) are situated on the anterior face of the pedal ganglia. Each otocyst is a hemispherical sac whose flattened base is attached to the pedal ganglion of its side. The wall of the sac consists of a thin non-ciliated epithelium. The connective tissue which enwraps the whole nervous system covers the otocyst too, and separates it from the nervous tissue of the pedal ganglion. Within the otocyst is a granule of calcareous matter. The sac is innervated from the cerebral ganglion, the auditory nerve lying between the cerebro-pedal and cerebro-pleural connectives. The otocyst forms the organ of orientation, and like the eye is epithelial in origin.

THE OSPHRADIUM.

(Olfactory Organ, Organ of Spengel.)

The single osphradium is situated at the base of the ctenidium on its anterior face. In the living condition it can usually be recognised as a yellowish patch, due to the branchial ganglion showing through the skin at this point and not to the osphradium itself. The osphradium is the water-testing organ. Should the water approaching the ctenidium become deficient in oxygen, the nerve impulse generated by the osphradium causes the animal to open its parapodia and thrust out the ctenidium so as to obtain as much oxygen as possible. If foul water enters, the parapodia are forcibly closed and the ctenidium withdrawn.

The osphradium consists of a slightly elevated patch of columnar epithelial cells. These are not ciliated, and the organ shows no trace of the leaf-like arrangement of the osphradium of certain Prosobranchs (e.g., *Buccinum*). The osphradium is innervated from the branchial ganglion.

GENERATIVE SYSTEM.

(Figs. 18-20.)

Aplysia, like other Euthyneurous Gastropods, is hermaphrodite. The genital organs consist of an unpaired ovotestis or hermaphrodite gland, a common genital duct, female accessory glands, reservoirs for the male elements, and a male copulatory organ or penis.

The ovotestis (Fig. 20, *herm. gl.*) is a compact gland of irregular shape, and is embedded in the visceral mass on its right posterior border. In the freshly-killed animal it can be easily separated from the liver, and its golden yellow colour forms a marked contrast to the dull brown of the latter. A common genital duct forms a mid-rib to the gland, and receives ductules from both sides. The size of the gland varies with the time of year and age of the specimen. On leaving the ovotestis the little hermaphrodite duct (*lit. herm. d.*) increases in width and becomes sinuous. It separates itself from the visceral mass and passes forward to the right of the latter beneath the floor of the pallial cavity. It is held in place by enveloping connective tissue, which fastens it to the right body wall. At the level of the anus an ovoid mass, consisting of the female accessory glands and a reservoir for sperms, occurs on the left of the duct. These accessory glands are small and poorly developed in young specimens, and only become fully developed when the animal is sexually mature.

The accessory genital mass comprises an albumen gland and a mucous or nidamental gland in connection with the female elements, and a spermatocyst (*spct.*) for storing the sperms introduced during copulation. The various parts are closely bound together, and owing to their brittle nature are difficult to separate in a preserved specimen. The little hermaphrodite duct passes forward to the right antero-ventral side of the mass and disappears from view. On turning up the glands, however, it is seen to become suddenly constricted (*lp.*), and the slender duct loops round a pear-shaped caecum, the spermatocyst. The duct then enters the mass, and its course can no longer be traced in surface view. The spermatocyst is a blind pouch which occupies the concavity of the hemispherical loop formed by the little hermaphrodite duct. It is usually densely packed with pure sperms. Its stalk or duct is bent in a figure S. It communicates with the central portion of the large hermaphrodite duct as described below.

Forming the anterior portion of the accessory genital mass is a much convoluted portion of the mucous gland (*wind. gl.*), called by Guiart the twisted or winding portion (glande contournée) and by Mazzarelli the "portion coiled like a ball of thread" (porzione a gomitolo). This is the first part of the voluminous mucous or nidamental gland which forms the outline of the accessory genital mass. If the folds of the winding portion be traced it can be seen that the narrow sinuous portion suddenly enlarges, opening into the smaller loop of the mucous gland (*muc. gl*^{1}.). After this small loop the mucous gland makes a larger loop, and discharges into the base of the large hermaphrodite duct on its sacculated right side. The surface of the mucous gland appears transversely striped owing to the presence of internal septa, arranged in a parallel fashion at right angles to the walls of the gland. The centre of the mass is occupied by an albumen gland (*alb. gl.*), which is greenish or yellowish in colour and forms a contrast to the whiteness of the mucous gland. Like the latter it shows transverse stripings due to internal septa, but these are less regular than those of the mucous gland.

The large hermaphrodite duct (*la. herm. d.*) arises from the right anterior portion of the genital mass, close to the point of entrance of the little hermaphrodite duct. It connects the accessory genital mass with the common genital aperture, conveys the egg ribbon and the sperms to the exterior, and receives the foreign sperm. All three products pass through the same aperture, which is undivided and is therefore described as monaulic, in contrast to the diaulic condition in *Tritonia*, where male and female ducts separate, and to the triaulic condition in *Doris*, where the male, female, and copulatory portions of the duct are distinct. The large hermaphrodite duct is divided into a posterior and anterior portion, the two being abruptly marked off both internally and externally. The posterior part lies between the accessory genital mass and the swelling called the bursa seminalis (*b. sem.*), the anterior part between the bursa and the external aperture. The former portion lies in the connective tissue beneath the sub-pallium, the latter is embedded in the muscles of the sub-pallium.

The posterior portion of the large hermaphrodite duct is divided longitudinally into two parallel divisions separated internally by folds, but readily discernible externally owing to a difference in appearance. The portion on the left, which is the vaginal portion of the duct (*vag.*), into which the penis is thrust during copulation, is straight, that on the right is thicker walled and sacculated (*od.*), and conveys the egg cordon to the exterior. The part along which the sperms pass on their way outwards is not visible externally.

At the anterior end of this portion of the duct a slight constriction occurs. On the left or vaginal side a glandular pouch, the bursa seminalis (*b. sem.*), is present ; on the right side the sacculations of the female portion disappear. Immediately anterior to the bursa enters the slender duct of a spherical vesicle, the spermatheca (receptaculum seminis, Swammerdam's vesicle, copulatory pouch of Guiart). The spermatheca (*spth.*) lies ventral to the pericardium, to the floor of which it is attached by connective tissue. Its wall is thin and the matted contents are of a purple or pinkish colour. The duct is so slender that unless care be taken it will be cut through in dissection and the vesicle left attached to the floor of the pericardium.

Anterior to the bursa seminalis there is no distinction externally between male and female portions of the duct, which narrows and becomes more muscular as it nears the external opening. Muscle bands encircle it, and also connect it with the sub-pallium, in which it becomes embedded.

The common genital aperture (*c. gen. ap.*) is situated on the right side of the body at the junction of the sub-pallium and the neck, at the level of the anterior insertion of the parapodium. There is here an abrupt change from unpigmented to pigmented skin.

Through the genital aperture pass (*a*) the sperms of the animal that produces them (this animal will be referred to as A), (*b*) the egg cordon of A, and (*c*) sperms from another individual B, for the fertilisation of the eggs produced by A.

From the genital orifice a shallow ciliated groove (*sem. gr.*) runs forward somewhat diagonally to the penis, situated at the base of the right anterior tentacle. This groove, the seminal or spermatic groove, is unpigmented. Its lateral walls are formed by projections of the body wall, the left fold being rounded in section, the right sharper and frilled. By approximation of the two folds, a tube is formed along which the sperms pass from the common genital aperture to the penis.

The penis (Fig. 19, *pn.*) is completely retractile within its sheath, but is not invaginable. It is a pedal structure. The sheath (*pn. s.*) is a muscular cul-de-sac whose blind end, to which the penis is attached, is posterior. The walls of the sheath are attached by numerous muscles to the body wall in this region, and there is a large retractor muscle situated posteriorly. On slitting up the sheath the penis itself is seen attached to the blind end by its base, with its free end directed forwards. In shape it is spatulate or like a leaf with the edges curled upwards. The surface is chitinised, but does not bear nodosities as in *Aplysia depilans* and *A. limacina.* A deep groove runs along its dorsal side. On the ventral side is a linear longitudinal groove of uniform diameter throughout. This is the seminal groove, which terminates close to the tip of the penis and can be traced backwards to its base, then forwards along the right ventral side of the penis sheath and over the edge of the penial aperture, where it is continuous with the lateral seminal groove on the exterior of the body. When the penis is everted by afflux of blood and relaxation of the muscles attached to its base, it is thrust from its sheath, the latter becoming evaginated. The seminal groove is thus straightened out. When the penis is withdrawn the groove becomes S shaped. There is no prostatic gland in *Aplysia punctata.*

It is now necessary to describe the internal structure of the parts of the reproductive system. The hermaphrodite gland is a racemose gland consisting of innumerable acini, each of which produces eggs and sperms, which, when ripe, are discharged into the cavity of the acinus. The various acini are connected with the little hermaphrodite duct. Young individuals are protandric and produce only sperms, but later both eggs and sperms are found in the same acinus, though the latter are always the more numerous. The ova are discharged in an unripe condition, so that their fertilisation by the sperms of the same individual is impossible at this stage. The ovum is a large cell with distinct nucleus and nucleolus, and is crowded with yolk granules. The sperms are produced in groups or bunches, fastened together by their heads. They are of the usual elongated type common amongst the Mollusca. The head of the mature active sperm is narrow and sinuous, its tail very long and slender. In the younger stages the head may bear a clear disc of protoplasm, or this may be distributed in the form of droplets along the course of the tail.

The cavity of the gonad, together with the renal and pericardial cavities, constitutes all that remains of the true coelom of *Aplysia.* The eggs and sperms are thus discharged into the coelom before making their way to the exterior.

The little hermaphrodite duct is thin-walled and is lined by a non-ciliated epithelium. According to the age of the animal and the condition at the time of death, the duct contains either pure sperm or mixed eggs and sperms. On reaching the level of the accessory genital mass it has already been noticed that a constriction occurs, and that the duct loops round the spermatocyst. At this point the epithelial lining of the duct becomes ciliated and a fold appears internally. (Fig. 20d, *lp.*) This fold later becomes the sperm fold, which is continuous from this point to the penis. As the duct plunges into the accessory genital mass it becomes extremely slender, and is difficult to trace in a hardened specimen. Very shortly after entering the mass the duct suddenly enlarges to form a large thin-walled chamber, whose inner walls are strongly ciliated. This is the fertilisation chamber (*fert. ch.*). Part of the albumen gland and of the winding portion of the mucous gland must be dissected away to expose it. By careful dissection it is seen that the sperm fold of the loop passes along the right side of the fertilisation chamber and so travels forward to the large hermaphrodite duct. Its course will be traced later.

The fertilisation chamber receives the discharge of the albumen gland, whose walls are very thick, with parallel septa arising from the internal walls in order to increase the secretory surface. The cells stain deeply. Leaving the chamber on its left side is a short thin-walled duct leading to the winding portion of the mucous gland. The winding portion, as has been already seen, is continuous with the small and large loops of the mucous gland. Both the winding and the loop-like portions stain feebly in contrast to the albumen gland. Parallel septa occur in the looped portion.

The large hermaphrodite duct leaves the mass on its right side. If the duct be split up longitudinally along its ventral side the connection between the various parts can be traced. The oviducal portion can be followed from the accessory genital mass to the external aperture, but the sperm duct and vaginal duct are best traced backwards from the external aperture. The anterior portion of the large hermaphrodite duct (i.e., the part between the bursa seminalis and the external genital aperture) consists of two chambers (Fig. 20a and 20b), a large one (*vag.*) into which the penis of the copulating individual is thrust and out of which passes the egg string, and a small portion (*int. sem. gr.*) partly cut off from the former by paired folds which are continuous with those of the spermatic groove. These are the vaginal or copulatory duct and the spermatic duct respectively. The spermatic groove leaves the genital aperture on its right side, but within the duct it passes dorsalwards and to the left, reaching the latter position posterior to the entrance of the duct of the spermatheca. The groove becomes less distinct as it is traced backwards, though its identity is clear in sections owing to the fact that the cells are of greater height and more strongly ciliated than are those of the rest of the duct. The groove is continuous with the channel along one side of the fertilisation chamber (Fig. 20d), and so with the fold that arises in the loop of the little hermaphrodite duct.

The vaginal portion of the large hermaphrodite duct lies on the left of the duct near the opening, the penis entering it from the left during copulation. In its anterior portion the walls are only slightly folded. It is connected with the lateral pocket or bursa seminalis. The walls of the bursa are composed of tubular glands (Fig. 20b, *b. sem. gl.*) which discharge into the cavity of the bursa. The duct of the spermatheca (*spth. d.*) enters the bursa anteriorly. The spermatheca (Swammerdam's vesicle) is thin walled, and both vesicle and duct are ciliated internally. The vesicle is rarely empty, but usually contains a mass of waste matter agglutinated together by the secretion from the glands of the bursa. The contents consist of effete eggs, granules of yolk and albumen, and a few sperms.

Just as the spermatic portion of the duct crosses from right to left of the large hermaphrodite duct, so the vaginal or copulatory portion crosses from the left to the ventral side. It is difficult to trace the vaginal duct with accuracy by the ordinary methods of dissection. The investigation was carried out in the following way. The penis of an individual acting as male was cut as close to its base as possible during copulation. The "female" was then killed, and the reproductive apparatus removed and sectioned with the penis still within the vagina. It was found that the penis penetrated much further into the large hermaphrodite duct than is usually stated. Mazzarelli describes it as reaching to the level of the bursa, and discharging its sperms in an impure condition into the duct leading to the spermatheca. It was found, however, that the tip of the penis was thrust into the vaginal pocket (*vag. p.*) leading to the spermatocyst, i.e., almost to the base of the large hermaphrodite duct. It was held in place, not only by the folds separating the copulatory duct from the sperm duct and oviduct, but by a double fold, within the trough of which it lay, arising from the wall of the copulatory duct. From the pocket a double fold runs into the tortuous stalk of the spermatocyst. The stalk also communicates, along the opposite side of the fold, with the base of the large hermaphrodite duct and so with the fertilisation chamber. Sections show that in this region the oviduct and sperm duct are together separated by a complete partition from the copulatory duct, which leads to the spermatocyst. The latter, therefore, receives foreign sperm, and is not a vesicula seminalis in the true sense of the word. The same conclusion follows from an injection of the vaginal duct through the external aperture by means of a glass pipette drawn out to a very fine point. The injection (Prussian blue) ran into the bursa, overflowed into the duct of the spermatheca, reached the stalk of the spermatocyst, and finally entered the fertilisation chamber, whence it arrived at the albumen and mucous glands. By dissecting out the apparatus in a freshly-killed animal before injecting, the order in which the injection mass reached the various portions was ascertained.

There remains only the oviduct (*od.*). This, on leaving the mucous gland, passes up along the right side of the large hermaphrodite duct. Its walls are thick, glandular and sacculated, especially during the breeding season. Internally numerous folds project inwards and so increase the glandular surface. The glands probably secrete a fluid which lubricates the passage and so aids in the extrusion of the egg cordon. It has already been noted that the sacculations disappear at the level of the bursa seminalis, and that the anterior portion contains only a vaginal and a spermatic duct.

The spermatic groove is strongly ciliated. The surface of the penis is covered with a ciliated epithelium, the cilia being longest within the sperm groove. Numerous unicellular glands open on the surface and secrete a lubricating fluid. In some places a depression occurs, and a number of glands open into the crypt so formed. The interior of the penis consists of loose tissue with large blood spaces. By the rapid filling of these spaces with blood, aided by muscular action, the penis becomes tense and is thrust out of its sheath, appearing large and swollen. Interlacing muscle fibres occur, but the main muscle is a stout hollow band which occupies the centre of the penis and is continuous with the retractor muscle at the base of the sheath.

Copulation and Oviposition.

It is often the case in hermaphrodite animals (e.g., Earthworm, many Gastropods) that the passage of sperms from one individual A to another individual B is effected simultaneously with the passage of sperms from B to A. The possibility of this depends to a large extent upon the relative positions of the male and female apertures, which must be so arranged that lateral coupling can take place. In *Aplysia* the mutual interchange of reproductive elements between two individuals does not occur, and if only two individuals come together one acts as male and the other as female. After an interval the rôles may be reversed. Usually, however, a far more remarkable thing takes place. A number of individuals, varying from three to as many as ten, form a chain. (Fig. 5.) A member of the chain fixes itself above and behind the preceding member of the chain. The lowermost individual of the series acts as female only, the topmost as male only, and all the intermediate ones function as male for the preceding (i.e., lower) and female for the succeeding (i.e., higher) individual of the chain.*

Copulation may be observed in *Aplysia punctata* in spring or in late summer. The first individual of the chain (A) fixes itself by its foot to weed or rock. Individual B crawls over the visceral hump of A and takes up a position with the aperture of the penis on a level with the common genital aperture of A. B then attaches the anterior portion of its foot to the mantle of A and grasps it with considerable tenacity. The posterior part of the foot of B, however, remains free and

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* Coupling in chains occurs also in other Gastropods, e.g., *Crepidula.*

curls round the "tail" of A. The parapodial lobes of A open widely and embrace the body of B, but the anal spout protrudes. The penis of B is then thrust from its sheath and curves downwards and backwards in the form of an inverted U, to be inserted into the common genital aperture (vaginal portion) of A. The whole of the penis is thrust into the vagina and reaches to the base of the vaginal pocket close to the spermatocyst, as already described. Sperms pass along the spermatic groove of B, along the penis groove, and into the vaginal cavity of A. Individual C, in the same way, inserts the penis into the vagina of B, fixing itself above and behind B. Owing to the curvature of the body of each of the individuals forming the chain, a large chain rolls itself almost into a ball. The coupling lasts for several hours or even days. Judging by the emptiness of the spermatic groove in many individuals that were examined during the long coupling period it is probable that the actual passage of the sperms takes place in a few minutes.

There is always a certain amount of debris introduced with the sperms, and this, agglutinated by the secretion of the glands lining the wall of the bursa seminalis, is drawn up into the spermatheca, where it is either absorbed or discharged through the external aperture. No satisfactory evidence, however, has been obtained on this point. The sperms travel down the vagina to be stored in the spermatocyst at its base. It is not known where the separation of detritus from pure sperm takes place. Mazzarelli states that the spermatheca receives all the spermatic fluid, but the description given above shows that this is not the case. Further, the spermatheca never contains many sperms either during the quiescent period or immediately after copulation. Whenever, however, the spermatheca is full of detritus the spermatocyst is full of pure sperm. It seems probable, therefore, that the separation of the detritus from the pure sperm takes place on their entry into the vagina, and not after an interval. This would be effected by the motility of the sperms, enabling them to wriggle free from the waste matter and make their way down to the spermatocyst, either along the penial groove or down the vagina itself.

During the coupling it is not unusual for the female to extrude the egg cordon, or the eggs may be laid some hours after the individuals have separated. Fertilisation takes place within the fertilisation chamber by sperms from the spermatocyst meeting the eggs which have just entered by the little hermaphrodite duct. The albumen gland provides the eggs with a coating of albumen, but as eggs are not found within this gland, it is inferred that the albumen gland discharges its secretion into the fertilisation chamber. The eggs then leave the fertilisation chamber and enter the winding portion of the mucous gland, pass through the smaller of the loops of the mucous gland, and finally through the large loop of the same gland. Here a group of from six to ten eggs is provided with a clear gelatinous capsule, the shells are coated with mucus and the balls so formed are strung together to make the cylindrical egg string. It is not known, however, what portion of the mucous gland makes the shell, though the natural inference is that the winding portion does so. The cordon passes out by the oviduct, whose glandular walls secrete a lubricating fluid. On leaving the common genital aperture the cordon often makes use of the spermatic groove as a guide, so that the eggs may even appear to come from the penial aperture. More frequently, however, the string becomes free about an inch in front of the genital orifice, distorting the spermatic groove at the point where it does so. It is thus possible to infer, from the presence of the crinkle in the otherwise smooth groove, that oviposition has recently taken place.

The egg string is not extruded continuously, but in little spurts of about an inch at a time "like paying out lengths of cable." As it frees itself it curls backwards and forwards, forming an orange or pink tangled mass on or around the weed. Deposition usually takes place at night in the aquarium. The number of eggs in a single cordon is always very large. Fischer measured an egg string eighteen metres in length, and estimated that it contained about 108,000 eggs. Relatively few of these, however, will reach maturity. In addition to the hazards of a pelagic larval period and of the metamorphosis, the spawn is often eaten by Crustacea, and it is said that *Aplysia* itself will consume its own mutilated egg strings.

The account given above of the function of the spermatocyst and spermatheca agrees in the main with that described by Eliot for *Doris*, where the genital apparatus is triaulic and therefore less complicated. It differs from the description given by Mazzarelli and by Guiart of the reproductive apparatus of *Aplysia*. Mazzarelli* did not find the connection between the external seminal groove and the little hermaphrodite duct, but states that the sperms pass out by the oviduct. He describes the penis as being directed by a fold so that the sperms enter the spermatheca, whose function is to purify the sperms from extraneous matter. The sperms, he says, then pass in the pure condition to the spermatocyst. The above description shows, however, that the sperms pass out by a continuous groove from the little hermaphrodite duct to the external seminal groove, and examination of large numbers of individuals immediately after copulation revealed only a negligible quantity of sperm in the spermatheca, and pure sperm, in an active condition, in the spermatocyst.

Guiart,† on the other hand, homologises the spermatocyst of *Aplysia* with that of other Opisthobranchs, and says that it is a true vesicula seminalis and does not open into the vagina.

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* Mazzarelli, G. "Monografia delle Aplysiidae del Golfo di Napoli." Mem. Soc. Ital. Scienze, 3, IX, 1893, p. 120.

† Guiart, J. "Contributions à l'étude des Gastéropodes Opisthobranches et en particulier des Cephalaspides." Mem. Soc. Zool., France, 1901.

It should be noted that a spermatheca and spermatocyst occur on the vaginal portion of the reproductive apparatus of certain Prosobranchs, as described by Bourne* in the Neritacea. Here the spermatheca (sperm sac) receives spermatophores, whose sperms when liberated pass into the spermatocyst (receptaculum seminis). A duct of unknown function, called by Bourne the ductus enigmaticus, is thought by him to serve for conveying the debris to the exterior.

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EXPLANATION OF PLATES.

Reference Letters.

abd. ao. = Abdominal aorta.

aff. br. = Afferent branchial vessel.

alb. gl. = Albumen gland.

an. = Anus.

an. f. = Anal funnel.

an. in. = Anal incision in shell.

an. n. = Anal nerve (E2).

ant. ao. = Anterior aorta.

ant. giz. = Anterior portion of gizzard (first triturating stomach).

ant. giz. t. = Tooth of anterior portion of gizzard.

ant. ped. a. = Anterior pedal artery.

ant. ped. gl. = Anterior pedal gland.

ant. tent. = Anterior tentacle.

ant. tent. a. = Anterior tentacular artery.

ant. tent. n. = Anterior tentacular nerve.

ap. pn. = External aperture of penis sheath.

aud. n. = Auditory nerve (A6).

aur. = Auricle.

b. sem. = Bursa seminalis.

b. sem. gl. = Glands of bursa seminalis.

b. w. a. = Artery to body wall.

bas. m. = Basal muscles of buccal mass.

br. g. = Branchial ganglion.

br. n. = Branchial nerve (D2).

br. n^1. = Nerve to ctenidium.

buc. cav. = Cavity of buccal mass.

buc. f. = Buccal fold.

buc. g. = Buccal ganglion.

buc. m. = Buccal mass.

buc. n. 2 = Nerve to basal muscles of buccal mass (F2).

buc. n. 3 = Nerve to lateral muscles of buccal mass (F3).

c. buc. conn. = Cerebro-buccal connective.

c. comm. = Cerebral commissure.

c. g. = Cerebral ganglion.

c. gen. ap. = Common genital aperture.

c. pl. conn. = Cerebro-pleural connective.

caec. = Caecum.

caec. a. = Caecal artery.

caec. v. = Caecal valve.

cart. = " Cartilage " of odontophore.

centr. t. = Central tooth of radula.

ceph. a. = Cephalic artery.

con. = Concavity of shell into which liver projects.

conn. = Connective tissue.

cr. = Crop.

cr. ao. = Crista aortae.

ct. = Ctenidium.

d. hep. a. = Deep hepatic artery.

dors. a. = Dorsal artery.

dors. b. w. = Dorsal body wall.

e. = Eye.

eff. br. = Efferent branchial vessel.

eff. ren. = Efferent renal vessel.

f. = Foot.

fert. ch. = Fertilisation chamber.

g. oes. a. = Gastro-oesophageal artery.

g. oes. n. = Gastro-oesophageal nerve (E1).

gen. a. = Genital artery (from anterior aorta).

gen. a^1. = Genital artery (from abdominal aorta).

gen. g. = Genital ganglion.

gen. n. = Genital nerve (E3).

gt. = Gutter between mouth and foot.

haem. = Haemocoele.
hep. int. a. = Hepato-intestinal artery.
herm. gl. = Hermaphrodite gland.
int. = Intestine.
int. sem. gr. = Internal seminal groove.
l. bd. = Left bile duct.
l. m. o. = Longitudinal muscles of odontophore.
l. ped. m. = Longitudinal muscle band of foot.
l. pl. visc. conn. = Left pleuro-visceral connective.
l. sal. gl. = Left salivary gland.
l. sal. oes. n. = Nerve to left salivary gland and oesophagus (F4).
l. stom. v. = Left valve of stomach.
la. herm. d. = Large hermaphrodite duct.
lat. t. 1 = First lateral tooth of radula.
lat. t. 2 = Second lateral tooth of radula.
lit. herm. d. = Little hermaphrodite duct.
liv. = Liver.
lp. = Loop of little hermaphrodite duct.
m. = Mouth.
mand. = Mandible.
mant. = Mantle.
mant. f. = Mantle fold enveloping shell.
mant. n. = Mantle nerve (E4).
mant. r. = Mantle roof.
mant. sin. = Sinus from mantle to haemocoele.
muc. gl. = Mucous gland.
muc. gl'. = Small loop of mucous gland.
ne. a. = Neural artery.
o. m. = Muscles of odontophore.
od. = Oviducal portion of large hermaphrodite duct.
oes. = Oesophagus.
op. gl. = Opaline gland.
op. gl. a. = Artery to opaline gland.
opt. a. = Optic artery.
opt. n. = Optic Nerve (A4).
ot. = Otocyst.
p. giz. = Posterior portion of gizzard (second triturating stomach).
p. gl. = Purple gland.
p. gl. n. = Nerve to purple gland.
pall. cav. = Pallial cavity.
par. g. = Parietal ganglion.
para. = Parapodium.
para. a. = Parapodial artery.
para. b. = Cut base of parapodium.
para. n. 1 = Large parapodial nerve (C4)
para. n. 2 = Small parapodial nerve (C6).
para. ped. comm. = Parapedal commissure.
para. sin. = Parapodial sinus.
pc. = Pericardium.
pc. n. = Pericardial nerve (D3).
ped. a. = Pedal artery.
ped. comm. = Pedal commissure.
ped. g. = Pedal ganglion.
ped. gl. = Pedal glands.
ped. lac. = Pedal lacunae.
ped. n. 2 = Middle pedal nerve (C7).
ped. n. 3 = Posterior pedal nerve (C8).
peribuc. a. = Peribuccal artery.
ph. can. = Pharyngeal canal.
ph. can. n. = Nerve to pharyngeal canal.
ph. cr. = Pharyngeal crest.
pl. g. = Pleural ganglion.
pl. ped. conn. = Pleuro-pedal connective.
pn. = Penis.
pn. a. = Penial artery.
pn. s. = Penis sheath.
post. ped. gl. = Posterior pedal gland.
pz. = Brush cell (Pinselzelle).
r. bd. = Right bile duct.
r. oes. n. = Right oesophageal nerve.

r. pl. visc. conn. = Right pleuro-visceral connective.

r. post. ped. a. = Right posterior pedal artery.

r. sal. d. = Right salivary duct.

r. sal. n. = Nerve to right salivary gland.

rad. = Radula.

rad. a. = Radular artery.

rad. n. = Radular nerve (F1).

rad. s. = Radular sac.

rect. = Rectum.

ren. n. = Renal nerve.

ren. mant. sin. = Sinus to kidney from mantle.

ren. p. = Renal pore.

ren. peri. sin. = Sinus to kidney from roof of pericardium.

ren. s. = kidney.

ren. sin. = Main renal sinus.

ret. mant. = Retractor muscle of visceral hump.

ret. pn. = Retractor penis muscle.

rh. = Rhinophore.

rh. a. = Artery to rhinophore.

rh. n. = Nerve to rhinophore (A3).

ros. = Rostrum of shell.

s. hep. a. = Superficial hepatic artery.

sal. ap. = Aperture of salivary duct (left).

sem. gr. = External seminal groove.

sem. gr. a. = Artery to seminal groove.

sh. = Shell.

sh. ap. = Shell aperture in mantle.

sh. f. = Shell forming region of mantle.

sin. 1 = Sinus from left anterior body wall.

sin. 2 = Sinus from left anterior portion of haemocoele.

sin. 3 = Sinus from posterior portion of haemocoele.

sin. 4 = Sinus from right body wall.

sin. 5 = Sinus from anterior portion of haemocoele.

spct. = Spermatocyst.

spth. = Spermatheca.

spth. a. = Artery to spermatheca.

spth. d. = Duct of spermatheca.

spth. n. = Spermathecal nerve (D4).

stom. = Stomach.

sup. ped. gl. = Supra-pedal gland.

t. m. o. = Transverse muscles of odontophore.

teg. n. 1 = Anterior tegumentary nerve (A1).

teg. n. 2 = Tegumentary nerve (A5).

teg. n. 3 = Tegumentary nerve (B1).

teg. n. 4 = Tegumentary nerve (B2), left side only.

teg. n. 7 = Tegmentary nerve (C5).

vag. = Vaginal portion of large hermaphrodite duct.

vag. p. = Vaginal pocket for tip of penis.

ventr. = Ventricle.

visc. g. = Visceral ganglion.

vul. n. = Vulvar nerve (D1).

wind. gl. = Convoluted portion of mucous gland.

PLATE I.

[All the figures are of *Aplysia punctata.* Unless stated otherwise the drawings are of full-grown specimens.]

Fig. 1. Right lateral view of the living animal in the expanded condition. × ½.

Fig. 2. Left lateral view of the head of the living animal. Expanded. × ½.

Fig. 3. Front view of the head of the living animal. × ½.

Fig. 4. Side view of the living animal in the contracted condition. × ½.

Fig. 5. Chain of three individuals. Drawn from life from a chain of five individuals seen in the tanks at the Laboratory, Plymouth. The lowermost individual A is acting as female only. B is acting as male for A, but as female for C, while C is acting as male only. The parapodium of A has been turned back to show the penis of B curved backwards to enter the common genital aperture of A. × ½.

Fig. 6. Shell from ventral aspect. The dotted lines represent lines of growth. × 1.

Fig. 7. The mantle and pallial complex from the dorsal aspect. The parapodia have been cut close to the base, and the edge of the mantle has been reflected to expose the purple gland. × 1.

PLATE II.

Fig. 8. General dissection from the dorsal side to show the alimentary canal and reproductive apparatus. Part of the nervous system is shown. Only the outline of the liver is seen; the remainder has been dissected away to expose the coils of the intestine. Stripings on the gut represent the direction of the muscle fibres where these are visible externally. × 2·5.

PLATE III.

Fig. 9. Longitudinal optical section of the head to show the interior of the buccal mass. The pharyngeal crests, arising from the walls of the pharyngeal canal, are not shown. (See Fig. 22.) × 2·5.

Fig. 10. Posterior view of five teeth of the radula. Drawn under the Edinger Projection Apparatus. × 70.

Fig. 11. Three teeth from the gizzard. *a* and *b* are from the anterior and *c* from the posterior portion of the gizzard. × 3.

Fig. 12. Dissection of the stomach, caecum and the beginning of the intestine, from the ventral side. The portion from A to B, with the exception of the intestine, is embedded in the visceral mass, which has been dissected away to expose it. The intestine comes to the surface and lies in a channel on the surface of the visceral mass. The stomach, intestine, caecum, and the left bile duct have been cut open longitudinally. × 3.

Fig. 14. Dissection to show the afferent and efferent vessels of the ctenidium. The kidney has been partly cut away to expose the heart. The efferent renal vessels lie on the ventral side of the kidney. × 1·75.

Fig. 15. Dissection to show the kidney and renal portal system. From an injected specimen. The afferent renal vessels lie on the dorsal surface of the kidney. × 1.

Fig. 17. Dissection of stomato-gastric system as seen from the ventral side of the buccal mass. The cerebral and pedal ganglia, pedal and parapedal commissures are shown, but the cerebral ganglia have been separated from one another and their commissures cut. × 3·5.

PLATE IV.

Fig. 13. General dissection from the dorsal side to show the heart and blood vascular system. Other organs are shown only where necessary to demonstrate the relations of the parts. The genital annexe has been displaced backwards. The position of the genital artery relative to the hermaphrodite duct is variable. The cerebral ganglia are not shown, and the pleural and pedal ganglia have been laterally displaced. × 2·5.

PLATE V.

Fig. 16. General dissection of the nervous system from the dorsal side. The stomato-gastric ganglia and nerves are not shown. The branchial and genital ganglia have been isolated from the organs they innervate. Cerebral nerves 1, 3, 4, 6 are shown on the left side, nerves 2, 5, 6 on the right. The distribution of the first three nerves from the pedal ganglion, all of which run ventral to the buccal mass, is not shown. The remaining pedal nerves are shown on the right side only. × 2·5.

PLATE VI.

Fig. 18. Ventral view of the accessory genital organs. The hermaphrodite gland and external portions of the male apparatus are not shown. × 2·5.

Fig. 19. Dissection of male copulatory organ from the dorsal aspect. × 3.

Fig. 20. Scheme of the reproductive apparatus as seen from the ventral side. The various portions of the accessory genital mass have been separated to show the course taken by the genital elements. The external portions of the male apparatus are not shown.

(*a*) Transverse section of the large hermaphrodite duct with the penis in situ. The section is taken along the line *a* on the schematic figure. In this and succeeding sections the dorsal side of the section is uppermost in each case.

(*b*) Transverse section of the large hermaphrodite duct along the line *b*, viz.: through the bursa seminalis and entrance of the spermathecal duct.

(*c*) Transverse section of the large hermaphrodite duct along the line *c*.

(*d*) Transverse section of the accessory genital mass along the line *d*.

In these sections note the travelling of the seminal groove from ventral to dorsal sides of the large hermaphrodite duct until in section *c* it no longer lies in the wall of the duct, but passes over into a fold from the wall. In section *c* there are therefore three tracts within the large duct, viz.: the oviducal portion and the seminal groove, both carrying the genital elements of individual A, and the vaginal portion which receives the penis, and with it the sperms, of individual B. There is not, however, a complete partition between these three portions. In section *d* the sperm groove and oviducal portion are separated completely from the portion receiving the sperm of individual B. The entrance of the spermatocyst into the fertilisation chamber is not shown. All sections drawn under the Edinger Projection Apparatus. × 20.

Plate VII.

Fig. 21. Transverse section of a young individual, 9 mm. in length when preserved. (The specimen was much contracted.) The section passes through the visceral hump, above which lie the mantle cavity, the mantle, and the shell. Note that there are differences between this and the adult stage, e.g., the upward projections of the mantle have not yet enclosed the shell, the opaline gland is proportionately much larger and the purple gland smaller than in the adult. The connective tissue surrounding the organs is not shown. The section was drawn under the Edinger Projection Apparatus and is slightly diagrammatic. × 10·5.

Fig. 22. Transverse section of the same individual as Fig. 21 passing through the buccal mass. The radula is imperfectly developed. × 10·5.

Fig. 23. Semidiagrammatic transverse section to show the relations of the ganglia forming the circum-oesophageal ring. The cerebro-pedal connectives are not shown. The drawing has been made by projecting structures occurring in five consecutive sections each 10 μ thick into one plane. The telescoping chiefly affects the buccal ganglia, which are situated slightly anterior to the other parts. Drawn under the Edinger Projection Apparatus from the same individual as the two preceding figures. × 10·5.

Fig. 24. Transverse section through the "tail" region of an adult specimen to show the posterior pedal gland. The gland consists of paired invaginations of the foot opening by separate ducts to the exterior. The section is somewhat oblique so that the duct of the right portion of the gland is shown, but not that of the left. × 34.

Fig. 1.

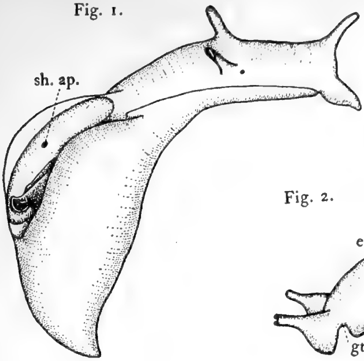
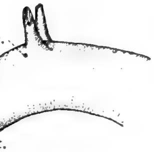


Fig. 3.

Fig. 2.



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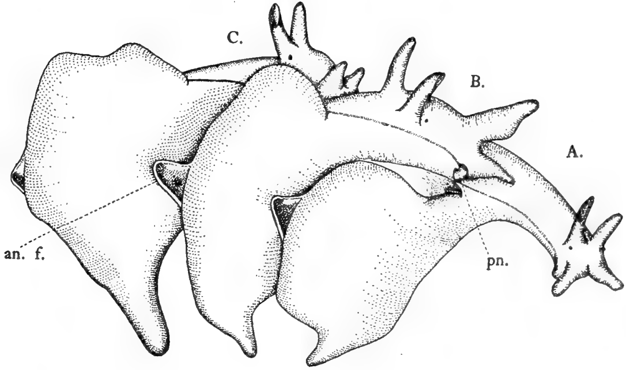

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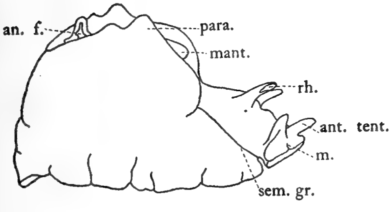

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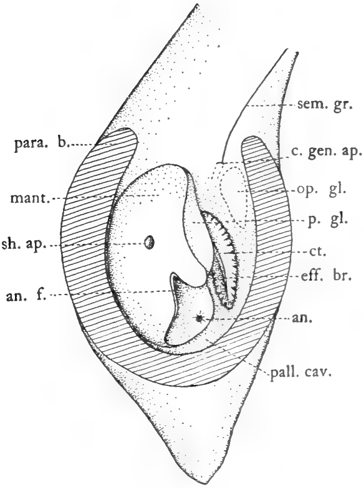

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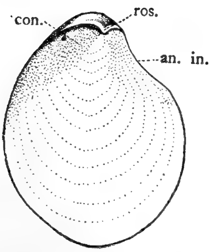

N. B. E. del.

APLYSIA

Fig. 8.

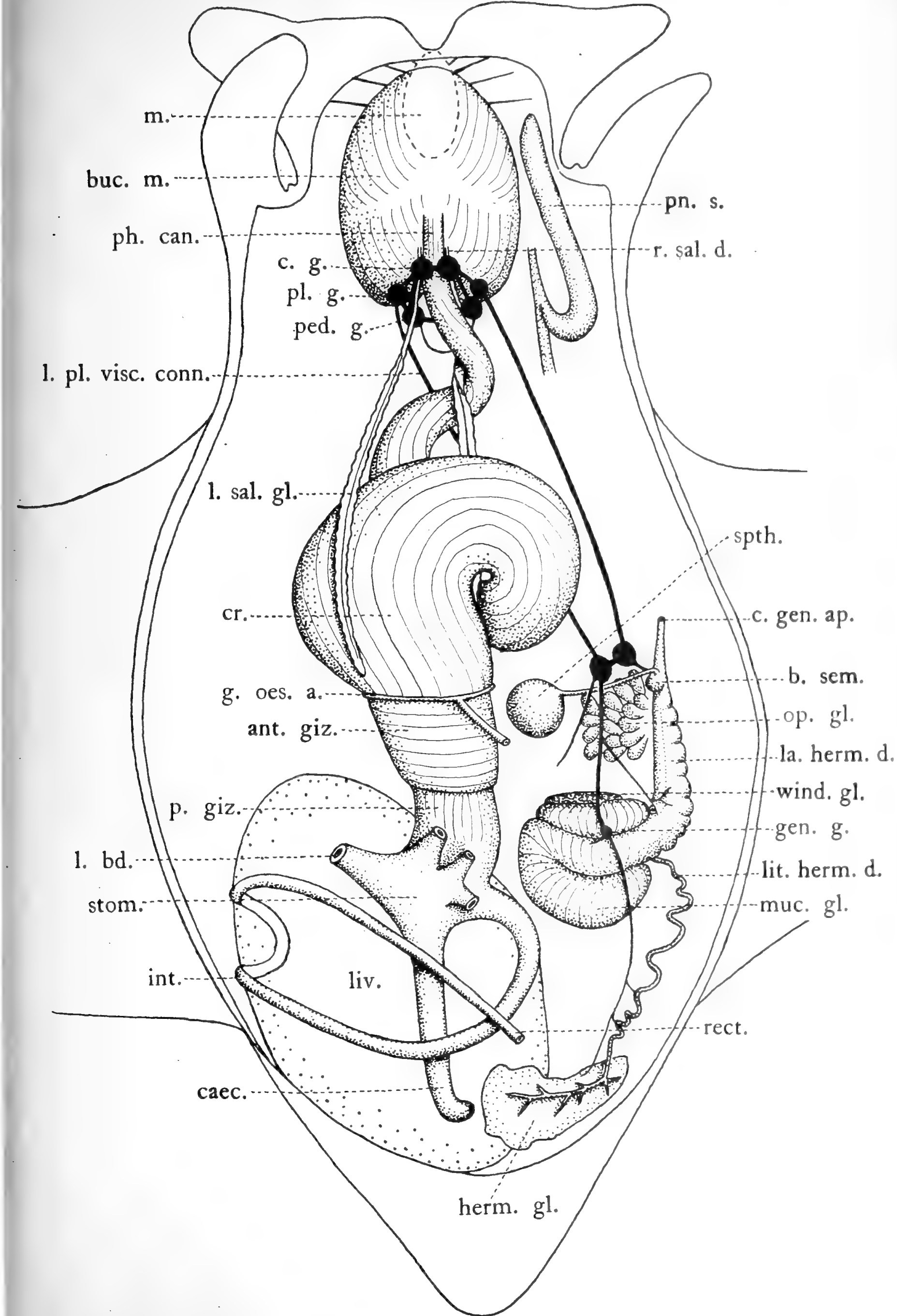

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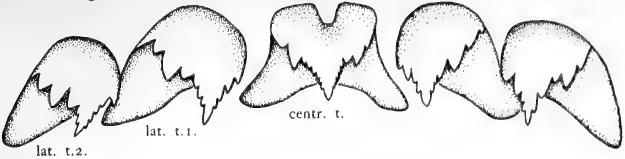
Fig. 10.



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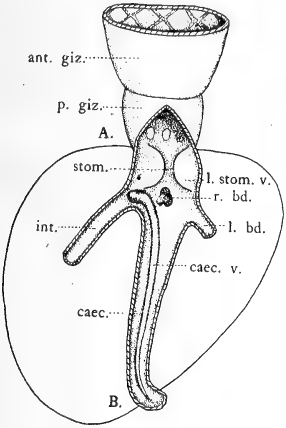

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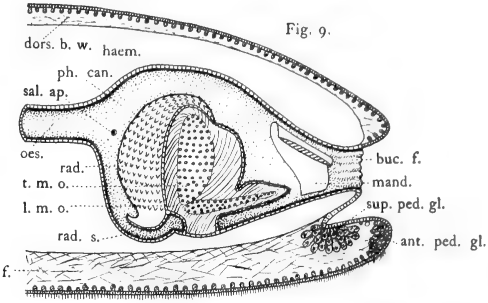

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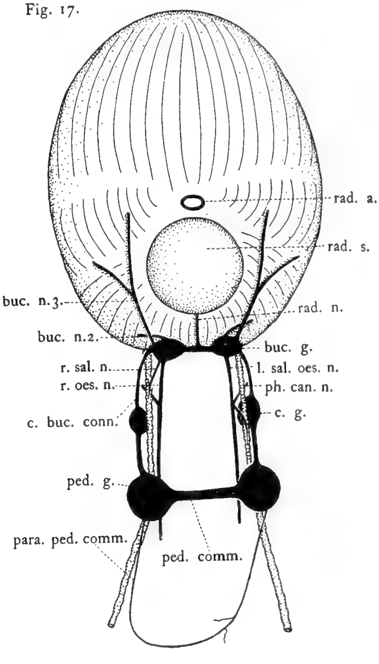

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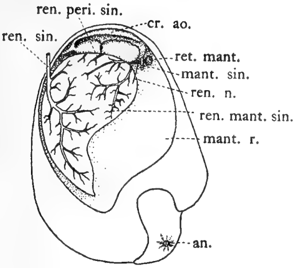

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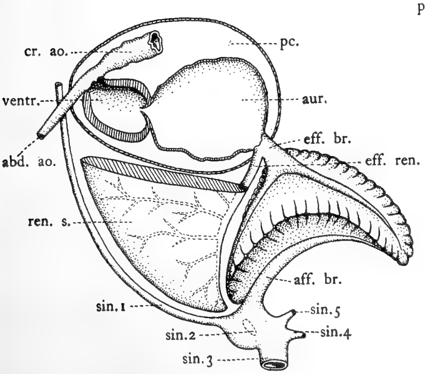

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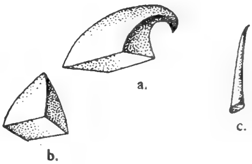

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Fig. 13.

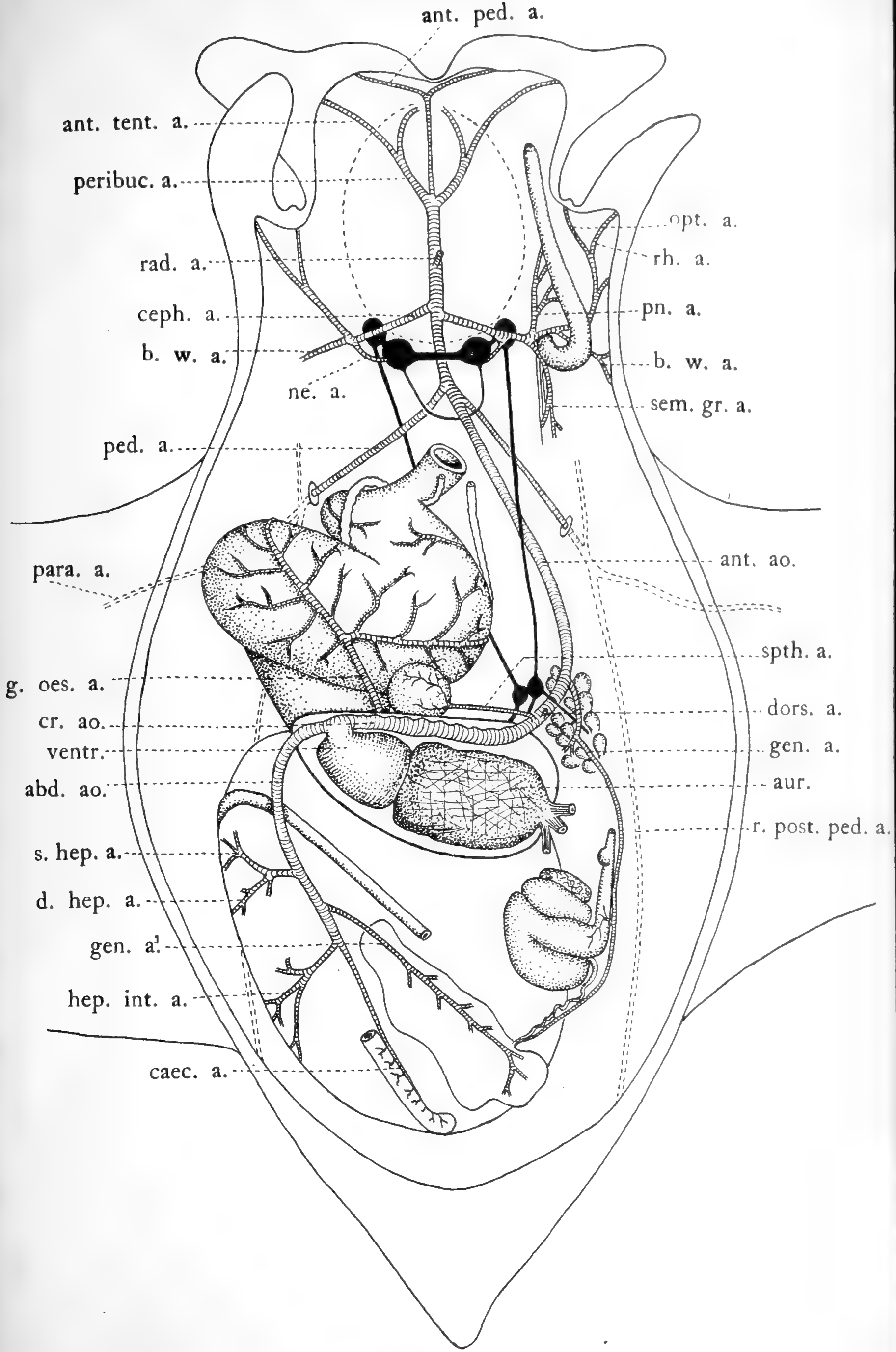

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Fig. 16.

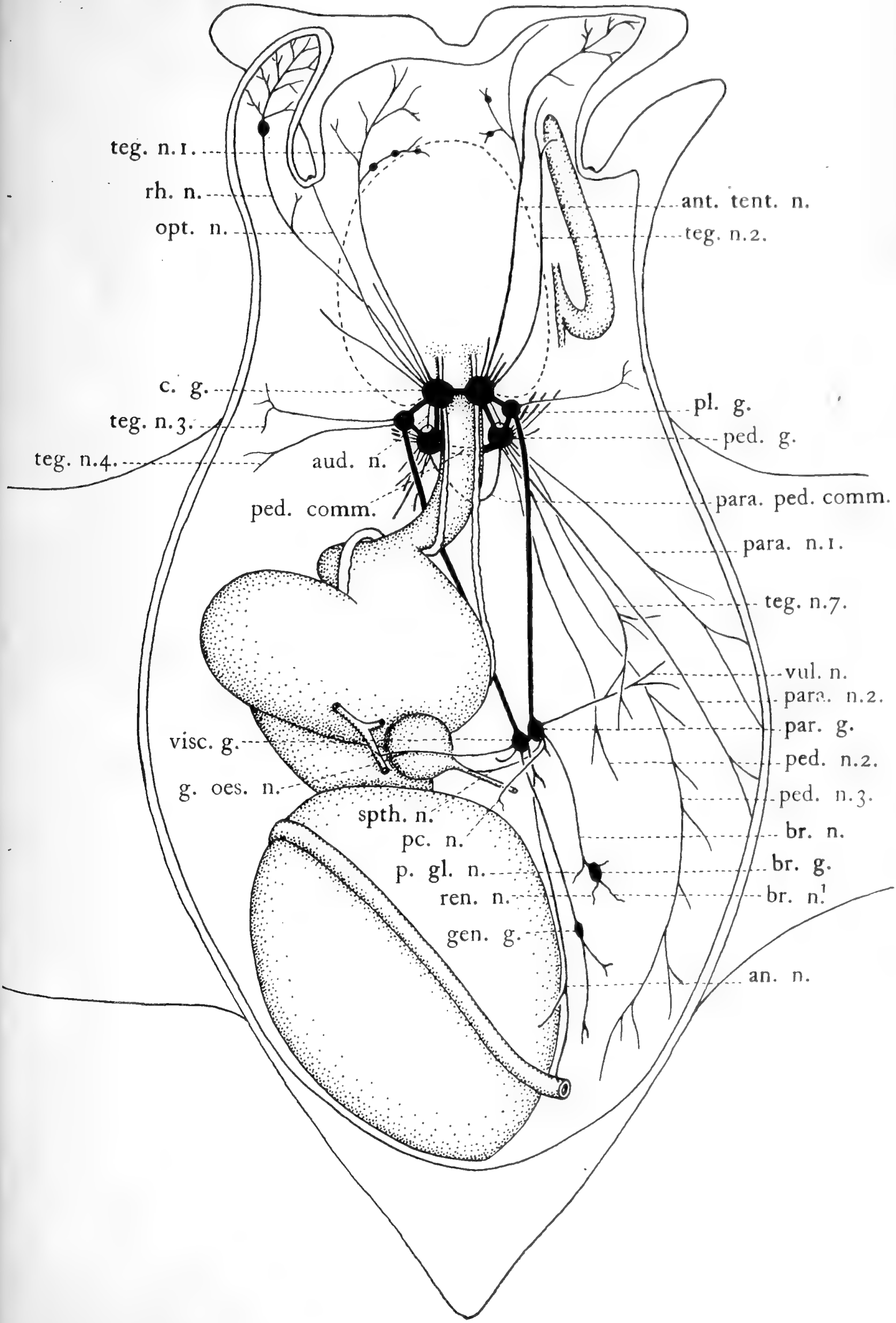

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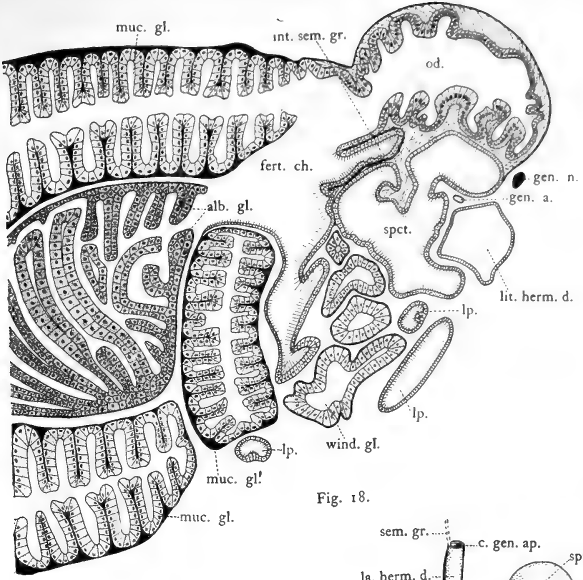
Fig. 20. d.



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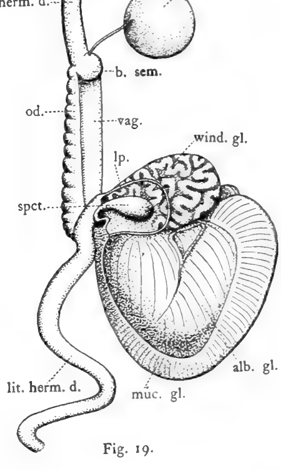

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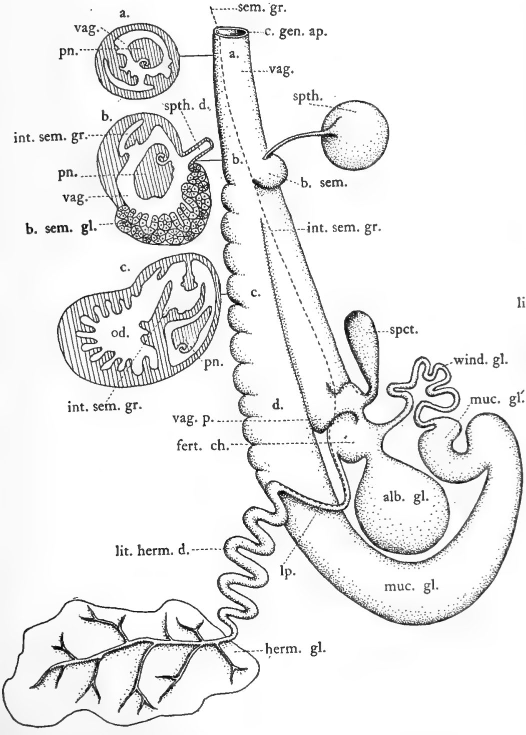

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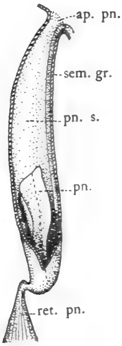

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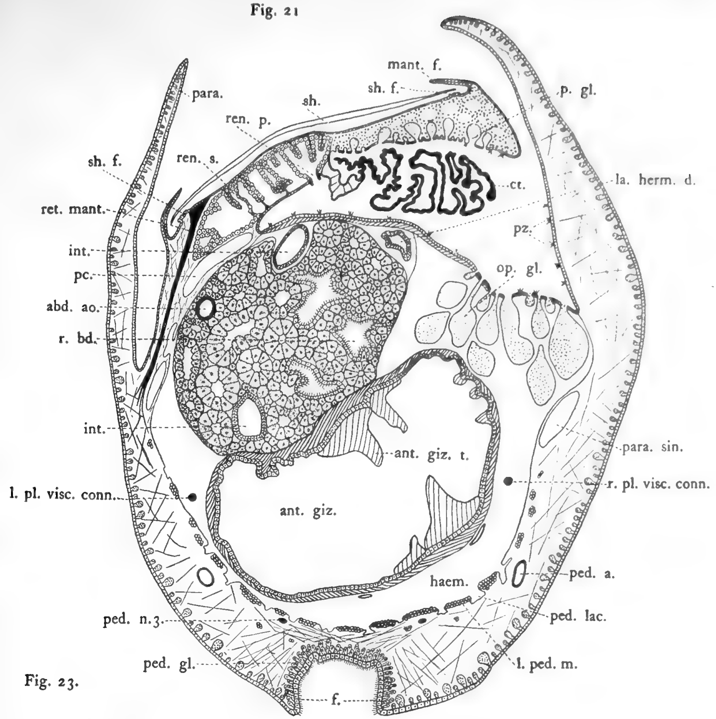
Fig. 21



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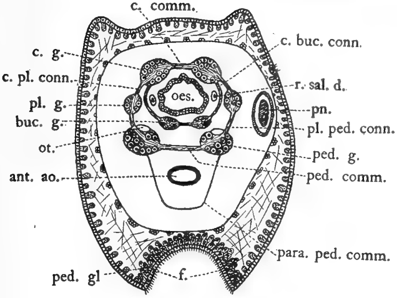

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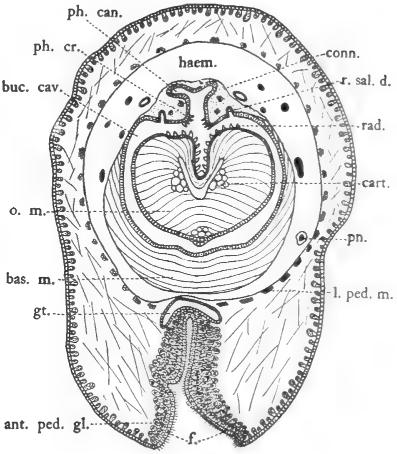

Fig. 24.