were challenged, and in that time, so far as I have learned, no single implement has been reported from the gravels, although the exposures are as extensive as they ever were. The first chapter in the prolonged search for glacial man at Trenton may, therefore, be regarded as practically closed; but some new evidence furnished by examination of certain superficial deposits of sand come up for consideration. My remarks upon this subject will appear in a subsequent number of SCIENCE.

W. H. HOLMES.

U. S. NATIONAL MUSEUM.

ON SOME IMPORTANT SOURCES OF ERROR IN THE PLANKTON METHOD.

THE Hensen method of plankton collection consists essentially in drawing a silk net vertically through the water. A part of the column of water traversed by the net is pushed aside, hence the actual catch must be multiplied by some factor to obtain the amount of plankton present in the given column of water. This factor, 'the coefficient of the net,' has been calculated by Hensen, for a series of velocities, from empirical data, and is applied uniformly to all catches without regard to the character of the plankton. The coefficient of the net used at the Illinois Biological Station, according to Hensen's formula, is 1.32 (velocity 0.5 meter per second). A series of field tests in which a column of water, similar to that traversed by the net was pumped and strained, indicates that the coefficient of the net varies with the amount and constituency of the plankton, ranging in the case of our net from 1.5 to 5.7. This variation is, in part at least, due to the increased clogging in the case of heavy planktons. The effect of the progressive clogging upon the coefficient is shown in a series of horizontal hauls of 5, 10, 15, 20 and 25 meters, which were made successively in similar water. The coefficient rose from 1.5 in the 5-meter haul to 4.83 in the 25-meter haul. A comparison of 15-meter hauls with those of 30 meters indicates that from 84% to 96% of the 30-meter catch is taken in the first 15 meters of the haul. Four places of decimals in a computed coefficient can hardly offer compensation for an error so fundemental as the variation in the straining capacity of the net. This error can be avoided by adoption of the pumping method and straining of a known quantity of water.

The plankton method as elaborated by Hensen and others depends upon the efficiency of the finest silk bolting cloth in removing the contained organisms from the water which it filters. It has been accepted by planktologists that the use of this cloth furnishes a satisfactory basis for the volumetric determination of the plankton and the enumeration of its constituent organisms. Hensen* (p. 75) states that the openings in the silk are so small that not many organisms can pass through them. Apstein† (p. 235) says: "With nets of this cloth almost all organisms are caught, only a few diatoms, which happen to meet an opening with their long axis, escape." Again‡ (p. 35) he maintains that almost all organisms are removed from the water by the use of No. 20 bolting cloth. No protest has been raised by our American workers§ || to these claims of the founders of the plankton method. The leakage of the plankton through the silk has thus been minimized or ignored, and without tests of the extent to which it occurs.

* V. Hensen. Methodik der Untersuchungen bei der Plankton-Expedition. Kiel und Leipzig. 1895.

† C. Apstein. Uber die quantitative Bestimmung des Plankton in Süsswassers: in Die Tier- und Pflanzenwelt des Süsswassers. Dr. O. Zacharias. Leipzig. 1891.

‡ Das Süsswasserplankton. Keil und Leipzig. 1896.

§ J. Reighard. A Biological Examination of Lake St. Clair. Lansing. 1894.

|| H. B. Ward. A Biological Examination of Lake Michigan. Lansing. 1896.

The bolting cloth (No. 20), when new, contains from 5,100 to 5,600 meshes per square centimeter, varying with the maker and the sample; when thoroughly shrunken the number of meshes increases as much as 30%. The total area of the openings in a square centimeter, on the other hand, decreases over 50%, falling from .133 to .066 sq. cm., and the average area of a single opening is reduced from .000024 to .00001. sq. cm. This latter figure represents an area of 32 x 32 μ, the average area of the openings at the maximum efficiency of the silk. These dimensions do not, however, constitute a precise limit to the size of objects which can escape through the openings, for many meshes exceed this area, and some even double it. The struggles of the imprisoned organisms and the pressure of the filtering water also materially assist the escape of the planktonts through the yielding meshes of the silk.

For the past year and a-half the leakage of the plankton through the silk has been a subject of experiment at the Illinois Biological Station. The results were at first so surprising as to require the most careful corroboration, and they have been witheld from publication in the hope that an adequate remedy might be offered therewith. Water from a number of sources, collected at different seasons of the year, and containing plankton varying in amount and constituency, has been subject to examination in several ways, and their relative efficiency determined by the Sedgwick-Rafter counting method. In order to reduce the error incident to this process, the enumeration of the planktonts was extended over from five to ten times the customary fraction of the catch. The leakage has been tested as follows: by the Sedgwick-Rafter sand filter; by hard-pressed filter paper; by the centrifuge, and by the Berkefeld filter. The silk catches were made from measured quantities of water, thus eliminating the uncertainty as to the amount of water which the drawn net filters. Tests were made of the filtrate from the silk, and also of the unfiltered water. Owing to diversity in the constituency of the plankton, the ratio of efficiency of these various methods cannot be precisely stated. In a general way the order above given is that of increasing efficiency. The silk, *in the pumping method of collection*, retains from 5% to less than 0.1% of the total *number* of organisms present (excluding bacteria), as contrasted with the catch of the Berkefeld filter.

The Sedgwick-Rafter sand filter was used according to the published directions of Calkins,* and later of Jackson† and Whipple‡. This method is far more efficient than the silk, but proved to be subject to considerable loss, especially in the case of water richly charged with plankton. Not only do the minute forms, as *Raphidium* and the smaller diatoms, readily slip through the sand, but also the more active species, as *Euglena* and *Trachelomonas*, escape in considerable numbers. Examinations of the filtrate from the sand revealed the fact that this method captures from 40% to 65% of the number of organisms present, the greater losses occurring with abundant planktonts.

The filter paper employed was No. 575 Schleicher & Schüll. It is very free from lint and does not easily tear when wet. As the filtering proceeds the plankton is condensed in the bottom of the funnel by means of a fine spray from a hand bulb. When the required condensation is reached the plankton can be washed from the paper by the

*G. N. Calkins. The Microscopical Examination of Drinking Waters. 23d Ann. Rep. Mass. Board of Health, for 1891.

†D. D. Jackson. On an Improvement in the Sedgwick-Rafter Method. Technology Quarterly, Vol. IX. 1896.

‡G. C. Whipple. Experience with the Sedgwick-Rafter Method. Ibid.

same means, care being exercised in removing the plankton quickly and thoroughly to reduce the loss occasioned by its adherence to the paper. This method is very simple, rapid, and, in my experience, more efficient than the sand filter, yielding from 75% to 85% of the planktonts.

The centrifuge at first employed was a small one having a capacity of 60 c. cm. Later, we had constructed for this work a large machine geared to give 3,000 to 4,000 revolutions per minute and arranged to act upon a continuous stream of water, all of which was subjected to the maximum and uniform action of the centrifugal force. This machine is more efficient than the filter paper, securing in some instances 98% of the planktonts. It is, however, subject to a selective error, in that the individuals and species whose specific gravity is the same as or less than that of the water are not removed by the action of the centrifugal force. Samples rich in water blooms proved to be most troublesome. *Anabæna* and *Clathrocystis*, as a rule, and many individuals of other genera, as *Euglena* and *Chlamydomonas*, readily pass through the machine. Water kept in the dark, or at low temperature, for some hours yields up such plankton more readily. The addition of alcohol to the water also facilitates precipitation. The most accurate results, however, were obtained after adding chloral hydrate to the water in quantities sufficient to kill the plankton. The selective character of this error, and its consequent uneven distribution in plankton varying greatly in the abundance of water blooms with the season and situation, render the use of the centrifuge of questionable utility as a basis for a complete analysis of the biologic contents of water.

The cylinders of the Berkefeld filter are made of 'infusorial earth' of such fineness as to remove effectually all solid matter from the water passing through them. The smallest cylinders were encased in a suitable mantle and attached to the centrifugal machine. The catch obtained in this manner contained from one-fourth to one-third more organisms than that of the filter paper, and was not subject to the irregularities resulting from the use of the centrifuge. This preliminary test was so promising that a larger form of the Berkefeld filter, known as an 'army filter, System Bruckner,' which has of late been introduced in the German and Austrian armies, was tried as a means of collecting plankton. It has the following advantages: its maximum capacity under favorable conditions is about two liters per minute; it is portable and can be used in the field; its simple construction favors the removal of the catch, and its capacity for filtration can be quickly renewed when it becomes clogged. At present it seems to offer the most effective method for the collection of the plankton which eludes the silk. It is, however, subject to one serious drawback; the removal of the catch from the filtering cylinder is accompanied by the addition of a considerable amount of the infusorial earth to the plankton. This renders the 'Danaid task' of counting doubly difficult and precludes volumetric determination. The desideratum for a filtering cylinder for this work is yet to be found. It should be an inexpensive porous earthenware cylinder whose outer surface is of sufficient fineness to preclude the penetration of minute organisms, and of a firmness sufficient to permit the removal of the catch with a stiff brush without disintegration. Experiments in this direction are now in progress.

This leakage of plankton through the silk is a matter of fundamental importance. A considerable volume of the contents of the water is lost at all seasons of the year, and in some instances the actual catch of the silk net is but a small fraction of the total plankton present. Filter-paper catches from a

variety of situations made at intervals throughout more than a year indicate that the silk net retains from one-half to one forty-fifth of the total solid contents of the water, the greater losses occurring from waters containing *Trachelomonas*, *Chlamydomonas*, *Euglena*, *Melosira* and other minute forms in abundance. The relative amount of silt is, however, much greater in the filter-paper catches than it is in those made with the silk, so that the actual volume of plankton lost is less than the above figures indicate. The amount escaping through the silk bears no constant relation to the amount retained. Under these conditions the volumetric determination of the plankton by the use of the silk net as a test of the productiveness of water is not only incomplete but may be misleading.

For the examination of the plankton by the statistical method the silk affords a satisfactory basis only for the larger forms, such as the *Entomostraca* and the larger *Rotifera* and *Protozoa*. For the smaller and often very abundant planktonts, such as *Melosira*, *Peridinium*, *Dinobryon*, *Raphidium*, *Scenedesmus Euglena*, *Trachelomonas* and *Chlamydomonas*, the Hensen method is wholly inadequate. For example, from water in which these smaller forms were not extremely abundant the silk retained organisms to the number of 248,200 per cubic meter, while the catch of the Berkefeld filter indicated the presence of 767,556,000 planktonts in the same amount of water. Many of the organisms listed in the counting tables of Apstein may in reality escape in large numbers through the silk. Thus, of *Codonella* as many as *twenty-one* individuals may escape to *one* retained. The Hensen method must be supplemented by a more accurate system of collection if a complete census of the water world is to be taken.

From the œcological point of view the plankton lost by leakage through the silk s of prime importance, for it is composed very largely of minute algæ, which constitute a fundamental link in the cycle of aquatic life. Any attempt to unravel the complex interrelation of the constituents of the plankton or to correlate its ever-progressing changes with the factors of its environment must be based upon reliable data. Biological theory and aquaculture alike demand improvement in the plankton method.

The errors enumerated above are doubtless exaggerated by the situation with which we deal—waters rich in plankton and more or less turbid with silt. The tests, however, cover a considerable seasonal and local range of quantity and constituency, and have been made in both clear and turbid waters. The plankton, moreover, is composed very largely of the same genera as those found in the lakes in which Apstein and Zacharias have carried on their investigations, and over 50% of the species are identical. The desirability of experiments in other waters is at least suggested.

C. A. Kofoid.

Illinois Biological Station.

SOUTHERN STAR-CLUSTERS.

The last of the great contributions of Benjamin Apthorp Gould to astronomy is contained in the large volume recently published under the title *Cordoba Photographs: photographic observations of star-clusters from impressions made at the Argentine National Observatory*. This work gives the measurements of the relative positions of nine thousand stars included in thirty-five clusters of the southern heavens and in the Pleiades and Præsepe.

In addition to the other large enterprises which constituted the regular work of the Argentine Observatory, over twelve hundred plates of southern clusters were secured (no important one being omitted) in the decade beginning in 1872, of which 281 have been measured and 177 are now computed. Inasmuch as the dry plate pro-