about these things. He can well leave this worry to the biologists, and simply enjoy and muse over the amazing and fascinating wonders of life among the lowly as they are reliably and clearly described by author and translator.

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SPECIAL ARTICLES

ON ABUNDANCE AND DIVERSITY IN THE PROTOZOAN FAUNA OF A SEWAGE "FILTER"*

I

ENUMERATIONS made of the animal population of the "film" held among the broken stone of a sewage purification "filter" of the intermittent sprinkling type have given data for a quantitative account of the associations and seasonal successions of these forms.[1] The abundant protozoan fauna exhibits a peculiar relation between the total number of organisms of any one class and the number of its genera then represented in the sample. Under natural conditions the abundance of organisms of any one type found in a given situation at different seasonal periods is in a general way inversely proportional to the diversity of their kinds. This phenomenon is well recognized in plankton studies and is demonstrable in published counts of organisms occurring in polluted streams.[2] In the sewage film there is on the contrary a direct correlation between number of rhizopod individuals or of ciliate individuals and the corresponding numbers of their genera. The ethological significance of such relationships seems not to have been investigated. Obviously, they are important for the problem of specific adaptation; and in this connection they suggest a means of estimating the comparative selective stringency of environments.

II

Samples of "film" were obtained from the surface and from three levels within the filter-bed, by means of a centrally-located sampling-pit analogous to that described by Johnson.[3] The figures given are the average numbers of organisms calculated present in one cubic centimeter of centrifuged fixed film material;[4] counts[5] of organisms from the three interior levels of the bed have been averaged, the surface layer being omitted. The detailed findings will be presented in another place.

Except for an interval during summer, peritrichous, hypotrichous, and holotrichous ciliates are present in abundance. Two well-defined maxima occur in the frequency of these forms, one in Nov.–Dec., the other in May–June (1921–22). These maxima correspond, in a general way, with the seasonal distributions evident in less artificial environments. When conditions in the filter permit ciliates to flourish, a variety of their species is likewise permitted. The attached peritrichs (chiefly Opercularia), whose numerical increase is subject to somewhat different mechanical conditions, are omitted from the totals plotted in Figure 1. The graph (Fig. 1) shows that with certain minor

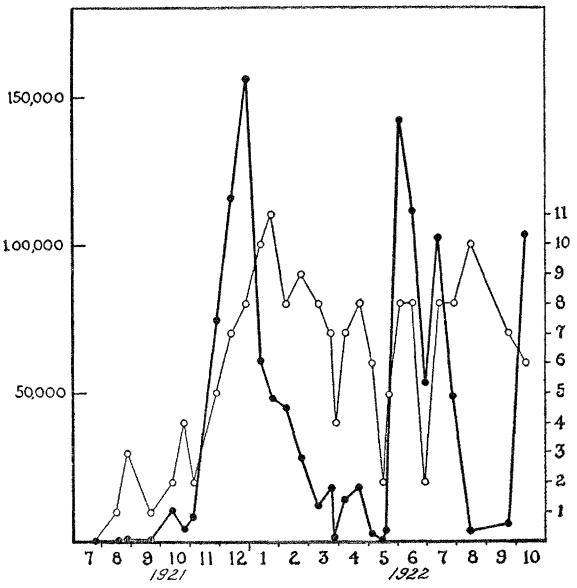

FIG. 1. Mean number of non-peritiuchous ciliates per cubic centimeter of "film" in bi-weekly samples, July, 1921, to Oct., 1922 (heavy line, ordinate scale at left). Corresponding numbers of genera (light line, ordinate scale at left).

deviations of special origin, the abundance of non-peritrichous ciliates (number of individuals per cubic centimeter of "film") varies directly with the diversity of their kinds (number of genera).

A similar relation is even more precisely shown in the rhizopod fauna. The seasonal distribution of the

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1 *Cf.* Crozier, W. J., and Harris, E. S., 1923, Ann. Rept., N. J. Agr. Expt. Stns., 1922 (in press); 1923, *Anat. Rec.*, Vol. 24, p. 403.

2 *Cf.* data of Weston, R. S., and Turner, C. E., 1917, Contrib. Sanit. Res. Lab., Mass. Inst. Tech., Vol. X.

3 Johnson, J. W. H., 1914, *Jour. Econ. Biol.*, Vol. 9, p. 105–124; 127–164.

4 In the fresh, uncentrifuged film the numbers per cubic centimeter are about one half as large. The film (also studied alive) was fixed in mercuric chloride solution before counting the organisms in a unit volume of the diluted film.

5 The collaboration of Mr. E. S. Harris in making the enumerations is gratefully acknowledged.

rhizopods shows a single maximum (Aug., 1921; 1922).

The nature of the connection between abundance and diversity, in the case of rhizopods and of (non-peritrichous) ciliates, is brought out in Figure 2.

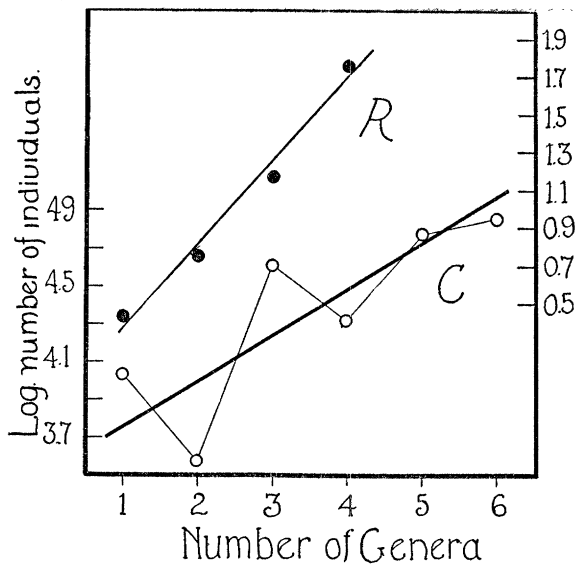

FIG. 2. Mean numbers of individuals correlated with number of genera they disclose; *R*—rhizopods; *C*—Holotrichous ciliates. (In the latter case, *C*, the period of vernal re-organization of the film, "sloughing," is excluded.)

The number of genera represented is a linear function of the logarithm of the corresponding average number of individuals.

III

From these results it may be argued that the sewage filter film is an environment of essentially artificial quality, for the relation between abundance of individuals and diversity of type is the reverse of that detected in situations lacking so plentiful a food supply for the growth of these organisms. It is to be presumed that under natural conditions the character of various specific adaptations plays a significant, even a determining rôle in survival and multiplication. Hence the view that if any one species initially present be the most suitably adapted in an environment sufficiently selective, this form will show greatest number of individuals. Whereas, if the integrated environmental effect be on the whole inimical to organisms of a particular group, a few of its species may be represented, but no one of those in especial specific selective restraint, for here diversity is at frequency. It follows that when conditions in the sewage filter "film" permit ciliates or rhizopods to flourish, there is interposed, broadly speaking, no maximum simultaneously with density of population. In all probability, therefore, temperature and gross mechanical circumstances, rather than food, limit the quantities and proportions of these particular organisms in the "film." This is consistent with the view that they are in the main subsisting upon bacteria[6] rather than directly upon putrescible constituents of the sewage.

IV

Certain difficulties interfere with the development of hypotheses concerning the meaning of specific diversity. We may safely accept the view that failure of a given type to survive in a specified location is evidence for its absence of suitability. Considering closely related types, as different genera of one order, it should be possible to obtain for different environments the curve connecting the abundance of these creatures with their corresponding diversity of forms, by means of analytic enumerations covering a period of a year or more. The widely distributed and rapidly multiplying protozoans are admirably suited for such investigation. According to the viewpoint here advanced, it should be possible to compare in this way the selective stringency or "selective potential" of different environments (with respect to the group of organisms considered). In the case of sewage "film" it is clear that environmental stress at times tends to eliminate rhizopods or ciliates, but that it is the general *kind* of creature, rather than particular species of it which is in this way suppressed. Such an environment has for these organisms no specific selective potential; the adaptive peculiarities of the species are not called into play in determining survival.

SUMMARY

In the film of organisms and débris retained among the broken stone of a sewage purification filter it is found that ciliate and rhizopod protozoans show seasonal variation in abundance of individuals and a directly correlated fluctuation in diversity of their types. An inverse correlation is recognized in natural environments of greater selective stringency. Such relationships may provide a basis for comparing the "selective potentials" of different environments.

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[6] This is of course to be expected; but it has sometimes been suggested that the abundant animal life of the filter film "must" contribute to purification of the percolating sewage. It is apparent, however, that in the filter food is probably never a limiting factor for these animals, even when purification is at high efficiency.