Experimental Analysis of Vito Volterra's Mathematical Theory of the Struggle for Existence
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tinuously until all the plants are dead. The length of time each plant survives is used as a criterion of drought resistance, together with the moisture content of the soil at death. Ordinarily only a few plants remain alive until they have exhausted the soil moisture to critical values.

A description of a sample run follows. The plants tested were white spruce, *Picea canadensis,* of three different classes, *viz.:* 2–0 (two-year old seedlings), 3–0 (three-year old seedlings) and 2–1 (three-year old trees which have had two years in the seed-bed and one year in the transplant bed). Ten plants of each class were used. The temperatures averaged 38 degrees C. and the relative humidity about 10 per cent. The soil moisture at death was above 14 per cent. for all pots. The results are shown in Table 1.

TABLE 1

Class of stock	Number of days surviving	
	Mean	Standard error
2–0	20.2	1.2
3–0	21.4	1.5
2–1	13.2	.9

In this case the transplant stock proved to be far less resistant to atmospheric drought than either of the two classes of seedlings.

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A MODIFIED SABOURAUD MEDIUM SUITABLE FOR CULTIVATION OF ACID-FAST ACTINOMYCETES

THE study of five strains of Actinomycetes isolated at this hospital during the past four years from the blood of patients suffering both from acute and chronic ailments, has demonstrated the practical value of a simple medium such as Sabouraud's. By means of a modified formula for this medium one strain of Actinomycetes was found to be acid-fast, although it was non-acid-fast on such media as standard Bordet-Gengou, potato, synthetic phosphate and Difco Sabouraud.

The formula which we employ consists of 4 per cent. maltose, 1 per cent. Difco peptone, 1.8 per cent. flaked agar dissolved in unfiltered beef heart or veal infusion instead of water. No adjustment in reaction is made. Glycerine and other carbohydrates may be added if desired. Slanted agar favors development of acid fastness in about four days. A grayish brown powdery substance develops upon the upper portion of the slant simultaneously with the appearance of the acid-fast portions of growth.

The strain was isolated from the blood of a case of acute mastoiditis complicated by sinus thrombosis, septicemia and arthritis. The acid-fast component appeared in young cultures (seventy-two hours) on this medium as branching non-acid-fast mycelia containing acid-fast pleomorphic portions. Old cultures consisted of non-acid-fast oval components and mycelia interspersed with acid-fast oval-shaped components. The acid-fast characteristic was inhibited on all other media. The other strains of Actinomycetes were consistently non-acid-fast on all media employed so far.

Sabouraud's medium, in which unfiltered meat infusion is employed in place of water, is therefore recommended for cultivation of Actinomycetes isolated from human tissue. An attempt is being made to standardize this type of unadjusted unfiltered medium.

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SPECIAL ARTICLES

EXPERIMENTAL ANALYSIS OF VITO VOLTERRA'S MATHEMATICAL THEORY OF THE STRUGGLE FOR EXISTENCE

IN the last four years I have carried on an experimental investigation of the processes of the struggle for existence among unicellular organisms. Experiments on the competition between two species for a common place in the microcosm agreed completely with Volterra's theoretical equations, but as regards the processes of one species devouring another our results are not concordant with the forecasts of the mathematical theory. All this extensive experimental material is described in my book on "The Struggle for Existence," which is now ready for publication. Since, however, this book will appear only after some time, I am taking the liberty of communicating here briefly the main results of our investigations.

The competition between two species for a common place in the microcosm may be either (1) a competition for a certain fixed and limited amount of energy, or (2) a competition for a source of energy kept continually at a certain level. In order to investigate the first of these problems experiments were made with two species of yeast cells producing alcoholic fermentation: *Saccharomyces cerevisiae* and *Schizosaccharomyces kephir.* If we calculate the coefficients of multiplication in these species, and if by studying the factor which limits their growth (alcohol produc-

tion) we evaluate the coefficients of the struggle for existence (alcohol production per unit of yeast volume), and if we then correlate these parameters in the form of an equation of the struggle for existence given for the first time by Vito Volterra (1926) and slightly modified by Gause (1932), we shall obtain an agreement in general features with the observed growth of a mixed population.[1] Further experiments confirmed this conclusion and showed also that under slightly different conditions (a greater content of oxygen in the nutritive medium) the complicating effect of the by-products of fermentation decreases, and the forecasts of the theory coincide entirely with the values observed. In all these experiments we had to deal with the distribution of a certain fixed and limited amount of energy between two populations.

In order to investigate the competition between species for a source of energy kept at a certain level experiments were made with various protozoa, and very clear and convincing results were obtained for *Paramecium caudatum* and *Paramecium aurelia*. These infusoria were cultivated in a buffered balanced Osterhout's salt solution (pH = 8.0), in which a suspension was made of *Bacillus pyocyaneus* (of fixed density). It has been found that bacteria do not multiply under these conditions.[2] Every day infusoria were centrifuged, the nutritive medium changed, and every other day the microcosms underwent a cleansing process with a salt solution. Specially arranged experiments showed that the deficiency of food was the only limiting factor in these cases. We had under such conditions (a) a competition of *P. caudatum* with *P. aurelia* for the still unutilized food resources, but after the source of energy had been altogether taken hold of, we had (b) a redistribution of energy between two components which always resulted in a complete driving out of *P. caudatum* by *P. aurelia* (Fig. 1). All this agrees with the mathematical theory. The corresponding equations are somewhat complicated, because the coefficients of the struggle for existence vary with time: one species may be favorable for the growth of another at the beginning of the experiment, and the depression of one species by another will only begin later on.

The destruction of one species by another has been studied with *Paramecium caudatum* being devoured by another infusoria, *Didinium nasutum*. Experiments showed that this biological system presents no oscillations in the numbers of individuals peculiar to itself, and that in spite of abundant food for *Paramecium* the latter are completely destroyed by predators which perish in their turn later on. However, oscillations appear if we admit a controlled and simultaneous immigration of predators and prey into the

[1] Gause, *Jour. Exp. Biol.*, 9, p. 389.
[2] Johnson, *Physiol. Zool.*, 6, p. 22.

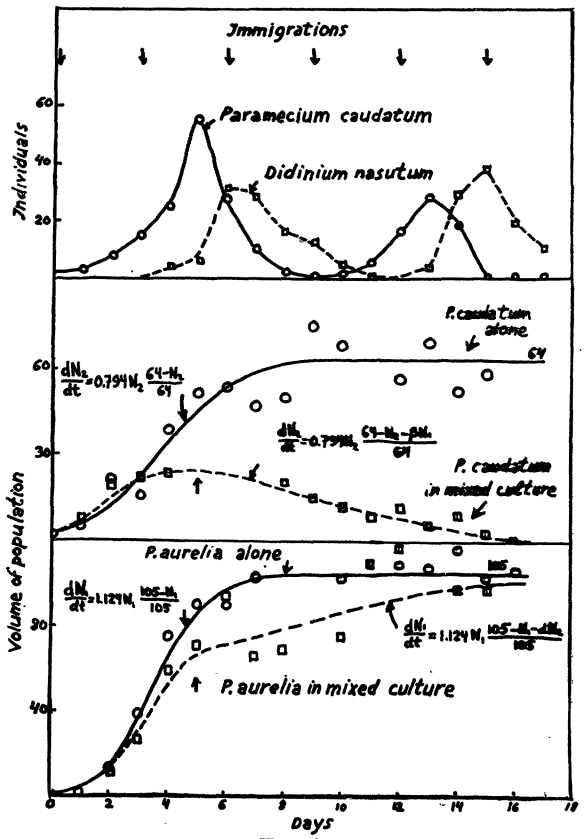

FIG. 1

microcosm. Therefore, it is not the interaction itself, as would be expected from the mathematical theory developed by Lotka (1920) and by Volterra (1926), but the constant interference from without that leads to the oscillation in numbers. The corresponding equation of the struggle for existence has no periodic solution. This is owing to the particular biological adaptations of our predators, which have not been foreseen in the theoretical equations. In our experiments an analysis was made of the rôle of cover or refuge for the prey in the processes of the struggle for existence. This showed that when the number of individuals becomes reduced, and the conditions in the microcosm complicated, instead of the "deterministic" processes subject to differential equations we are confronted with "probabilities of change" in one direction or another. The corresponding material will be found in the above-mentioned book.

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THE AMYLASE SYSTEM OF THE LIVER

COMPARISON of rat liver preparations, using the method for observing starch digestion introduced by Waldschmidt-Leitz and Samec,[1] showed that the

[1] *Zeitschr. für physiol. Chem.*, 203: 16, 1931.