VALUES OF kA CALCULATED FROM EQUATIONS OBTAINED BY JULL AND TITUS

Lot	Sex	A	k	kA (Efficiency of feed for growth)
		Kilograms		
1	Females	3.0726	.0970791	.298
2	Females	3.6084	.0817604	.295
3	Males	4.9142	.0710867	.349
4	Males	4.1954	.0873561	.366

of a group of White Leghorn pullets, having an average live-weight of 1,632 grams, Titus found that a gram loss in live-weight was equivalent to about 3.45 grams of feed. Taking the reciprocal of this value, a gram of feed is found to be equivalent to .290 grams of body tissue. This value agrees very well with the corresponding values calculated for the cross-bred pullets by means of the equation of the diminishing increment.

The writers have calculated the maintenance requirements of chickens at various ages from the above-mentioned data, using the method described above. They appear to be of reasonable magnitude but, unfortunately, no experimentally determined values are available with which to check the results.

If the fundamental assumption that the fraction of the feed incorporated into the body tissues is always of the same chemical composition is valid, the maintenance requirements must be correct. By rewriting equation (3) in the form:

$$dW = C \cdot dF - mW \cdot dF \tag{7}$$

it is readily apparent that the time relationships are as follows:

$$\frac{dW}{dT} = C \cdot \frac{dF}{dT} - mW \cdot \frac{dF}{dT} \tag{8}$$

The maintenance requirement of an animal at any particular time is, according to this equation, proportional to the product of the live-weight of the animal and the amount of feed ingested, which agrees with the well-known fact that the heat production of an animal is increased as its plane of nutrition is raised. During the actively growing period the chemical composition of the animal probably does not change sufficiently to introduce any great error into the calculations.

In view of the number of possible factors which may affect the maintenance requirement of an animal and the relative lack of refinement of the conditions under which feeding experiments are ordinarily carried on, the expression of the maintenance requirement as given in equations (3) and (8) is probably as justifiable as any other proposed up to the present time. However, it should be regarded as being merely a tentative approximation to the true mathematical relationships involved. A better equation expressing the relation between feed consumption and growth can doubtless be evolved when more information regarding the metabolism of the growing animal is available. Until such information is available the law of the diminishing increment may be of much help in the interpretation of the results of a feeding experiment.

WALTER A. HENDRICKS
MORLEY A. JULL
HARRY W. TITUS
BUREAU OF ANIMAL INDUSTRY,
U. S. DEPARTMENT OF AGRICULTURE

THE RÔLE OF COPPER IN THE SETTING AND METAMORPHOSIS OF THE OYSTER

THE most important and critical period in the life history of the oyster is that during which the fully developed larva cements itself to some clean submerged surface such as old shells or stones and then undergoes a metamorphosis into a spat and adult oyster. The term setting is applied to this process of attachment, which is a biological reaction of a most positive character requiring a definite chemical stimulus for its initiation. A study of the setting reaction under natural conditions in Milford Harbor, Connecticut, showed that it occurred during the low water stage of the tide or, in other words, when river discharge had its greatest effect on the physical and chemical condition of the water over the oyster beds. The environment of the oyster is exceedingly complex from a physical and chemical standpoint, and at periods of low tide we find the extremes of many factors as the mixing of fresh and salt water is taking place. Experiments with the oyster larvae under controlled laboratory conditions showed that changes in temperature, salinity, hydrogen-ion concentration, oxygen content, CO_2 tension and water pressure would not induce in a single instance the setting reaction. However, if in reducing the salinity, river water was used instead of distilled water, the larvae gave a positive setting reaction, which indicated that there was some substance in the river water which served to stimulate and control their attachment and metamorphosis. Further experiments involving variations in the amount and proportion of the cations and anions of the neutral salts were found to be ineffective in producing setting of the larvae, as were also the compounds of iron, zinc, tin, lead, aluminum, manganese and silver. The only element of those tested that produced a positive setting reaction was copper in the form of a pure metal or as a carbonate, sulphate or chloride. This heavy metal was effective in concentrations of one part copper to 25 million or 50 million parts of sea water and initiated almost immediately the setting process. In the river water, copper was found to be present in amounts varying from 0.2 mg to 1.25 mg per kilo, and is apparently the specific element that is necessary for the attachment, metamorphosis and survival of the oyster. River water from which the copper had been removed by precipitation and filtration was no longer effective in producing setting.

Conditions in Milford Harbor, Connecticut, were unusually favorable during the past summer for the setting of oyster larvae, so that it was possible to determine under natural conditions the relation between the time and intensity of this reaction and the copper content of the water. Several series of observations were made covering complete tidal cycles, one of which is shown for July 22 in the following figure.

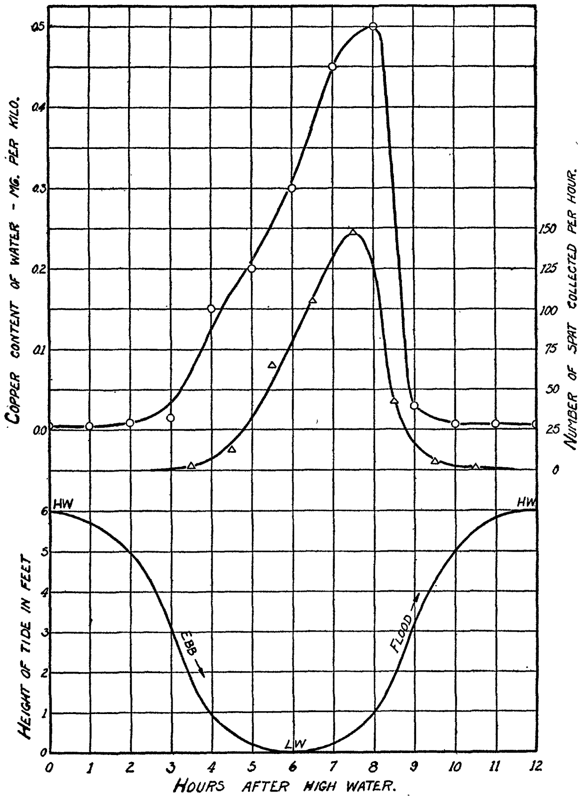

FIG. 1. Relation between the copper content of the water and the setting of oyster larvae.

The intensity of the setting was determined through the use of standard partition collectors for oyster seed, 12 of which were planted under uniform conditions at the time of high water and removed singly every hour thereafter to ascertain the number of spat which they had gathered during each interval. The difference in the number of spat collected from hour to hour shows the relative intensity of setting, during each period, which can be closely correlated with the copper content of the water. A concentration of approximately 380 spat was found on collectors which were left in the water during this complete tidal cycle, and of this number over 97.5 per cent. had become attached during the period when the copper content of the water ranged from 0.15 mg to 0.50 mg per liter.

The water of highest copper content is found in Milford Harbor in the surface layer shortly after the time of low water, while in other regions this relationship may vary according to the existing hydrographical and tidal conditions and thus produce differences in the distribution of oysters and heavy setting areas. The sudden rise in the copper content of the water on the first of flood tide, as shown in the accompanying figure, was due to the upstream movement of water from the Indian River which continues to run ebb into the harbor near the mouth, for an hour or two while the tide there is running flood. Samples of water from the Indian River showed a copper content ranging from 0.8 to 1.2 mg per liter, which clearly accounts for its effectiveness in stimulating the swimming and setting of oyster larvae during low water and the first two hours of flood tide. At the time that this water was passing over the tidal flats there occurred on five acres of this area the setting of over 100 million oyster larvae. However, as the tide rose rapidly above the two-foot mark, the flow from Indian River stopped, as did also the setting of the larvae when they were subjected to water having a higher salinity and a very low copper content of less than 0.01 mg per liter.

Cytological studies of the larvae showed that during its development there were gradually being deposited near the liver two dark green pigmented bodies which disappeared with its metamorphosis into the adult form. These pigment spots on closer examination were found to consist of a mass of densely packed cells, containing numerous green-colored granules, which with the beginning of the setting reaction were observed to gradually break apart and migrate into the blood stream. Approximately 300 of these deeply pigmented cells came from each pigment spot and exhibited such structural and functional characteristics as to identify themselves as the leucocytes of the spat and adult oyster.

Copper plays an important rôle in the respiratory processes of the oyster, and its assimilation by the larva would serve to increase the oxygen-carrying capacity of the blood and release cells during the metamorphosis for carrying out this function, both of which would greatly facilitate its rapid growth and development into the adult form.

Though copper, like other heavy metals, may have a beneficial and stimulating effect in infinitesimal amounts, it will in slightly higher concentrations quickly produce cytolysis and death of the oyster larva.

These studies indicate that in the development, distribution and survival of marine animals traces of certain mineral elements in their environment are of considerable biological significance and may constitute some of the chief limiting factors.

By the use of copper in the form of a pure metal or salt, it was possible in 1928 to observe in detail for the first time the setting and metamorphosis of the oyster larva, a brief description of which has been given in Bureau of Fisheries Document No. 1068 (Progress in Biological Inquiries, 1928).

HERBERT F. PRYTHERCH

U. S. BUREAU OF FISHERIES

EXPERIMENTS IN TERMITE CASTE DEVELOPMENT

FOR many years two main theories have been invoked to explain the production of termite castes. According to one set of advocates the important factors are seated in the germ plasm, while an equally illustrious group of investigators maintain that the worker and soldier castes at least owe their origin to environmental agencies. For several months I have been conducting a series of experiments whose results appear to be pertinent, but as some years will probably elapse before the completion of the work this note is published in the hope that students may be induced to study other species, especially those in which the worker caste is represented.

The material serving as a basis of these experiments are the Pacific Slope species, *Termopsis angusticollis* and *T. nevadensis,* in which only soldiers are developed during the first four years. When, in other words, the colony is approximately four years old, and comprises about four hundred soldiers in various stages of development a few winged individuals, representing the reproductive caste, put in an appearance. As the population increases the two classes gradually become equally represented, and often in old nests, where the food supply is running low, the reproductive caste is practically the only one present. Furthermore, the first soldier developed in a new colony is probably in the fifth instar. The second one is undoubtedly in the sixth, and as the community enlarges the number of molts increases until in long established societies the adult soldiers are in the ninth instar. No exception is known to the rule that the winged or perfect insects make their first appearance only at a point where the soldiers are in the eighth instar. Caste development in the case of *Termopsis,* for the first four years at least, is thus a well-ordered, gradual and invariable series of events, judging by a careful examination of scores of colonies.

It has been demonstrated in the case of certain other insects that within limits the number of molts is dependent upon temperature or the food supply. In the present instance temperature appears to be of minor importance. On the other hand, when the colony is small the food administered to the young is obviously limited, and the fact that the increase in the number of molts bears a fairly definite relation to the increasing number of attendants strongly suggests that food is the important factor. The following experiments also lead to the same general conclusion.

Several large colonies of both species of *Termopsis* were selected in which the reproductive and soldier castes were equally represented. In some cases they were headed by the original king and queen, which were isolated and placed in an experimental jar. An examination six months later showed in every instance that these individuals had died without making an effort to construct a burrow. The remaining colonies were headed by from three to twenty-one substitute or neoteinic royal insects. When the number of these was five or less they were removed from each colony and placed in a separate jar; where the number was larger they were divided into groups of not more than five. Thirty-six such lots have been kept under observation for a period of from two to two and one half years. Four of these died during the period of experimentation; the others evidently set to work almost immediately on the construction of burrows, and evidently commenced to produce young during the first six months. From time to time an individual colony was preserved and measurements taken.

The results show conclusively that when these small groups of kings and queens are deprived of attendants they cease abruptly to produce members of the reproductive caste, and develop soldiers only. And furthermore, the important fact appears that the first soldiers are in the fifth and sixth instars, and the number of molts increases in proportion to the growth of the population. In short, the history of the young colony, headed by a few royal neoteinic insects, is exactly the same as that of the young colony normally headed by the winged king and queen. There is nothing obvious in these experiments which suggests germ plasm as an important factor; rather it appears to be a question of quantitative or possibly qualitative feeding.

HAROLD HEATH

HOPKINS MARINE STATION,
PACIFIC GROVE, CALIF.