PACIFIC COAST BRANCH

University of California Hospital, San Francisco, Cal., February 18, 1925

166 (2689)

The regression of age with size, a neglected aspect of growth.*

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Growth, always an attractive study, has of recent years received the attention of several distinct types of workers who have amassed much data for man, for some domesticated animals of economic importance, for the ever-useful white rat and guinea pig, and for a very few invertebrates. Almost invariably the results have been presented as average weights or lengths at stated ages. Thus presented, the growth data of most animals agree in certain general features. There is an early period of rapid growth which gradually slackens with age. In some forms growth continues, though at a very reduced rate, throughout life; in others, notably in man and birds, growth completely ceases for a long period of adult life. This is followed by a period of declining size.

A graph constructed from these values shows the average length (or weight) for any age. Recently while working on the growth of the razor clam, a bivalve of considerable commercial value, which is in need of protective legislation, a growth curve of this kind was used in studying the possible effects of different proposed legal sizes, and, as often happens in work of this sort, it became desirable to determine the average age of clams of different lengths. At first it would appear that the same graph contained these values if the process of reading were merely reversed. Is such a process correct?

The correlation between age and weight or length is nonlinear; the correlation ratio, as usually calculated, is very high, often exceeding 0.9. As is well known in ordinary linear correlations, the line of regression of x on y is not the same as that of

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y on x, though with correlations above 0.9 the difference is not great. A moment's reflection, however, will show that the present case is less simple, and that the correlation is not the same at all ages. In early life, size increases rapidly with age, and a high correlation might be expected; when, however, an age is reached beyond which length or weight does not increase, the correlation must fall.

In order to see what relation actually obtains in different parts of the course of growth, we have calculated for the razor clam, in addition to the customary average length for each age, the average age for each length, and both of these regressions are presented in Figure 1. As we anticipated, the two curves were very nearly coincident in the early part; but as the curve of average length flattens out, the curve of average age rises above it, flaring up sharply toward the end. As a result while the average length of four-year-old clams is 9.2 cm., and the average age of clams 9.2 cm. long is four years, the average length of 11.0 year old clams is 15.25 cm., but the average age of clams 15.25 cm. long is only 9.5 years; thus an error of 1.5 years would result from reading the age from the curve of average length in this part of its course.

Since the effect of the reduction of growth with age is far more marked in man, the discrepancy between the two curves might be expected to be greater here. We were unable to find

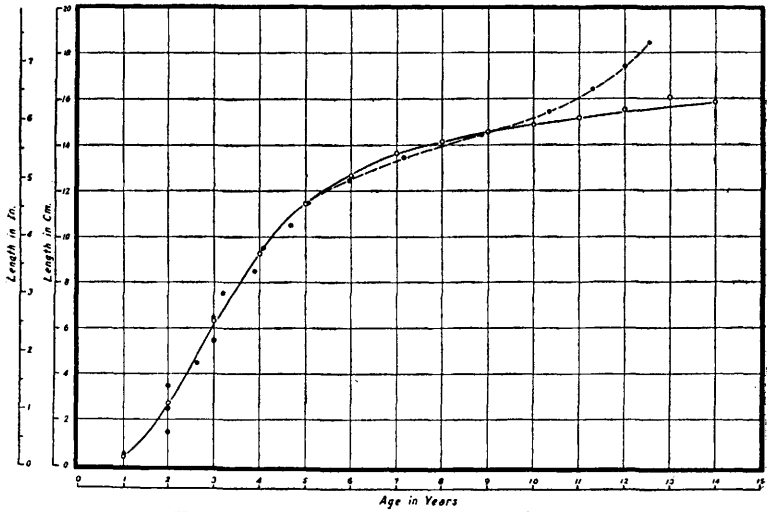

FIG. 1. The Growth of the Razor Clam.

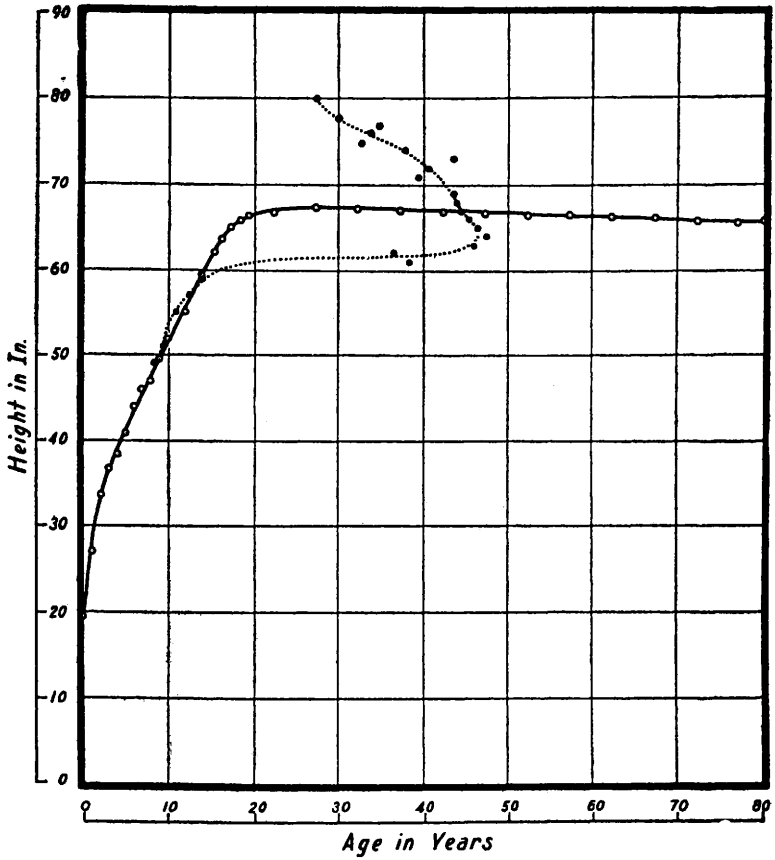

FIG. 2. The Growth of Man (English Males).

records of average ages for different heights or weights, and it proved surprisingly difficult to locate data from which they could be calculated. When located, the data required careful treatment since the mortality during adult life greatly reduces the number of individuals contained in the older age classes, but has a lesser effect in reducing the abundance of the larger size classes. It was finally decided to give equal weight to all of the age groups by reducing the number of individuals for the included heights to percentages. Though some of the details are unsatisfactory, owing to the necessity of combining two sets of data,[1, 2] the gen-

[1] Powys, A. O., 1902, Data for the problem of evolution in man, *Biometrika*, Vol. 1, Oct., 1901, Aug., 1902, pp. 45-47.

[2] Baldwin, Bird T., 1921, The physical growth of children from birth to maturity, *Studies in Child Welfare*, Vol. 1, No. 1, pp. 149, and (Roberts) 267.

eral features are clear and very striking. Of course no new data are involved, but some of the relations appear in an unusual aspect, and it seems probable that this method of presentation will aid in the analysis of growth.

We have first a period of rapid growth with a high positive correlation between age and height. When a height is reached which first includes a considerable number of adults—approximately the minimum adult stature—there occurs a sudden transition to a condition in which each increasing height gives a younger average age and each age a lower average height, that is, a condition of fairly high negative correlation. It is thus clear that a correlation ratio between age and height calculated for the entire span of man's life has little meaning. There are two distinct periods: One of youth up to the point where growth in height ceases, characterized by a high positive correlation, and a second period from the attainment of adult stature to death, characterized by a moderate negative correlation. This negative correlation in adult life apparently results from two factors. One is the actual decrease in height (and weight) of the individual with increasing age. The other is the effect of selective mortality. Persons of extreme height (there are authentic records of heights up to 282 cm.) or weight (which may exceed 600 lbs.) represent for the most part pathological cases and are not long lived; hence the low average age of the tallest men. This is borne out by the refusal of the insurance companies to accept as risks men above a certain size.

In conclusion we wish to emphasize two points: One is the danger of reading from growth curves other values than those specifically contained. The second is the incomplete picture of growth presented by the ordinary graph showing the average height or weight at each age, and the opportunity for further analysis offered by the simultaneous study of the converse relation, the average age for each height.