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THE APPLICATION OF STATISTICS TO EVOLUTION STUDIES.

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As an illustration of an application of statistics to evolution studies I will give some account of my work during the past two years on the scallop of our east coast, *Pecten irradians*.

Pecten irradians is a bivalve mollusc of flattened, lenticular form, that inhabits our coast from Cape Cod southward. The Cape Cod limit is a rather sharp one, but southward our scallop passes gradually into the closely related forms of the South American coast. This fact would seem to indicate its southerly origin. To get light on the evolution of the group, I have studied and measured over 3,000 shells, chiefly from four localities: (1) Cold Spring Harbor, Long Island; (2) Morehead, North Carolina; (3) Tampa, Florida, and (4) the late Miocene or early Pliocene fossils of the Nansemond River. The fossil shells, to which I shall frequently refer, were found imbedded in the sand at Jack's Bank, one mile below Suffolk, Virginia. The bank rises to a height of 25 to 30 feet. Shells were obtained from three layers, respectively, one foot, six feet and 15 feet above the base of the bluff. Of course, the upper shells lived later than the lower ones and may fairly enough be assumed to be their direct descendants. The time interval between the upper and lower levels cannot be stated. As I have measured sufficient shells from the bottom

and top layers only I shall consider them chiefly. I wished to get recent *Pecten* from this locality, but the nearest place where they occur in quantity is Morehead, North Carolina. These *Pecten* may therefore stand as the nearest recent descendants of the *Pecten* of the Nansemond River.

The *Pecten* shells have a characteristic appearance in each of the localities studied. After you have handled them for some time you can state in 95 per cent. of the cases the locality from which any random shell has come. First of all, the shells differ in color, especially of the lower valve. In the specimens from Cold Spring Harbor this is a dirty yellow; from Morehead, yellow to salmon; from Tampa, white through clear yellow to bright salmon. Second, the antero-posterior diameter of the shell becomes relatively greater than the vertical diameter as you go north. Thus, the antero-posterior diameter exceeds, on the average, the dorso-ventral diameter: at Tampa, by about 1.5 mm.; at Morehead, 2.5 mm.; and at Cold Spring Harbor, 6 mm. The fossil *Pecten* have an excess of about 4 mm.

Comparing the fossils with the *Pecten* of Morehead we find, as shown above, that the fossils are more elongated. Comparing the depth of the right valves having a height of 59 mm., we get:

From the lowest level, Jack's Bank	8.8 mm.
From the highest level, Jack's Bank	9.1 mm.
From Morehead	19.7 mm.

Hence the recent shells are much more nearly spherical than the fossils; there is a phylogenetic tendency toward increased globosity.

The average number of rays in the different localities is as follows:

Lower level, Jack's Bank	22.6
Middle level, Jack's Bank	22.1
Upper level, Jack's Bank	21.7
Morehead and Cold Spring Harbor	10.3
[Tampa]	20.5]

Here it appears that there is a phylogenetic tendency toward a decrease in the number of rays of *Pecten irradians*. To summarize: The scallop is becoming, on the average, more globose,

and the number of its rays is decreasing and its valves are probably becoming more exactly circular in outline. The foregoing examples illustrate the way in which quantitative studies of the individuals of a species can show the change in its average condition both at successive times and in different places.

But the quantitative method yields more than this. It is well known that if the condition of an organ is expressed quantitatively in a large number of individuals of a species the measurements or counts made will vary, *i. e.*, they will fall into a number of *classes*. The proportion of individuals falling into a class gives what is known as the "frequency" of the class. Now it appears that in many cases the middle class has the greatest frequency (and is consequently called the mode) and as we depart from it the frequency gradually diminishes, and diminishes equally at equal distances above and below the mode. One can plot the distribution of frequencies by laying off the successive classes at equal intervals along a base line and drawing perpendiculars at these points proportional in length to the frequency. If the tops of these perpendiculars be connected by a line there is produced a 'frequency polygon.' The shape of the frequency polygon gives much biological information. When the polygon is symmetrical about the modal ordinate we may conclude that no evolution is going on; that the species is at rest. But very often the polygon is more or less unsymmetrical or 'skew.' A skew polygon is characterized by this: that the polygon runs from the mode further on one side than on the other. This result may clearly be brought about by the addition of individuals to one side or their subtraction from the other side of the normal frequency polygon. The direction of skewness is toward the excess side. The skew frequency polygon indicates that the species is undergoing an evolutionary change. Moreover, the direction and degree of skewness may tell us something of the direction and rate of that change. There is one difficulty in interpretation, however, for a polygon that is skew may be so either from innate or from external causes. In the case of skewness by addition we may think that there is an innate tendency to produce variants of a particular sort, representing, let us say, the *atavistic* indi-

viduals. In this case skewness points to the past. The species is evolving *from* the direction of skewness. In the case of skewness by subtraction there are external causes annihilating some of the individuals lying at one side of the mode. Evolution is clearly occurring away from that side and *in* the direction of skewness.

Now so far as we know at the present time there is no way of distinguishing skew polygons due to atavism from such as are due to selective annihilation. But in many cases at least the skewness, especially when slight, can be shown to be due to atavism; and this is apparently the commoner cause. This conclusion is based first upon a study of races produced experimentally and whose ancestry is known, and secondly upon certain cases of compound curves. Take the case of the ray flowers of the common white daisy. A collection of such daisies gathered in the fields by De Vries gave a mode of 13-ray flowers with a positive skewness of 1.2. The 12- or 13-rayed wild plants were selected to breed from, and their descendants, while maintaining a mode at 13, had the increased positive skewness of 1.9. The descendants of the 12-rayed parents had a stronger leaning towards the high ancestral number of ray flowers than the original plants had. The 21-rayed plants were also used to breed from. Their descendants were above the ancestral condition as the descendants of the 12-rayed plants were below. The skewness is negative (-0.13) although comparatively slight. In this case we have experimental evidence that polygons may be skew *toward* the original ancestral condition.

Of the compound polygons it is especially the bimodal polygon that frequently gives hint of two races arising out of one ancestral, intermediate condition. Consequently we should expect the two constituent polygons to be skew in opposite directions; and so we usually find them to be. For example, Bateson has measured the horns on the heads of 343 rhinoceros beetles and has got the bimodal polygon. The polygon with the lower mode has a skewness of $+0.48$; that of the higher mode a skewness of -0.03 . One might infer that the right-hand form, the long-horned beetles, had diverged less than the short-horned from the

ancestral condition. Again, as is well known, the chinch bug occurs in two forms—the long-winged and the short-winged. Now, in a forthcoming paper my pupil, Mr. Garber, will show that the frequency polygon of the short-winged form has a skewness of $+0.44$, while that of the long-winged form has a skewness of -0.43 . On our fundamental hypothesis the ancestral condition must have been midway between the modes.

Still a third class of cases that gives evidence as to the significance of skewness is that where two place modes have moved in the same direction, but in different degrees. Thus the index (breadth $\div$ length) of the shell of *Littorina littorea*, the shore snail, as measured by Bumpus, has at Newport a mode of 90, at Casco Bay, of 93. The skewness is positive in both places and greater ($+ .24$) at the more southern point than at Casco Bay ($+ .13$). This indicates that the ancestral races had a higher index than even those of Casco Bay, probably not far from 96, and also that the *Littorina littorea* of our coast came from the northward, since the northern shells are the rounder. We have historical evidence that they did come from the northward. Likewise the *Littorinas* from South Kincardineshire, Scotland, have a modal index of 88 and a skewness of $+0.065$, while those of the Humber, with a mode of 91 have a skewness of $+0.048$. These figures suggest that if the mode were 97 the skewness would be 0, and this would give practically the same value to the ancestral index, as arrived at from the *Littorinas* of our coast. It will be seen from these illustrations that the form of the frequency polygon may be of use in determining phylogeny.

While skewness is thus often reminiscent, we must not forget the possibility that it may be, in certain cases, prophetic. This has come out rather strongly in a piece of work I have been engaged on during the past year. I have been counting the number of rays in recent *Pecten irradians* from various localities and have obtained in some cases evident skewness in the frequency polygons. To see what phylogenetic meaning, if any, this skewness has, I sought to get a series of late fossils. After careful consideration I was led to go to the Nansemond River for the late Tertiary fossils found there and already referred to. These

served my purpose admirably. We may now compare the average number of rays from the two extreme layers at Jack's Bank and at Morehead with the indices of skewness of the frequency polygons from the same localities.

PLACE	AV'G NO. OF RAYS.	INDEX OF SKEWNESS	<i>s</i>
Morehead, N. C.	17.3	—0.09	0.81
Upper Layer, Jack's Bank	21.7	—0.16	1.0
Lower Layer, Jack's Bank	22.6	—0.22	1.24

This series is instructive in that it tells us that the gradual reduction in the number of rays has been accompanied at each preceding stage by a negative skewness. This skewness was thus *prophetic* of what was to be. The skew condition of the frequency polygon we may attribute to a selection taking place at every stage, and the interesting result appears that the selection diminishes in intensity from the earliest stage onward. It is as though perfect adjustment were being acquired. If adjustment were perfected, we might expect a decrease in the *variability* in the rays at successive periods. And we do find such a decrease. This is indicated in the last column where *s* stands for the index of variability. From this column it appears that the variation in the number of rays has diminished from 1.24 rays in the Miocene to 0.81 rays in recent times. This fact again points to an approach in perfection and stability on the part of the rays. Just why or wherein the reduced number of rays is advantageous I shall not pretend to say. It is quite possible that it is not more advantageous, but that there is in the phylogeny of *Pecten irradians* an inherent tendency towards a reduction in the number of multiple parts. As a matter of fact there are other *Pectens* in which the number of rays is less even than in *irradians*.

The reduction in the variability of the rays with successive geological periods has another interest in view of the theory of Williams and of Rosa, according to which evolution and differentiation have of necessity been accompanied by a reduction in variability. Evolution consists, indeed, of a splitting off of the extremes of the range of variation, so that in place of species with

a wide range of variability we have two or three species each with a slight range of variability. In the particular case in hand, however, it is not certain that the lower Jack's Bank form-unit (named *Pecten eboreus* by some one) has given rise to any other form than something of which *Pecten 'irradians'* of Morehead is a near representative. The evidence indicates that the reduced variability is solely the effect of the skewing factors.

The upshot of this whole investigation into the biological significance of skew variation is then this: Skewness is sometimes reminiscent and sometimes prophetic. In our present state of knowledge it is not possible by inspecting a single skew curve to say which of the two interpretations is correct in the given case. But by a comparison of the frequency curves of allied form-units the state of affairs can usually, as in the examples given, be inferred. A method of interpreting the single skew curve is a discovery for the future.

ASTRONOMICAL OBSERVATIONS IN GEOGRAPHY.

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Efforts to improve the teaching of geography in the elementary public school have been numerous and varied among us. Nor does the present exhibit any abatement of them. The present tendency, however, seems to be setting strongly in the direction of physical geography. This paper is confessedly an effort to show that more observational work should be done in the teaching of what may be termed astronomical geography.

Probably the strongest argument for such work is to be drawn from the almost uniformly unsatisfactory answers given by high-school graduates to geographical questions involving a concrete knowledge, as opposed to a verbal knowledge, of such easily demonstrable facts as the earth's daily motion on its axis. Correct mental images of the earth as a sphere, and of the position