PRESIDENTIAL ADDRESS: ADAPTATION AND EVOLUTION.*

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FELLOWS OF THE NATIONAL INSTITUTE, DISTINGUISHED VISITORS, LADIES AND GENTLEMEN,

The Constitution of the National Institute enjoins on the President to review the work of the Institute at the Annual General Meeting and to deliver his Presidential Address at the Anniversary General Meeting. Though the scope of the remarks to be made at the Annual General Meeting is limited, the President is happily left to exercise his own choice of the subject for the Anniversary General Meeting. On this occasion, it has been a practice that the President addresses the Fellows on a subject of his research or intensive study. Since this meeting is linked with the session of the Indian Science Congress, I shall also abide by the past practice.

At the Annual General Meeting of the National Institute of Sciences of India, held in October last, I reviewed the work of the Institute and put forward certain suggestions for implementing the objects for which the National Institute was established. Towards the end of that address, I drew the attention of the Fellows to the serious neglect in India of the biological sciences, which have an important bearing on national welfare, especially when increased production of food, improvement of health and raising of the nutritional standards of the Indian masses are some of the most urgent needs of the country. It was my intention to follow up this subject and speak this morning on the rôle of the biological sciences in the future development and progress of India and I had, in fact, collected notes from several experts in different branches of biology, more competent than myself to appraise the value of biological sciences in national welfare. But, I have found that the subject is so vast and its various ramifications so important that justice could not be done to it in a single address. It is accordingly being suggested that it should be treated as a subject for a Symposium under the auspices of the National Institute. The Council's interest in the development of biological sciences will be evident from the following resolution passed unanimously at its October meeting:

> 'Realizing that there is considerable scope for fundamental research in the field of Biological Sciences and for co-ordinating research in them on an all-India basis, and also realizing financial and other limitations for the establishment of full-fledged new National Laboratories under the present circumstances, it is recommended that steps be taken to develop "Wings" for these purposes in suitable existing institutes and financed from central revenues.'

This and other resolutions explaining the scope of 'Wings' have been forwarded to the Ministry of Natural Resources and Scientific Research and the hope has been expressed that, when funds permit and the various 'Wings' are sufficiently stabilized, the question of establishing a unified and centrally controlled National Biological Institute will be taken up, of which the 'Wings' in different subjects will form the components. It is my earnest desire and sincere hope that the Government of India will pay sympathetic consideration to this suggestion of the National Institute of Sciences of India; for therein lies the future competence to deal with for most of

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the ills of this country, constantly in the grip of starvation and ill-health but not so mindful of rapid increases in population. The importance of theoretical or fundamental research cannot be exaggerated, as the question of practical application can arise only after the theory is known. Today, therefore, I shall address you on some most recent developments of a very important biological concept of the rôle of adaptations in evolution.

Adaptation and Evolution

In selecting an alternative subject for my address, I have been greatly influenced by the correspondence in the recent issues of *Nature* received in this country during the last six weeks or so. In the issue of September 8, 1951, Dr. A. J. Cain raised the question of the value of 'So-called Non-adaptive or Neutral Characters in Evolution'; and, in my view, rightly concluded 'that those characters or variation patterns that have been described as non-adaptive or random should properly be described as "uninvestigated". One must not assume randomness (or selection) without proof'. Professor G. S. Carter (1951), in commenting on Dr. Cain's observations, suggests that we must accept 'non-adaptive evolution as theoretically possible, and, until it is shown to play no significant part in natural differentiation we must give it a place in our general view of evolutionary theory'.

It seems to me that there is considerable confusion in dealing with the subject of 'Adaptations' and their significance in organic evolution. In fact, political ideologies have become intertwined round this subject with the result that in certain countries freedom of thought in science is now denied to individuals who hold views for or against adaptations and inheritance of acquired characters.

I attempted to elucidate the problem of adaptations in 1930, when dealing with the ecology, bionomics and evolution of the torrential fauna. I asserted then 'that evolution is no more than the adaptation of organisms to environment' and that 'Structural modifications are produced through changes of functions'. Further studies, both in the field and the laboratory, have now convinced me that changes in environment initiate functional changes in organisms as a first step in evolution and that such functional changes ultimately lead to structural modifications. The repetition of this sequence of events at shorter or longer intervals has determined the rate of evolution during various epochs of the earth's history and among diverse groups of animals. To substantiate this hypothesis, I shall first refer to some previous observations of other workers and then place before you the nature of the evidence that has influenced me to come to these conclusions:

The traditional viewpoint

In his Bancroft Memorial Lecture, Professor Frederic Wood Jones (1931) gave a comprehensive historical review of the concept of adaptations and showed how this point of view has been changing through the centuries. He starts with the Galenical Outlook of the 2nd Century A.D. The earliest clear conception of the phenomenon of adaptations is, however, given in *Suśrutasaṃhita* where the correlation between the form of fishes and their respective environments is discussed (*vide* Hora, 1935). A free translation of the relevant Sanskrit passage reads thus:—

> The river fish are bulky in the middle because they move with their head and tail; the lake and tank fish are similar to the above but are characterized by a relatively smaller head; the spring and pool fish, as they have not much space to move about, are extremely deep behind the head; the fishes of the torrents are traditionally well-known by the possession of two characteristics, the greatly flattened body on account of their habit of crawling with the chest, and a relatively reduced anterior part of the body.

Unfortunately the age of *Suśrutasaṃhita* is not at present definitely known. Some scholars place it as early as 600 B.C., while others consider the present text

only as old as 200 to 500 A.D. Whatever may be the date of this work, it can be stated without any fear of contradiction that the concept of adaptation brought about by environmental factors was well-known to the ancient Hindus.

Annandale on adaptations.

In the study of adaptive evolution, the most outstanding work of the late Dr. N. Annandale seems to have been lamentably ignored but modern students will find in it a wealth of accurate information unrivalled for its clarity of thought and lucidity of expression. He was the foremost naturalist of his time and it was always his habit to study animals against the background of their respective environments. I shall here draw attention to two of his papers written just before his death in April 1924. Firstly, in his Presidential Address to the Eleventh Indian Science Congress in 1924 on 'Evolution—Convergent and Divergent', he stated that 'A simple explanation (of evolution) becomes more and more impossible and environment with its unlimited gradations assumes an ever greater importance. *Indeed it seems hardly too much to say that evolution is ultimately no more than adaptation of organisms to environment*'. (Italics are mine.) Again, in dealing with the evolution of the shell-sculpture in fresh-water snails of the family Viviparidae (1924*a*), he stated:

> 'My explanation of the phenomena discussed in this paper implies an acceptance of the doctrine of the survival of the fittest and at the same time a firm belief in the inheritance of one kind of acquired character. The traumatic injury of an individual can probably not affect the race, *but unless we assume that the long-continued and gradual influence of environment can do so it is difficult to see how adaptive characters have ever arisen.* The very existence of such characters may be denied by observers in a laboratory or a garden plot, but in tropical nature they are continually being forced on the notice of the field zoologist'. (Italics are mine.)

Doctrine of the survival of the fittest

Annandale's acceptance of the doctrine of the survival of the fittest, it will be observed, is not Darwinian for variations in the sense used by him are not random nor are they selected by Nature from any haphazard lot but they are due to the 'long-continued and gradual influence of environment' and are thus acquired by the individual as an adaptation towards the external conditions of its existence. Nature is undoubtedly a very hard task master and, whatever may be the source of variations, the doctrine of the survival of the fittest must hold good. What I believe is that the animal, while still capable of growth, responds to the new situation by a slight alteration of growth; and, having thus responded successfully hands over to the next generation an increased capacity to respond, which is continually increased generation after generation till it becomes firmly engraved on the hereditary power. This implies that there are no random variations and that 'variation is due to the different efficacy with which the individual responds to the influence of the environment and that this is due to the varying degree of *vigour* possessed by the animal and that vigour is the one thing which varies continually (probably due, I think, to the position of the germ-cell in the genital organ and its varying amount of nourishment) and that natural selection chooses not the random variation but the individual which is most responsive to the environment' (quoted from a letter of Professor E. W. MacBride to the writer, dated November 8, 1928). The point made out by Professor MacBride is that one has not to consider the survival value of a character under study but of the individual as a whole, for an organism is a combination of many characters showing responses to unlimited factors in its environment.

Adaptations are functional modifications

From what is stated above, it is implicit that all adaptations are functional and that when in the economy of life of an organism a particular morphological structure becomes non-functional, it persists for some time as a vestigeal organ. I shall

take here a very simple case of the modification of the air-bladder in hill-stream fishes. In most of the sluggish-water Cyprinid fishes, the two-chambered air-bladder is well-developed to serve a hydrostatic function. When a fish enters fast-flowing waters, buoyancy will be a disadvantage, for the fish must tend to live near the bottom or in fact it must take to the ground habit of life. We have various species of *Garra*, for instance, in which we can correlate the reduction of the air-bladder with the development of the adhesive disc and the swiftness of the water in which the various species live (Hora, 1921). In loaches of the genus *Nemachilus*, I (1930*a*) showed how the air-bladder becomes reduced under the influence of stronger and stronger currents and when the air-bladder is so reduced and enclosed in bone that it cannot respond to the external environmental conditions, it is left alone as a vestigeal organ. Thus a new air-bladder is developed in species of *Nemachilus* (=*Diplophysa*) which inhabit lakes or other deeper waters at high altitudes in Central Asia. Here we have a remarkable instance of the normal functional air-bladder undergoing structural modifications induced by the environment to ensure proper adjustment of its functions to the needs of the organism concerned. So long as it is sufficiently plastic, it goes on reacting to the external conditions of its existence, but the moment it is reduced beyond a certain stage it becomes vestigeal and if there is need for such a structure for the functional activities of the fish, a new air-bladder makes its appearance. Moreover, though functionally the new bladder may be similar to the old normal bladder, morphologically it is different, for the pneumatic duct in the normal bladder opens in the constriction between the two chambers while in the new bladder it opens at the anterior end. What differences in the environmental factors or genetical variations have produced these dissimilarities, it is not possible for me to say, for the finer gradations between the two environments still remain to be investigated.

The reduction of the air-bladder in hill-stream fishes is correlated with the ground habit of life. This assumption is justified, for whichever group of fishes, Carps, Catfishes, Gobies, etc., has entered swift currents, the fate of the bladder has been the same. Furthermore, if the ground habit is a necessity in other types of habitats, such as the estuaries, marshes, etc., the air-bladder becomes reduced in more or less the same way as in hill-streams. It follows that adaptations are functional irrespective of types of environment.

Animal plasticity and environment

A remarkable instance of structural modifications was observed among the two groups of individuals of a species of fish, *Acanthophthalmus pangia* (Hamilton), living within a short distance of each other in the same stream by the writer (1930*b*) long ago. In one set of specimens, collected from among the débris at the bottom of a pool, the pelvic fins were absent (genus *Apua* Blyth), while in the other set collected from among the pebbles in a swift current, the paired pelvic fins were present (genus *Acanthophthalmus* Blkr.). Those whose interest is to study characters only have already pronounced their judgment by keeping apart the two sets of individuals in two different genera and thereby confusing the issues of evolution. We have seen the same taxonomic treatment accorded to the species of *Nemachilus* that develop a new bladder, though still retaining the old as a vestigeal organ. My knowledge of the environment in both cases is yet too incomplete to explain these adaptations.

Study of environment neglected

Whenever I have studied the taxonomy of a group of fishes, which I have observed alive in nature, it has always been possible for me to understand the functional values of the taxonomic characters, however trivial they may appear in separating species or subspecies. But, though I am trained to describe in the minutest detail the characters of an organism, I am afraid I have always been handicapped in describing the environment in the same detail, for it entails an advanced knowledge of engineering, physics and chemistry. As

'Adaptation' signifies correlation of an animal with its habitat, the study of an animal alone, however detailed, without a similar study of the environment cannot lead to the proper understanding of this universal phenomenon.

For evaluating factors responsible for evolutionary changes, it is thus necessary to know the details of the environment. Though, in a humble way, I have attempted such a study in reference to a few habitats of animals, I am fully conscious that they are very imperfect indeed. As early as December 30, 1928, Dr. E. J. Allen wrote to me in reference to my studies on the torrential fauna already referred to:

> 'The work is very interesting indeed, and the more we can have of the same kind the better. I hope too you will try to start some experimental work, and try and find out "how it is done". It is all very fundamental.'

Only recently, on the 3rd October, 1951, an American friend suggested that it would add significantly to the value of my work if someone could go out in the field and measure water speed to permit correlation of the development of adhesive devices with proportionately faster flow.

Here I must confess that I have never seriously attempted such field studies, which require a detailed knowledge of hydrostatics and hydrodynamics, though only such studies could enable the evaluation of the influence of rapid currents in reference to graded evolution of structures. However, Dodds and Hisaw (1924) have discussed the adaptations exhibited by certain Mayfly nymphs of *Baetis* for life in swift currents, and have shown that a direct correlation exists between the swiftness of the current and the degree of reduction of the median caudal seta. *B. tricaudatus*, with 3 tail setae, lives in currents flowing at the rate of 5 feet per second; *B. intermedius*, with a shorter middle seta, lives in waters flowing as fast as 8 feet per second and *B. bicaudatus*, with the middle seta vestigeal, lives in places where the water flows at the rate of 10 feet per second. The reduction of the middle seta ensures proper stream-lining of the body to present a stream-line form to the swift current.

Difficulties of studying environment biologically

Though a physical scientist may be able to study in detail the physico-chemical factors in an environment, he may not be able to evaluate their biological significance with reference to the fauna under study, unless he is also a trained biologist. The study of adaptations therefore, requires a team-work approach and I think it will be worthwhile to start this work as a co-operative project by biologists and physicists. Whenever I have been able to get the assistance of a physical scientist, the apparent biological riddles have been resolved into simple elementary facts. For example, in Blepharocerid larvae from torrential streams, I was surprised to see that some had long spinous processes on them, while in others the surface was smooth. In ordinary circumstances, the development of spines would be considered not only useless but distinctly harmful to the animal in a rushing torrent. Though it seemed to me a paradox, it was shown to me that under certain conditions such processes help to decrease resistance. For instance, it is known to the engineers that 'in some such bodies as spheres and cylinders, the law of resistance may change widely with comparatively small alterations in the conditions; thus, for example, at certain speeds the resistance of a sphere may actually be reduced by roughening the surface'. (Gibson, 1923.)

I shall refer here to another instance which baffled me for long. Certain Sisorid Catfishes, such as *Conta* Hora, *Glyptothorax* Blyth and *Laguvia* Hora, living in swift-flowing rocky streams have an adhesive apparatus formed of longitudinal folds of skin on the thorax while certain others, such as *Pseudecheneis* Blyth, *Propseudecheneis* Hora and *Parapseudecheneis* Hora, have developed transverse folds in the chest region (Hora, 1952*b*). After considerable study and thought,

it became clear that when a cylinderical fish enters swift currents, it will develop longitudinal folds along the ventral surface to increase friction, while a flattened fish will develop transverse folds. This view is strengthened by the fact that when the cylinderical fishes, as an adaptation to the ground habit of life on rocks in swift currents, become depressed and flattened and the function of adhesion is passed on to the paired fins, the outer rays become flattened and develop transverse adhesive folds.

The above two instances show that a biologist alone cannot properly interpret variations in structures, unless he understands the responsible physical factor or factors in the environment equally well.

Magnitude of adaptive variations

It is now conceded, even by geneticists, that 'adaptation is very unequally distributed through the several taxonomic ranks. In general it is considerable in the high ranks, slight or wanting in the low ranks' (Shull, 1951). According to this dictum, the characters that define classes, orders, families and genera have perhaps some adaptive significance, while those characterizing genera, species, and subspecies have rarely any adaptive importance. In my opinion, this merely indicates that we understand very little of the unlimited gradations in the environment against which only the minor characters of an animal can be equated. I have mostly worked on the taxonomy of hill-stream fishes during the last 32 years and have made extensive collections from all over India myself. I have not only collected fishes from mountain torrents, but have also tried to understand their ways of life through observations and simple experiments carried out in the field. In classifying these fishes right up to the subspecies rank, I can say with a considerable degree of confidence that even the so-called most insignificant characters, such as number and disposition of scales; number of rays in various fins and the shape of fins, nature of the mouth and associated structures, appendages in the axils of fins, etc., etc., have some adaptive significance when considered against the background of environmental factors. For instance, it has been observed over and over again that in fishes that adhere firmly to rocks by applying their ventral surface, the ventral portions of the gill-openings, being non-functional in such circumstances, gradually close up; and ultimately they are greatly reduced and are restricted to the dorsal surface above the pectoral fins. A critic from America has recently written to say that 'This is simply not true. Many Gobies which have adhesive discs and sit on the bottom have terrific gill clefts. My guess would be that Hora's fishes have their gill-openings restricted because they are living in such thoroughly oxygenated water and are not active and have, as a consequence, an easy time respirationally'. The adhesive disc of the Gobies is formed by the union of pelvic fins and the ventral surface of the body is, therefore, usually not closely applied to the substratum. Accordingly, in Gobies as a rule, there is no interference with the ventral extensions of the gill-openings. But when the Gobioid fishes enter torrential streams and the body becomes greatly flattened, the gill-openings are restricted to the sides and extend to the ventral surface for a short distance only (Hora, 1932*b*).

It is probably true that, when the gill-openings thus become restricted to the dorsal surface in hill-stream fishes, further reduction of their size is due to the highly oxygenated nature of the water. The adaptation that I have not yet been able to account for is the extensive nature of the gill-openings in the Chinese Homalopterid fish *Sinogastromyzon* Fang, in which the ventral surface and the paired fins do form an adhesive disc. Some observations on the respiratory mechanism of this fish will no doubt help in elucidating this adaptation. For the present, it can be included in the list of those adaptations which need to be investigated.

Parallel evolution signifies adaptation

As early as 1922, Annandale and I commented on a remarkable case of parallel evolution in the fish and tadpoles of mountain torrents by referring to the development of a suctorial disc in the fishes of the genus *Garra* Hamilton and tadpoles of *Rana afghana*

Günther. Annandale (1924*a*) again referred to it and, on the basis of my work on *Garra*, pointed out that the different forms found in different types of environment correspond very closely with different stages in the post-larval development of the most highly specialized species. He then predicted that though 'our knowledge of the tadpoles is less complete, the analogy between them and the fish is so close that it is impossible to avoid the conclusion that a similar (but of course not an identical) line of evolution has been followed'. Annandale's prediction came true when I (1932) studied the development and probable evolution of the suctorial disc in the tadpoles of *Rana afghana* Günther. Similarly, in the case of Homalopteroid fishes, I (1932*a*) predicted that forms intermediate between *Vanmanenia* Hora and *Formosania* Oshima still remain to be discovered, and so it was no surprise when Fang described *Praeformosania*. The entire classification of the Homalopteroid fishes is based on adaptive characters and when discoveries of future taxonomic units can be predicted, it seems reasonable to believe that there is some directiveness in evolution.

Taxonomy and adaptations

In 1949, I discussed how a taxonomist assesses a species and how the value of characters may change with individual workers or when more material becomes available. I shall extend this point by referring to the changes that have taken place in recent years in the classification of the Homalopterid fishes, in which even the minutest characters used for taxonomic purposes can be shown to have some adaptive significance.

In 1920, I published a revision of the Indian Homalopteridae and Day's *Homaloptera* was divided into three genera. In 1932, after examining considerable material in European museums, I found that this very characteristic family is polyphyletic and showed on the basis of morphological characters that, whereas *Homaloptera* and its allied forms were derived from the Cyprinidae, *Gastromyzon* and its allied forms have been derived from the Cobitidae. In 1949, I had an opportunity to examine the material of these fishes in the American museums. As a result, the previous view was confirmed and the old Homalopteridae was definitely divided into two families, the Homalopteridae and the Gastromyzonidae (Hora, 1950). Though the material available for study of these fishes is very limited, we have studied them from several aspects, such as cranial osteology (Ramaswami, 1952), structure of scales (Law, 1950), and systematics and zoogeography (Silas, 1952). These studies have shown that the Gastromyzonidae comprise two definite stocks independently evolved from the Cobitidae, the Crossostominae and the Gastromyzoninae. Further, both the Gastromyzoninae and the Crossostominae are independently evolved on the mainland of Asia and in the island of Borneo (Hora, 1952*a*). In each group and in each geographical area, there are several lines of independent evolution showing thereby that the over-riding influence of swift currents has moulded several Cobitid forms independently and have made them converge so as to look superficially alike. For lack of enough material, our investigations into the so-called Homalopteridae of the older writers are not complete though I have been studying this family of fishes for over a generation now. True enough, Darwin enunciated his theory of the *Origin of Species* on the basis of accumulation of a great deal of data, but such encyclopaedic knowledge is perhaps not possible in these days. Now is the age of intensive studies, not of a single order or family but sometimes of a genus from all aspects. Though on account of the time factor, it may not be possible to demonstrate experimentally the rôle of adaptations in speciation, one will have to turn to the specialists of genera and species to build the edifice of the science of Organic Evolution.

Evolution: divergent and convergent

Both Annandale and I have been greatly impressed by the fact that evolution does not follow a straight course. One notices at every step that to meet the requirements of the environment sometimes the characters converge and sometimes they

diverge, but always with the ultimate aim of achieving the same object. In the study of the Homalopterid fishes or the fishes of the Glyptosternoid group of the family Sisoridae, one comes across divergent and convergent evolution in regard to every taxonomic character (Hora & Silas, 1952). The sum total of all the characters constitutes the organism which shows a remarkable adaptation to the environment, whatever may be the line of evolution of each character. The evolution of each character is determined by the initial stage at which it starts so that it acts as mere clay under the pressure of its environment, which moulds it and remoulds it so as to keep it fully adjusted to the requirements of the external condition of its existence.

How do new characters arise

Annandale (1924*a*) thus summarized his views on evolution:

> 'Mendelism is true in some cases; some species produce mutations, but gradual changes also take place under the influence of environment, and are perpetuated. In some circumstances these changes are utilized and become more strongly developed, in some they produce harmless by-products; in others the result is harmful and the race perishes. No one formula can express, much less explain, evolution.'

Since Annandale's time we have observed many more facts concerning adaptations; we are accordingly in a position to take a much bolder stand in evaluating their importance in evolution. Whatever may be the source of variations, Lamarckism, Mendelism, Darwinism, Weismannism, or any other, each variation is subjected to the test of its fitness to the environment: if it passes that test it survives, otherwise it is wiped out. The most predominant factor in evolution is adaptation and Dr. Cain is, thereby, perfectly justified in cautioning students of evolution 'that those characters or variation patterns that have been described as non-adaptive or random should properly be described as "uninvestigated". One must not assume randomness (or selection) without proof'.

In the evolution and distribution of the hill-stream fishes of south-east Asia, we have now found that the orogenic movements that gave birth to the Himalayas had a great rôle to play. The movements affected the neighbouring countries and produced many resultant mountain ranges. The streams in the Himalayas and the associated mountain ranges became rejuvenated with each upheaval, thus providing a very favourable stimulus for the production of more and more specialized adaptive fishes. As the peninsular region remained more or less stable during these orogenic movements, we did not understand the evolution of new genera of fishes in the Western Ghats having affinities with those found in the Assam Hills, Eastern Himalayas and further east. Now we know that this was made possible by the tilting of the Peninsula by which the Western Ghats was uplifted and the streams in it were rejuvenated (Menon, 1951), thus providing a direct cause for the production of genera like *Bhavania* Hora and *Travancoria* Hora. Hence it will be seen that we require to supplement our biological studies with a knowledge of the palaeogeography of India before we can hope to understand the problems of evolution and distribution of our torrent-inhabiting fishes.

Principles of evolution

In the above account of various aspects of adaptations and their bearing on organic evolution, I have relied mainly on observations I have made myself or of which I have personal knowledge. I am, therefore, in the fortunate position of being able to substantiate each observation with more detailed information. It will be seen that the following biological principles can be enunciated for a proper understanding of evolutionary changes in nature:

1. New characters, as a rule, arise as modifications of some pre-existing structures. There is no such thing as the evolution of entirely new

characters. Thus there is always an organic link between the past and the present.

2. The evolution of characters is governed by the innate tendencies of heredity, as well as by the external environmental influences. In fact, both Nature and Nurture play a significant part in the make-up of an individual.
3. New variations or characters, by whatever means they may arise, are tested for their adaptiveness to the external conditions of the existence of the organism concerned. The non-adaptive characters, if harmful to the existence of the organism, disappear or the race perishes. In the end, only adaptive characters persist and form the basis of future evolutionary changes. It must be remembered that evolution is of the animal through the production of purposeful characters, and not of the characters without any relation to the life of the animal.
4. Evolutionary changes are thus directed towards achieving certain definite objectives. Evolution takes tortuous paths for the attainments of its objectives, for it goes on moulding and remoulding pre-existing characters to fit them to the needs of environment. This view is amply justified by marked divergences and convergences one comes across in Nature. The same objective can be gained by similar organisms by applying different means or conversely by different animals by resorting to similar modifications.
5. Fluctuations in environmental conditions, whether of the gene-complex or of the animal as a whole, are the main sources of variations and thereby of the production of new characters. In the case of the hill-stream fish-fauna of south-east Asia, the production of new families, genera and species can be correlated with the orogenic movements due to the birth of the Himalayas or other similar violent earth movements. So long as the environment remains static, the organisms do not change very much, but any dynamic environment, such as torrents, marshes, estuaries, shore-line, etc., is an open book for the study of evolution. Palaeogeographical changes have very often converted a static environment into a dynamic one and it is during such periods of the earth's history that vast evolutionary changes have been observed.

Conclusion

I believe I have made it sufficiently clear that the study of evolution is in the main a study of adaptations. Adaptations resolve themselves into two main lines of investigation: the study of the characters of the animals and the study of the environment in which the animal lives. The study of characters has advanced to a very high pitch of efficiency, for we are now studying the minute parts of chromosomes and interpreting them in terms of heredity. We are, on the other hand, still very ignorant of environment. This deficiency is mainly responsible for our quarrels about the theories of evolution and for the inadequate understanding of man and his needs. The future lies in ecological studies, whether of organisms or of man. So long as we remain ignorant of environmental gradations, it is better to follow Dr. Cain's advice and treat apparently non-adaptive character as 'uninvestigated'. This attitude of mind will at least enable the younger generation to investigate nature more thoroughly, and thereby, to cull from it the secrets of evolutionary changes.

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