The Ecological Viewpoint.*

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THE study of the history of science, and particularly the detailed history of single sciences, is of very great importance for all scientific workers. The history of botany is as interesting as any. As the content of the subject, like other sciences, increased so vastly during its development, specialisation in modern times became inevitable. Specialisation in itself is not necessarily a bad thing, indeed it is necessary for the progress of science; but by itself it is not enough. Specialisation should be combined with as sound a knowledge as possible of the subject in general.

The question is whether botanical specialisation in these days has become universal. Are there any botanists left who adopt the right attitude of mind? The answer is that this is exactly the claim put forward by the ecologist. Ecology, as its followers have maintained, is not a special branch of botany; it is simply a way of looking at the subject. The ecologist adopts what one might describe as the holistic point of view. Ecology seeks to explain, as fully as possible, not only why plants occur where they are found, but how and why they are as they are, and why they behave as they do. It is, therefore, essentially synthetic. It draws upon palæobotany, for example, because to understand why plants are as they are to-day it is necessary to study their past history. The study of plant pathology is essentially ecological because disease in plants, as in animals, is due to maladjustment to their environment. Experimental work in ecology, as Clements has pointed out, is purely a study of evolution, and the facts of the latter are the materials with which taxonomy deals. The value of genetics to the ecologist is sufficiently obvious. Ecology and physiology are clearly so allied that the latter may very well be included in the former.

SOUTH AFRICAN ECOLOGY.

In many ways in South Africa I was fortunate, for, when I began work here in 1910, I was brought closely into touch with the late Dr. Medley Wood, with Dr. T. R. Sim, with Dr. Marloth, Mr. J. S. Henkel, and others from whom I was able to learn a great deal in a comparatively short time. Descriptive ecology can, of course, be made as detailed as one pleases, but the recognition, description, and rough general analysis and distribution of the major plant communities in Natal and some other parts of South Africa could be carried through fairly rapidly.

The second stage of my South African ecological studies dealt with the developmental history of various plant communities, or what is commonly referred to as plant succession. One of the most important things is to be always on the lookout for cases of plant suppression, that is, examples of one type of plant being killed by another. For example, as one walks along the margin of a forest one can often discover the dead remains of light-demanding shrubs just within the outside belt of trees. This means that the forest is progressive and is gaining ground at the expense of the surrounding grassland. Similarly, in the grassland itself, tufts of deep-rooted wire grasses (*Aristida*) may be found being smothered by the more shallow-rooted, more luxuriant red grass (*Themeda*).

Everywhere, a dead or dying plant should act as a 'flag signal' to the ecologist. The immediate cause of death is usually the attack of some fungal or bacterial parasite. But the more remote causes are various, depending usually, in a general way, on the lack of power to respond to changes in the environment, and, since the biotic environment is most liable to change, death is most often brought about in this way. One stage of development of the plant community gives way to the next, until a climax, a more or less stable condition, is reached.

As soon as one has obtained a sufficient number of carefully recorded comparative observations in different areas, a complete analysis of the full developmental history of any plant community can be given, and, for the more important plant communities in South Africa, that has been done. Over the whole eastern side of South Africa the main course of the plant succession is similar to that found in other parts of the world. Bare surfaces are colonised by light-demanding plants, among which annual weeds and other 'ruderal' plants are common and characteristic. The earlier stages of all succession on dry land are more xerophytic than succeeding stages.

In a pastoral country such as South Africa, the proper management and control of the natural pastures is of paramount importance. It is possible to sum up almost in a single sentence what are the results of overstocking, veld burning at unsuitable seasons, and other modes of interfering with the natural vegetation. Man's interference always tends to send back the plant succession. Climax stages are destroyed and earlier stages take their place. Over wide areas of climax grassland this is undesirable, for the earlier wire-grass stages are less palatable and less nutritious. On the other hand, in forest climatic areas it may be a good thing to replace trees and shrubs by earlier pure grassland stages. A careful study of the plant succession can show us when burning the grass is necessary and when it is not. There are many other practical problems in connexion with veld management that can be solved by studying plant succession, plant indicators, and, in general, applying field ecological methods.

Pioneer species tend to be very widespread; they are more plastic physiologically; they show a greater range of physiological variation. It is also particularly interesting to note that pioneer species are usually to be regarded as advanced

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types from the phylogenetic point of view. On the other hand, the species that belong to later stages of the succession differ in all these respects from the pioneers. They are much more numerous than the pioneers, and they belong to a greater variety of growth forms, since, in addition to the dominating species, there are so many that occupy subordinate positions. One of our South African forests, for example, does not consist merely of trees. There are abundant climbing plants, epiphytes, shrubs, undershrubs, and herbs, as well. Since they vary so much in form, so also they vary in their phylogenetic standing. Many of the trees are relatively primitive in this respect. Some of the subordinate forms may be very advanced. For the climax stages the living environment (or biota) is as important as, if not more so than, the inorganic environment.

The third phase of the ecological work which I have been privileged to carry out in South Africa followed naturally from the previous work. It consisted in the study of the interrelationships of taxonomy (based on phylogeny) and field ecology, and in particular dealt with the origin and migrations of the South African flora and the evolutionary history of plant forms. More recently I have applied the same methods to the study of a single group of flowering plants—the grasses.

By combining the study of taxonomy with the study of distribution it soon became apparent that the oldest flora lay to the north of us, in the great moist tropical areas of Africa. In support of this view is the further important fact that the tropical flora of Africa in many of its elements unites closely with the tropical floras of Asia and America. It is probably the oldest angiospermous flora in the world. In South Africa, from this tropical element, a subtropical one has been produced, which has become more and more highly evolved and modified in response to the winter resting season and dry conditions generally, until in our Karroo regions and dry desert areas of the western side we find the culmination of the process. The Karroo has a flora which has good claims to be ranked as the most highly evolved in the world.

The temperate element of our flora, however, is rather distinct from the tropical and subtropical. It is allied to the tropical, from which many of its elements have obviously been derived, but the temperate flora of the southern hemisphere occurring to-day in South Africa, Australia, and South America is undoubtedly a very ancient flora. It connects along our great mountain ranges of central Africa with the flora of the Mediterranean region.

The evolutionary history of plants can only be described with any degree of certainty when we know a great deal more, not only about palæobotany, but also about the past history of the world throughout geological time. With the aid of geology, the syntheses can be made more complete. The history of the flowering plants in the world has been mainly a history of response on the part of a widespread, uniform, moist tropical flora to climates which became gradually cooler and drier. In South Africa, owing to its relative geological stability ever since Cretaceous times, the whole process has had a longer time in which to take place, and, apart from certain climatic oscillations of which there is evidence, the process has not been interrupted in any drastic way, as would have occurred if large areas had sunk below sea-level. South Africa throughout the history of the flowering plants has been above the sea and has been joined to the tropical regions to the north. The derivative Karroo flora, therefore, is not only highly evolved but also, in comparison with similar semi-desert floras in other parts of the world, is a rich flora. Those arid plains have been colonised by families such as the Compositæ (regarded by all botanists as the highest of all plants), by relatively advanced members of other circles of affinity, for example, the tribe of Stapelieæ of the asclepiad family, the Mesembryanthemeæ among the Aizoaceæ, and so on. There is a magnificent field here for the study of plant colonisation on a grand scale. A comparative cytological investigation of the numerous species involved should at the same time be undertaken. The importance of isolation in the origination of new forms has long been recognised. Modern work in genetics has shown more clearly the reasons for it. They seem to depend chiefly on the fact that if a new form is prevented from interbreeding with the parent species then the chances of survival are enhanced.

The thing that interests us most for the moment is the undoubted fact that in South Africa we have unequalled opportunities for the study of the facts bearing on such problems. Ecology tends to unify the whole study of botany, and the adoption of the same point of view, with perhaps, to some extent, even the adoption of the same methods and technique, would, I think, tend to do the same thing for other biological sciences.

HUMAN ECOLOGY.

It is a very natural thing to inquire what bearing biological studies of any kind have on the life of man himself. Experience, however, ever since the publication of Darwin's "Origin of Species", and even before that, has gone to show that there is need for caution in applying biological theories to man. The point of view of no single one of the human sciences is broad enough to explain fully why man is as he is and why he behaves as he does. Ecology alone stands apart. The student of man and his works, whether he calls himself archæologist, ethnologist, anthropologist, sociologist, economist, geneticist, geographer, historian, educationist, psychologist, or physician, would do well to become more of an ecologist and try to adopt more and more the general point of view.

Plant ecology may be taken to include plant pathology, since diseases depend on a maladjustment to the environment. So human ecology should also include the study of medical science. Just as plant ecology binds together very effectively all the branches of botany, so human ecology should help to unify—so far as they can be unified—all the separate sciences which deal with man. No one, of course, can attempt to master them all, and no one would be foolish enough to advocate such procedure.

The development of the study of human ecology will probably follow lines similar to those followed by plant ecology. Man reacts to his environment as plants do, but man can control his environment in a way that plants cannot. Nevertheless, the point of view remains the same.

The first phase of human ecology must necessarily be descriptive. The greater the literature dealing with man is in point of bulk, the more need there is for seeking some means of determining the relative value and significance of all its varied content; and that, I feel sure, can be done by applying the test of its value to ecology. It is dangerous to press analogies very far, and it will almost certainly be found in practice that human ecology will not develop on exactly the same lines as plant ecology. The results obtained in the field of plant ecology must be applied with great caution when human communities are studied. At most they may be utilised to suggest hypotheses and useful lines of investigation.

Pioneer men, like pioneer plants, are more plastic in their reactions to the inorganic environment. If the environment is very adverse, complex plant communities cannot be built up; the pioneer stages remain more or less the final stages as well. This is equally true for human communities. The total numbers of pioneers among men as among plants are much smaller than those belonging to later stages of communal development. Pioneers among men, like their analogues among plants, tend to become widely scattered over the world. It is their business to conquer new habitats. They are ready to meet any emergency; they can fight their way through all the varied difficulties presented to them by Nature, but they fail to subordinate themselves to the community as a whole, when that becomes more complex. They remain pioneers and must always strike out along new pathways. They are stifled by the atmosphere of our great cities.

It is unnecessary to carry the analogy any further. It is enough if it has suggested to us that, fruitful as the comparison of pioneer and climax types in the plant world has been, a similar comparison of pioneer and climax types among men (without any reference to plant ecology) may prove even more interesting and valuable. I am aware, of course, that students of sociology have already contributed a great deal to the study of development in human communities: for example, Spencer, Bain, Mill, Hobhouse, McDougall, McIver, Graham Wallas, Westermarck, Saunders, and many others. But few or none of them, so far as I have discovered, have devoted much attention to the advances that have been made in plant ecology, or have adopted the ecological viewpoint. Nowhere could it be better carried out than in South Africa, where we still have almost every possible stage of development of human communities.

A comparison of different stages of development among human communities will probably at the very outset demonstrate quite clearly that our education policy in the past has not been a very wise one. Up to a very few years ago, we were teaching in all our South African schools (whether attended by whites, Indians, natives, or 'coloured' people) more or less exactly the same subjects. There has been and there still is far too much uniformity in our educational system. It is a mistake which is only slowly being put right, and it is doubtful whether it ever will be properly rectified until we carry through more intensive comparative studies of communal development such as I am advocating. In South Africa we are concerned not only with the development of a more or less uniform white race, but the problem is made more interesting and more complicated by the presence of a black race (not to mention the presence of South African Indians as well). The question at once arises as to whether two or more very distinct races can successfully occupy the same territory and, if so, under what conditions. More than ever is caution necessary if we try to apply results obtained in the study of plant ecology to such a problem. If two distinct races of man wish to occupy the same region, whichever of the two is the better suited to the environmental factors will in the long run succeed, while the other will fail.

We often hear the opinion expressed that South Africa is a black man's country. The white man, we are told, can only exist here by virtue of his superior intelligence, which enables him to dominate the blacks and force them to do all the really hard work. Some of the facts already established by plant ecology do seem to have an important bearing on this problem. The climate of South Africa is not tropical. Its vegetation is warm-temperate or subtropical, but not tropical; yet the Bantu peoples of South Africa are a tropical people that left the tropics and migrated southwards not so very long ago.

The idea that the black man is better suited than the white to the South African climate wants very careful consideration. It is true that so long as they do not come into very close and intimate contact with the white man, the black races can occupy and have occupied large tracts of land in South Africa, and that, too, at higher altitudes, such as Basutoland. On the other hand, during times of stress, for example, during the great influenza epdemic of 1918, apparently the black races suffered much more than the white. Those in the best position to know tell us that many diseases, such as tuberculosis, are spreading rapidly among the blacks, with disastrous results. But our information is all vague and unsatisfactory. I am not concerned now with possible explanations of these facts, if they are facts. What I do want to plead for is more organised systematic ecological research. It is surprising, in spite of the great advances in science during recent years, how little really scientific research work has been done on the kind of social problems that concern us most. I have said nothing about the mixed or so-called 'coloured' peoples of South Africa, though most of us probably realise that these present the most important and scientifically the most interesting problem of all, a problem calling for intensive research on ecological lines.

In conclusion, I should like to stress once more the importance of combining different lines of attack on any problem. However valuable specialised studies may be—and that they possess great value no one will deny—they must be combined with a study of each problem as a whole, and that, in its essence, is the ecological method. Of all the sciences which deal with man, modern geography, as it is studied in the best schools, perhaps comes nearest to what I have called ' human ' ecology. It is human ecology, but it scarcely attempts to cover the whole field of what I would include in that subject. It has, however, largely adopted the ecological viewpoint. Similarly, the study of sociology on modern lines, so far as it goes, is pure ecology.

The study of human communities is not the only science which deals with man. Ecology has gone further than sociology in its efforts to synthesise. Human ecology is certainly concerned with social studies and should make full use of all the social sciences, but it should aim also at making equally good use of every other branch of humanistic study, in seeking as perfect an answer as possible to that all-embracing question of how and why man has come to be as he is and to behave as he does.

The Architecture of the Solid State.*

By Prof. W. L. Bragg, F.R.S.

The electrostatic basis of the interatomic forces explains in a very elegant way the structures of compounds which contain a number of ions of different kinds. The principle of electrostatic valency in such compounds has been formulated by Pauling.

Suppose a number of ions to come together to form a crystalline solid. The ions are of different sizes, each kind has a characteristic positive or negative charge, and their relative numbers are necessarily such that the whole structure is electrically neutral. How will they arrange themselves so that the electrostatic energy in the interspaces is as small as possible? The governing factors are those of size and charge.

The first feature is that of ' packing '. The ions will fit closely together in order to reduce the interspace with its electrostatic energy. The largest ions are the negative ones, which therefore have the main effect in determining the packing, and the positive ions fit into the spaces in between. To see what arrangement will make the electrostatic energy as small as possible, it is useful to make a picture of the structure in which the electrostatic field is represented by lines of force. These start from the positive ions and end on the negative ions, their numbers being determined by the charges. Our complicated three-dimensional condenser will tend to take up a form such that all lines of force have as short a path as possible.

The result may be illustrated by a structure such as that of beryl, $Be_3Al_2Si_6O_{18}$, shown in Fig. 5. The large spheres are oxygen, and tucked between them one can see silicon (black), aluminium (shaded), and beryllium (white). The oxygens are the negative plates of the condenser, the other atoms the positive plates, and the packing is clear in the diagram. In order that all lines of force may have the shortest path, a certain relation must hold between the electric charges (Pauling's rule). Silicon has a valency 4, aluminium 3, beryllium 2. As shown in the lower part of the diagram, the lines of force Si^{4+} end on four oxygen ions, O^{2-}, thus balancing a charge $-e$ on each. Al^{3+} surrounded by six balances a charge $-e/2$ on each oxygen, and Be^{2+} surrounded by four also balances a charge $-e/2$. The same structure is shown ~~as a~~ skeleton in Fig. 6, and it will be seen that the oxygen atoms (large circles) are of two kinds, and that *each kind has its charge exactly neutralised*. One kind of oxygen is linked to two silicon atoms $(4/4+4/4=2)$ and the

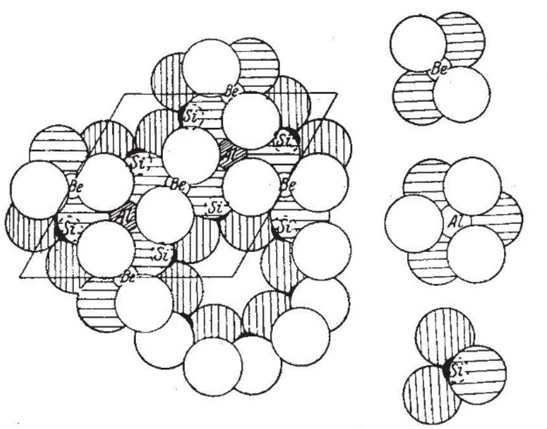

Fig. 5.—The arrangement of atoms in the structure of beryl, $Be_3Al_2Si_6O_{18}$. The large oxygen atoms are densely packed, and the atoms of metal and silicon are in the spaces between them.

other to silicon, beryllium, and aluminium atoms $(4/4+3/6+2/4=2)$. There is thus local neutralisation of charge in the crystal, and our picture of lines of force is one in which they merely join one atom to the next, and those starting from a positive ion are not forced to wander to distant atoms in the crystal before finding an equivalent negative charge on which to end.

It is surprising how the simple rule, with a few hints from X-ray analysis, enables one to build up very complex structures. One stacks the groups together, always obeying the electrostatic rule, and the whole crystal pattern falls into place. It is the electrostatic counterpart to the more rigid rule of valency in organic compounds, when each unit of valency is represented by a single indivisible bond. In the typical inorganic compound the valency can be divided into fractional parts, because it is due to an electrostatic charge, but it still remains true that when these fractional valency bonds between

* Continued from p. 212.