Structure of Plant Environment

by

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Abstract

It is not to mention that the meteorological phenomena are very significant environmental factors for the life of plant, but it is a rather difficult problem to clarify in what extent the factors act the rôle in the growing process of plant. The phytometer method, proposed as one of the methods of environmental analysis by Clements et al., does not yet work in practice, since the method is nothing more than one giving the plasticity of plant through a consideration that "the environmental variation reflects on the function and formation of plant," and then is not available for the analysis of practical process.

The present author presents a new method of environmental analysis, on the basis of the same consideration as in phytometer method, and demonstrates the through practicability of the new method for analysis for the actual cases with bamboo forest and pasture community. For example, it is clarified that the precipitation amount in June plays the major rôle as the first order factor in bamboo forest at Toyama Village in Chiba Pref., Japan, where was chosen as one of object sites in the present investigations. While, the thickness of surface soil is pointed out as the first order factor in the case of pasture community at Asama Village in Nagano Pref.

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INTRODUCTION

Modern science has now passed the descriptive stage of phenomena and makes inferences concerning functional structure, and by ascertaining them by experiments, tries to approach a correct understanding of the structure. In what situation does
ecology find itself? Very unfortunately, it seems to remain in the descriptive stage, simply recording the results of observation. However, recording of observation today is at a far advanced stage as compared with that of the 18th century or the so-called natural historical description. Especially since the latter half of the 19th century, ecological description has become quantitative and it now shows the beginnings of structural analysis of functional relations through measurement. This must not, however, be understood to mean that this branch of science has no serious problems left. Plant ecnology, which has developed around autecology on the foundation of plant geography, is still greatly troubled with the fundamental methodological problems in ecology, that is, “what is environment? and how can we grasp it correctly?”

If the idea of environment and the methodology of ecology which have been handed down to us and have been in general use do reflect the realities faithfully, there should be no serious problems to our science. As it is, the controversies over the methodology of ecology around the idea of environment and its treatment point to the fact that the conventional idea of environment is being shaken to its foundations. It may even be said that ecology which has developed around autecology or the study of environment is crumbling as a system.

In other words, the present-day ecology is forced to choose between the two alternatives of autecology and synecology, which are based on epistemologically different views of the life of a plant, one regarding environment from the individual’s point of view, the other regarding it as a group phenomenon (i.e. biotic society). As a salient feature of modern ecology, we can mention such new developments as quantitative ecology (T. ASHBY, 1935, 1948. G. W. GOODALL, 1952. M. NUMATA, 1954,), but this has not been enough to establish ecology as an experimental science.

Upon consideration of the above, research in the future should discard mere explanation and description and try to understand the phenomena from a positive point of view. This necessarily involves that we should resort to experiment in our study. But we do not mean by experiment merely translating into our field work what has been gained by physiological experiment. Precise and exact as this latter may be, it cannot in itself always provide us with working hypotheses in our field work.

The reason for this is that physiology and ecology have different objects to pursue in their experiments. [As NAKANO* says, experiments in physiology deal with the relation between one condition and life phenomena, while ecological experiments deal with that between complex conditions and life phenomena. That is why we must devise methods of experiment peculiar to ecolngy. At the same time, as the objects of our experiment, it may be necessary to re-examine plant indicator, life-form, phenology, phytometer, etc. which have been the primary measures of environment, since these measures seem to be the productions of intuition and experience. However, the fine intuition and rich experience of our forerunners have opened new fields and prepared the ground for the growth of a new science. The ideas of indicator plant and phenology of plants, etc. are still effective today in practical application, while the idea of life-form is ecologically very suggestive, although its contents involve elements of plant systematics. Phytometer, though based on the concept of plant

indicator, is not a mere instrument of recording the environment of an area. Rather, it should be looked upon as a structural view of environment. The sharp intuition and ingenuity of our forerunners have made clear not a few points in the structure of plant environment, though they remained "descriptive".

In view of the present status of ecological studies mentioned above, the following seems to be the steps we must now follow: to examine by experiment what has been achieved by our forerunners, and compare their achievements with the result of our mathematical treatment of them, to find out what has been left unregarded in the less developed parts of our science, to establish working hypotheses for future ecological experiments, and afterwards to re-examine these hypotheses. The above is a brief sketch of our position outlined before proceeding with the present study. Here follows a summary of the contents of this study.

(a) The first step of the study is the correct understanding of environment. For this it will be necessary to examine the idea of environment in its historical perspective. The changes of the idea of environment will be traced and its connection with the development of ecology will be clarified. At the same time, by examining how environment has actually been treated, the position of environment in ecology will be defined.

(b) On the dynamic side of an ecosystem, the principal role is played by the interaction of plant and external world.

In other words, it is a problem of the sphere of action of the outer world corresponding to the level of plant life (HAUSHALT), or a problem of the level of environment systems. The author has tried to find what kind of measures may be used in such a level of the system, and to define its meaning.

(c) The next step is to establish a method of analyzing the environmental system of a plant. The author has examined a bamboo forest and pasture to find how actually effective the method is in the construction of experiment plans in the field, the work of establishing hypotheses for such experiments and the analysis of environment.

CHAPTER I

Historical Survey of the Various Views of Environment

1. A survey of the concept of environment

It seems at first strange that ecology, which has developed with the idea of environment as a main theme, should be now hotly criticizing this idea itself. But this is inevitable, since as a branch of science advances, the ideas upon which it is founded are often called into question. Ideas, which are reflections of phenomena, are in this way refined so as to reflect the essence of things better. The writer would like to examine from this point of view the changes of the idea of environment.

The word, "environment" is not primarily a term used only in the field of ecology; it is extensively used also in the fields of agriculture, medicine, psychology,
geography, etc., where it means "the total of external conditions," and is used because of the very simple motive of convenience, without giving a thought to its essential meaning or its structure. As is well known, the original expressions for our "Kankyō" are milieu, Umgebung, environment, etc. What these terms signify is something that completely encloses a living thing. This corresponds to the physical idea of milieu (the material space through which substance moves) in the 18th century. It was Comte (A. Comte, 1931, T. Tanabe, 1958) of France who introduced this idea of milieu into the field of ecology. According to him, environment is the whole outer conditions of some kind which are necessary for organisms to live. Also Bernard (C. Bernard, 1938,) of France states that while it is enough to consider only one environment when we experiment on inorganic bodies, we must consider at least two different environments in the case of the experiment on organic bodies. This is clearly based on the view of environment which considers the peculiarities of non-living and living things, and it may be said to represent one aspect of the phenomena of living things. Nevertheless, in its essence, this is a view of environment on the physiological level, as Numata (M. Numata, 1953, a) pointed out. In other words, the internal environment in Bernard is nothing other than the physiological internal world and the place of life for the cell. His two environments, internal and external, are nothing but two aspects of what is thought to be a closed system, and when we look at the truth of the matter, we see that he is simply extending the physical view of environment from outside to inside. Over against this, Schimper’s (A.F.W. Schimper, 1953) idea of physiological dryness is entirely different from Bernard’s internal environment. With regard to the physiological dryness, we don’t know how well it can be applied to the actual phenomena, as Takeuchi (R. Takeuchi, 1941) pointed out, but according to Numata (M. Numata, 1953), it gave rise to a conception of environment with living creatures as active agents. His theory that environment is not all physical, was a great contribution to ecology which treats of the world of living creatures. Along this line of thought, Raunkiaer (C. Raunkiaer, 1934) later formed the conception of life-form by trying the evaluation of the external world through adaptable phenomena. On the contrary, Clements (F.E. Clements, and C.W. Goldsmite, 1924, a), who was the leading figure in American ecology, found through his studies on the plant indicator that there is a limit to the effectiveness of the values obtained by the physico-chemical measurement of environment, and that we must let the plant speak for itself.

Clements worked out the idea of phytometer by developing the theory that "the plant itself is the index of the various conditions which help the plant grow," which had been held for years, and proposed the phytometer method as a way of evaluating environment through plants.

We will now examine the problem of environment from an evolution viewpoint. Environment was brought to our attention through Darwin as the chief factor contributing to evolution. By the 20th century, palaeontology had provided many concrete illustrations of evolution. Nevertheless, they have been quite unsatisfactory in explaining the real causes of evolution. It is largely because the real structure of environment is not known to us that the causes of evolution are being much disputed in terms of external and internal causes.

The contributions of Darwin were highly ecological. He discussed various kinds of mutual action or process in a biotic society in order to clarify the major causes
of evolution.

We must be fully aware of the emphasis he put not only on physical environment but also on biotic causes as major causes of evolution. We can learn many other things from his work, but it is not necessary to take them up one by one. It will be enough for us to emphasize that the idea of environment as simply the external world represented by “milieu” and “Umgebung” does not reflect the dynamic conditions formed by the mutual actions and coactions of living creatures.

Today’s ecologists, especially dynamic ecologists, do not stick to the static idea that a living creature is something enclosed within an environment.

Ideas such as Clements’ (F.E. Clements, and V.E. Shelford, 1939) biome, the ecosystem by Tansley (A.G. Tansley, 1935) or the subject environment system emphasized by Numata (M. Numata, 1953) are reflections of the concrete state of the life of creatures. These ideas are the results of the development in the knowledge of the living phenomena of creatures. The author would like to close this chapter with a summary of the various views of environment proposed in Japan.

In Japan, up to now, scholars have been scarcely interested in the basic problems of environment. However, since the symposium (SOC. DEMOCRATIC SCIENTISTS ed. 1939) on Biological Science held in 1949, discussion on environment has become very active. Nomura (N. Yagi and K. Nomura ed. 1952) gave his view in a chapter wholly dedicated to environment in his “Introduction to Ecology.” He inclines to regard environment as a compound result of all conditions, discarding Nichols’ (G.E. Nichols, 1924) view that it is the total of external conditions. Nomura proposed the name “subjective environment” for the kind of environment meant by Balz (A.G.A. Balz, 1924) when he says that “there are as many environments as there are individuals.” This subjective environment, he says, should be given only as the final conclusion of observations. Shibuya (T. Shibuya, 1956) “recognizes first the existence of an independent and external world besides living creatures, and then calls it environment.” Kisaburo Ono (M. Numata, 1958 a) defines that “environment is what surrounds creatures.” Miyadi and Mori (D. Miyadi and S. Mori, 1953) say that “among the things and conditions which surround the subject, any thing which has some connection with it is to be called environment.” The connection with the subject can be recognized only through the response of the subject to external action. Hogetsu and Kitazawa (K. Hogetsu and Y. Kitazawa, 1951) call “anything which has some connection with living creatures their environment.” Numata (M. Numata, 1958) says that “environment is the various conditions that influence the life of living creatures” and “environment is one link in a system, and living creatures and environment together form an ecosystem or a life system which works as a body. This idea agrees basically with Morishita’s (M. Morishita, 1952) idea of environment, i.e. “conditions of a living place.” Recently, Shibuya (T. Shibuya, 1956) summarized the two streams of the views of environment in Japan and stated as follows: “The first recognizes the existence of an external world besides living creatures and regards it as environment, and deals with its relation with living creatures.” The second holds that “environment cannot exist apart from living creatures.” The first is further divided into three theories: the first one is the environment determinism, the second is the theory of mutual action, and the third is the theory of self-movement. Though we have some doubt as to whether his
statement really reflects the views of environment in Japan, we can at least see what Shibuya means.

The author would like to make his position clear including the question of what environment is. First of all, it seems to him that the definition supported by Pearse (A.S. Pearse, 1930) and others that environment is everything which exists around an organism is too vague to be of any practical utility. In other words, the author holds that living creatures and environment can’t be separated from one another.

Haldane’s (J.S. Haldane, 1941) coordinated environment expresses, indeed, one phase of actuality, but when one thinks of his totalitarian position, one is inclined to refrain from wholly believing in him. To those who consider environment as “Umwelt,” environment is the subjective world perceptible to the senses of living creatures, as is symbolized by Buddenbrock’s (W.Von. Buddenbrock, 1932) “world of senses.” As Shibuya points out, this leads to idealism. It is needless to say that in the process of long history, living creatures have secured the ways to meet their requirements, and have come to be relatively independent of the influence of physical nature, but this has brought about the paradoxical situation that they can’t live apart from physical nature. If, by the environment of a living creature, we mean the internal and the external causes and distinguish between the subject and the world external to it, this will be a very incongruous picture. But since opposing elements can exist in harmony in actuality, we must in this case admit the existence of two opposing elements in one system. It must be pointed out that Shibuya’s “self-movement theory” is very obscure with respect to the recognition of such a system. Clements’ idea of biome was very empirical. The idea of Tansley’s ecosystem was also lacking in concreteness. As Numata points out, neither biome nor ecosystem is clear about the subject of the system.

In spite of the few disputable points in the idea of ecosystem, however, this is excellent as a way of understanding environment. Here the relation between living creatures and their habitat composed of inorganic matter is grasped as one whole indicated by a certain organization. This position is superior to taking environment as “all the things existing around a living creature.” The present author is in favor of this position, but still there is the problem left of how to define the living creature and its habitat, which is a space composed of inorganic matter. “To define” here the defining of the units and parts of ecosystem as an object. This will be discussed later.

2. The view of environment and the method of measuring environment

It is hardly necessary to quote Bernal (J.D. Bernal, 1955) to prove that in the history of natural science the invention of new techniques has influenced, and been influenced by, the development of new theories of science. In ecology, this relationship is essentially the same, but compared with other fields of science, there are many obscure points. Anyway, it is true that the development of measurement apparatus for environment inevitably helps us understand the nature of environment, and this contributes more or less to the changes in the theory. At the same time, misuse of technique is likely to confuse methodology. In introducing a new technique into ecology, we must take full account of the present state of this science and have a
firm grasp of its methodology. EGLER’S (E.E. EGLER, 1951) criticism of American ecology clearly represents these considerations.

1) The traditional method of measuring environment, and its standpoint

By what methods has ecology, which has developed around the idea of the environment of living creatures, taken recognition of environment? In the ancient days, its method was nothing but a repetition of observation and description. If the period up to the 18th century is designated as the period of natural historical description, the 19th century is marked by comparison of experience, while the 20th may be considered the period of experiment. Up to the 18th century, the descriptions were unsystematic, and experiences were left unintegrated. No trace of any efforts to find a universal rule could be seen. Nor could be seen any methodology or systematic treatment. Breaking the tradition of natural history TOURNEFORT (J.P. TOURNEFORT, 1917) dealt with vegetation in the mountain area and described its vertical distribution. LINNE (C.Von. LINNE, 1951) tried to establish the classes of aquatic plant, alpine plant, mountain plant, grassland plant, parasitic plant, etc. Here we perceive not merely descriptions but an attempt at classification, at forming a basis for comparison. The work of LINNE, which dealt with the distribution of plants with special reference to habitat, should be understood to show that he was already aware of this standpoint at least methodologically. The latter half of the 18th century saw the major causes of plant distribution deliberately taken into consideration.

During the first half of the 18th century the tradition of natural history seemed to lose its force and even disappear, when it was given new force by A. Von HUMBOLDT (A.Von. HUMBOLDT, 1805, 1806, 1869) with, however, radical changes in its contents. Descriptions pure and simple were no longer considered enough; they must be co-ordinated by one consistent point of view, to elucidate the relations, interactions, and reactions among phenomena. According to him, the phenomena in the natural world cannot be separated mechanically. This idea of HUMBOLDT’S was the compilation of various views since the ancient times up to the 18th century. The study of ecological plant geography in the 19th century, which was carried forward by many scholars such as GRIESEBACH (A.R.H. GRIESEBACH, 1871) SENDTNER (O. SENDTNER 1854), KERNER (KERNER, Von Marilaun, A. 1863), DRUDE (O. DRUDE, 1890), WARMING (E. WARMING, 1896) SCHIMPER (A.F.W. SCHIMPER, 1898) inherited more or less of HUMBOLDT’S view. In this sense, this period can be regarded as the flowering time of HUMBOLDT’S view. Thus in the 19th century great progress was made methodologically. However, the method of measurement of the relationship between plant and its environment and the causal dependence between them were not seriously studied. The methodology in the 19th century was highly inductive and this century may be characterized as an age of qualitative comparison. In the latter half of the 19th century we must mention the contributions of DARWIN (C. DARWIN, 1939).

By him the field of ecological studies was greatly broadened, and our attention was directed to the qualitative problems of the biotic society. DARWIN’s work provided an occasion for reconsidering the relation between organisms and their environment, and subsequent scholars were attracted to this problem. Among them HAECKEL (E. HAECKEL, 1866) is worthy of notice because of his definition of ecology as a science. To-day’s two main schools of ecological thought ... autecology or experi-
mental ecology and synecology or biosociology ... have their origin in those days.

How is environment treated by experimental ecology which has developed around the problem of environment as a major theme? Also from what standpoint have synecology and phytosociology dealt with environment? With respect to autecology, since DESCARTES=HARVEY, the trend has been toward ever greater analysis on the level of microscopic unit or constituent, which is the tendency in modern biology. It was the direction toward the principle of elements and also the principle of reduction. (The goal of this tendency was mechanism as a matter of course. It is clear that EGLER's criticism of American ecology was directed toward its environmentalistic and causal principles which are based on mechanism in ecology.)

When one thinks of the fact that autecology has developed along physiological methods, and can be regarded equal to experimental ecology, one can easily imagine what its method is intended for. Since it is based in its method on experimentalism in its narrower sense, one felt no contradiction in asking what environment is. (In ecology, environment apart from the habitat is meaningless, but in physiological experiments such a field is disregarded.) On the contrary, those who made population or community their object or aimed at plant society from the beginning, thought that the physiological way of thinking or laboratory experiments were not good enough to clarify the function or structure of a community, and opposed themselves against experimental ecologists.

In fact it was synecologists rather than autecologists that have discussed seriously how to deal with the idea of environment or environment itself. If ecology in this century shows a tendency toward ecosystem-ecology, it may be defined as the science of relations between organisms and the external world evaluated biologically.

2) The standpoint of the experimental method

It is said that ecology is an explanatory science. It was in a sense true. Especially for the field ecologists who make plant communities their object, it is telling criticism.

However, these field ecologists were never satisfied with the mere explanatory method. For example, CLEMENTS (F.E. CLEMENTS, E.V. MARTIN, F.L. LONG, 1950) engaged in field experiments from 1901 to 1945, and emphasized the importance of experiment. But ecologists in general have not given enough thought to experiment, and many obstacles lie for ecology to establish itself as an experimental science.

However, ecologists themselves are opened to criticism, on account of their attitude toward experiment, and there are not a few problems to be solved before ecology can claim to be an experimental science. For instance, RAUNKIÆR'S (C. RAUNKIÆR, 1905) life-form system, CLEMENTS' biome, and TANSLEY'S ecosystem are excellent ideas from an ecological point of view, but the concrete methods of analysis and of determining the structure of environment that must accompany them remain to be established. It seems for us necessary to reexamine from an ecological point of view the experimental method, which is the only sure way of analyzing environment. As long as natural science is our object, we should not be merely speculative; we must seek for the objective method which quantifies the object of study. (However, meaningless quantification can be harmful in its results). Objective data concerning environ-
ment are necessary as well as quantification of the living subject. This does not mean that it is scientific just to measure as much of the external world as possible with the use of all physical instruments.

3. Ecological meaningso of measuring subjective environment

To clarify the structure of an ecosystem is none other than clarifying how the living creature and inorganic matter are combined. As the basic type of such combination we can cite the combination of the living creature and the external world through exchange of energy and matter, as revealed by such phenomena as action, reaction and coaction. What the present author means by the subjective measurement of environment is measuring the effect left on the living creature by such phenomena. And to this the following section is dedicated.

1) The subjective measurement of environment

As stated above, if the external world is equal to environment, the knowledge of environment should be deepened and broadened together with the chemico-physical development of technique. For instance, with regard to the measurement of temperature the measuring apparatus in the 20th century is incomparably superior to that of the 19th century, and this is the case with the measurement of light and water.

With the use of radioactive bodies, scientific technique has made such progress that much light has been thrown on the microcosmic world. But it does not seem that the knowledge of environment as a meaningful external world was greatly enriched by this, nor much comprehensive information has been gained about the structure of the ecosystem either. Even after recent progress in technique, Clements’ dictum at the beginning of this century still holds, i.e., that environment is known only by letting plants speak of themselves. Plant indicator, life form, phenology of plants, etc., as the measures of subjective environment have not all come into being as measures of the ecosystem. Here I would like to re-examine the contributions our forerunners made, and on the basis of them, prepare for further analysis of the structure of environment.

2) The method by plant indicator

In short, the plant indicator is a method to evaluate environment by using natural vegetation or some special kinds of plant.

This idea is based on the experimental fact that natural vegetation is the measure of various conditions for growth. This idea was refined by Clements as “Plant Indicator”, which latter developed into phytometer.

(a) The formation of the concept of plant indicator

It is said that ancient farmers had the vague idea that there were some relations between plant and soil (Clements) (F.E. Clements, 1920).

Interest had already been taken in habitat and climate in connection with plants in Ancient Greece (Numata) (M. Numata, 1952). These facts indicate that interest
in plants reflecting the condition of the land arose in connection with agriculture, and when farmers settled on new lands, they turned their attentions first to the wild plants growing there. This is not confined to the ancient times. In Japan we can mention the Grade List on Valuation of Undeveloped Land in Hokkaido and the List for Simple Discernment of the Fertility of the Soil, which were drawn up from this point of view (Dictionary of Biology) (R. YASUGI and K. MAEUNE, 1950). At that time, however, settlers did not have sufficient experience concerning the soil, climate or plants, and did not know the method of scientific treatment of the soil. This caused them to fail repeatedly to settle permanently in new lands, or to get a knowledge of the value or the way of utilizing the natural grassland and forage grasses.

The proper treatment commenced to be employed at the beginning of the 19th century. The concept of plant indicator in science could first be seen in the researches on the changes of plant growth by KING (W. KING, 1685), Degner (H.G. DEGNER, 1729), BUFFON (G.L.L. BUFFON, 1742) and Biberge (I.J. BIBERGE, 1749).

It could also be conjectured that there were contained faint concepts of plant indicator in the works of LINNE (C.VON. LINNE, 1751) and HENDENBERG (A. HENDENBERG, 1754) Schouw’s (J.F. SCHOUW, 1823) classification of soil moisture in a plant community, THURMANN’S (J. THURMANN, 1849) research on physical properties and the plant community and research by Nägeli (C.V. NÄGELI, 1865), Bonnier (G. Bonnier, 1879), Hilgard (E.W. HILGARD, 1860), and Schimper (A.F.W. SCHIMPER, 1903) all had something to say on the position of plant indicators in ecology.

But it was Hilgard (E.W. HILGARD, 1906) that first tried to systematize the concept of plant indicator. Bessey (C.E. BESSEY, 1901), the teacher of Clements (F.E. CLEMENTS, 1904 a), carried on his research on the indicative value of wild plants. His view of the practical value of plants in the research of the growth steps greatly stimulated the bioecology of those days. Clements emphasized the importance of the plant indicator from the results of his research on environment, plant community and their changes. At the same time he pursued his research of the relations between the structure of plants and various environment factors. He wrote his “ Research Method in Ecology (F.E. CLEMENTS, 1905)”, based on the result of these researches. On the other hand it is extremely difficult to clarify how a plant was used as climate indicator. According to Clements, however, Tournefort (J.P. TOURNEFORT, 1717) who made the observation of the vegetation zone in Mt. Ararat might be the first scientist that put the hand to this problem. Tournefort said that at the foot of the mountain he found many plants which were similar to those in Southern Europe. On the hillsides he found several kinds of plants similar to those in Sweden and at the top plants similar to those in the Lapland district. Many researches including studies on crop zone and life zone, made by Humboldt and Bonpland (A.V. HUMBOLDT, and A. BONPLAND, 1805), Kabisch (W. KABISCH, 1865), Köppen (W. KöPPEN, 1884), Drude (O. Drude, 1887) Schimper (A.F.W. SCHIMPER, 1898), and Merriam (C.H. MERRIAM, 1898), followed this, and thus the basis of the climate indicator was laid at last.

Although numerous researches have been made later on the plant indicator, they can be classified as follows from the standpoint of application:

1. agricultural indicators
2. forest indicators
3. grazing indicators
Plant indicators have been chiefly developed on the practical side as mentioned above. For a plant to be admitted to have a high practical value as indicator, it must correspond to some factors in the environment: for instance if a spinach (Spinacia oleracea L.) or soy beans (Glycine Max Merrill) do not grow well, it is known that the field is of acid soil.

Actually matters are not so simple, for there are very many factors that act upon the plant, and even different combinations of factors may affect a plant in exactly the same manner. Therefore it is dangerous to decide plant indicators on the strength of very limited experience. It is needless to say that the practical value of plant indicators is raised higher when supported by objective facts. The support, however, must not be sought from physiological experiments, because there is a little proof that the results of such experiments are applicable to the field in general, as will be mentioned later.

The plant indicator is not always a specific plant, but a whole plant community occasionally can have an indicative value. In such a case it is of course important to know the dominant species. But dominance is not indicative of physical factors alone, for it may be a result of the interaction of different species and thus have a highly biotic character.

In taking up the plant indicator, emphasis must be put on the distributional pattern of species or on the life-form besides the dominant species. If the plant indicator is really an indicator for something as the name claims, it must be a considerably useful means for the diagnosing of the habitat of a land.

3) The method by life-form

RAUNKIAER’s idea of life-form as a structural feature reflecting the dependence of plants upon climate has a great deal in common with the concept of plant indicator. But, as regards the conceptual basis, one can say that while the latter is an extremely empirical idea, life-form is a product of considerable abstraction and categorization, and so has a positive meaning in science.

(a) A survey of the concept of life-form

It is said that HUMBOLDT originated the concept of life-form. But if we include physiognomical concepts, interpreting life-form in a wide sense, we may admit that ARISTOTELES’ classification into trees, shrubs and herbs must be the earliest. Generally speaking, however, the “17 physiognomic types” established by HUMBOLDT is regarded as the first attempt at life-form. This concept has later been greatly developed by KERNER (Von. KERNER, and A. MARILAUN, 1863), WARMING, DRUDE and others. DRUDE set up several types on the basis of classificational categories such as Monocotyledons, Dicotyledons and Pteridophytes. On the other hand, RAUNKIAER and WARMING were in a position to disregard such classificational principles. KERNER (Von. KERNER, 1863) accomplished the twelve “Grundformen” as epharmonic forms, but GRIESEBACH (A.R.H. GRIESEBACH, 1872) and HULT (R. HULT, 1881) established the “Vegetations formen” by incorporating the categorical or systematic features. Thus, there came into being two schools of thought concerning life-form, one based on the ecological
form and the other on categorization or systematization.

Although RAUNKIÆR's life-form as an ecological form might be said to have some systematic elements, it still has obvious differences in respect of its way of thinking. The life-form for RAUNKIÆR is an ecotype produced by environmental influences, and here one can see the concept of adaptation consciously applied. From this it is clearly understood why RAUNKIÆR's idea is still alive in ecology.

(b) The method by life-form

Methodologically speaking, life-form can be defined as classifying into types according to modes of life. Among the many attempts at classification of life-form that have been done since the times of HUMBOLDT, RAUNKIÆR's method has still a large following. It is due to the fact that his is based on an adaptive concept without regarding a phylogenetic point of view in selecting units of classification. It must be admitted that his idea, which takes up as criteria the structural characteristics of a plant that enable it to survive in unfavorable seasons, is an extremely ecological conception. This has been extended to regarding a plant community as an expression of the climate, and an effective means in judging the biological characteristics of different climates. Meanwhile there is the habitat form or growth form originating form similar ideas to RAUNKIÆR's. This is based on the fact that a species shows a fixed pattern according to the habitat. WARMING (E. WARMING, 1894), who laid the foundation for this, defined the habitat form as the indicator for the limiting factors of the habitat. He set up the hydro-, xero-, halo- and mesophyte groups referring to water. CLEMENTS (F.E. CLEMENTS, 1902) accomplished a detailed classification of the habitat form. He gave the first place to water in his method, and further took up light, solute and aeration.

By making a flora statistically explicit in the above way, he considered it possible to indicate the conditions of the climate or geographical features of a district, as in the case of the biological spectrum.

The habitat form is a hereditarily fixed character. But in the case of an unfixed character as that of the alpine dwarf plants it has been called the epharmonic form.

As direct, visible reactions of a plant to physical factors, 'growth' constitutes a more susceptible index than 'ecad' adaptation. Although the growth form as well as ecad makes an index for environmental factors, the former changes responding to the yearly changes of the environment, and the latter can be interpreted as the reflection of the average condition of the habitat. The growth form can surely be considered the reflection of changes in space and time of environment. This method will be most effective when light, water and humidity are the limiting factors. The author said above that life-form was a visible reaction to physical factors. But in the case of the growth-form, the biological factors, such as interspecific competition, must be added to the physical factors.

In addition to these, there is another kind of life-form based on vegetation. DRUDE named this the vegetation form following the ideas of HUMBOLDT and GRIEBE. The vegetation form is decided by the dominant or the codominant species. In the climax vegetation, especially, the vegetation form of a dominant species is regarded as a climate indicator. The idea of vegetation form by DRUDE seems different in origin
from the idea of life-form by RAUNKIAER and other, but both are quite alike after all.

(c) Comments on life-form

It is needless to say that the concept of life-form has ecologically an important meaning. It contributes to the subjective evaluation of environment. But all the life-forms mentioned above do not necessarily have efficacy in this respect, and some have lost their importance with the progress in physical chemistry. The reason why Raunkiaer’s idea of life-form still remains useful is, as mentioned above, the fact that he gave due attention to the ecological characters of plants.

Even RAUNKIAER’s theory is not without its imperfections if we look at it from the present-day ecology that has come to pay much attention to the dynamic side of environment, for the study of life-form originated in the static classification of environment. RAUNKIAER regarded environment as a macroscopic reflection of the climate. Of course it was all right as a reflection of one phase of the climate, but it is no more than a reflection of a fixed environment, or static conditions. Looking from another point of view, one can say that his concept of life-form is not entirely exempt from the phylogenetic way of thinking. On the other hand as for the method by growth form, its effectiveness is not clearly to be seen, because the complex results caused by various factors of environment are reflected distinctly.

In the method by life-form, environment is classified with the plant as subject. This idea has, as mentioned above, something in common with the concept of plant indicator. Accordingly we may say that life-form is not different from the plant indicator in essence, but is quite different in its view of environment: the former takes an entirely empirical standpoint, while the latter seems to have, in a way, a scientific system because it implies hypothetic elements based on the results of observation. Methodologically speaking, however, life-form is as a matter of course insufficient for investigating the structural side of environment, for it is based on inductive reasoning.

4) The method by plant phenology

Plant phenology constitutes a part of phenology. Phenology has its origin in the changing figures of living creatures keeping pace with changes of seasons, and deals with season indicators in a wide sense. Phenology has been noticed by farmers since ancient times as a synthetic indicator of environment, as was exactly the case with the plant indicator mentioned above. But in the progress of science, the two have followed different courses: the idea of plant indicator has duly developed itself within ecology, while phenology has been given its place—not always high enough for its real value—within the framework of climatology.

(a) Methodological survey of plant phenology

Phenological observation is being made in various countries, but this does not necessarily mean that scientific importance is attached to it. It is rather because phenology is regarded to be of utility value in its various applications. The methods employed by phenology are confined to observation of phenomena and recording it. Although these methods may provide us with something more than mere routine observational results, it cannot be otherwise than macroscopic manifestations of envi-
environment, and observation by these methods, if limited to a specific area, can hardly have any meaning. England is most enthusiastic about phenology and extremely systematic observations have been carried out. The whole country is parceled out into ten districts and each is further divided into many sections, the entire observational network being composed of nearly 400 sections, with 460 observers. Forty kinds of plants are chosen as objects of observation. Observation is chiefly made concerning anthesis. According to Gunton (H.C. Gunton, 1938), it is one of the requirements of a plant to be chosen as the object of phenological observation that it can be found near at hand, for otherwise we are apt to overlook the phenomena to be observed. In phenology it is surely indispensable to observe the phenomena of a certain plant for many years. If we change varieties and localities year by year, the observation will have little value. In phenology it is important to observe one and the same kind of plant over a wide area. We should get more interesting information, if we increased the kinds of plants to be observed. As a matter of fact, if we increased the kinds, we should be unable to procure the same kinds over a wide area, and moreover we should be much confused in making observation. These facts make us use a very limited variety of plants for practical purposes. In Japan observation of phenology is in fact made by an organization in the Meteorological Agency (Central Meteorological Observatory, 1940). The observation items of plant phenology are germination, efflorescence, crimson foliage, defoliation, untimely germination and untimely efflorescence. The kinds of plants chosen are the camellia, polyanthus, plum tree, violet, cherry tree, mulberry tree, azalea, wisteria, bush clover, chestnut tree and others.


(b) Comments on plant phenology

According to some people, the great importance attached to plant phenology is to be explained by the fact that plant phenology is a synthetic indicator of meteorological elements. This idea is all right in its way, but in actual fact phenological studies are directed toward seeking for correlations with specific meteorological elements. This is a matter for regret. But on the other hand, there are some, like Geiger (R. Geiger, 1952), who utilize plants as aids in obtaining meteorological observation values. This idea, however, is in essence wide of the mark, and shows an extremely facile way of thinking. For those who hold this idea place physical index and biological index on the same level without regard to their essential differences. Plant phenology must inevitably be given a correct position on the basis of phytometer.

5) The method by phytometer

The word "phytometer" consists of two words and, and means plant measures (F.E. Clements, and G.W. Goldsmith, 1924, b). Phytometer cannot be put in
the same category with plant indicator, life form or phenology. It is rather a
method than a measure. It has, however, the same basis as they in considering plants
as indicators of environment. At the beginning of the history of phytometer, atten-
tion was paid merely to how a plant was influenced by environmental factors. But
as physiological botany developed, various changes in the plant's character have come
to be considered as reflections of its environment. The concept of phytometer was
at last established by Clements, giving a basis to ecology as an experimental science.

(a) Survey of phytometer

The idea of phytometer was already contained in the idea of plant indicator.
Improving on the theory that plants are an index of their environmental factors,
Clements considered that the environmental factors reflect themselves on plants in some
way or other, and that accordingly he could judge a habitat through the plants. The
idea of "Organisms as Indicators" has been developed further and has led to the
idea of surveying an environment not by physico-chemical apparatus alone, but by
the response of plants.

As you can easily understand from the above, the phytometer stood on the basis
of the plant indicator at the beginning. But the plant indicator is the reflection of
the static factors of environment and is empirical and descriptive in method while
the phytometer can be regarded as reflections of the dynamic factors of environment,
and methodologically speaking, the former is passive while the latter is very active.
The phytometer was firmly established as a method at the beginning of the 19th
century, and this was due to the great progress in physiological botany. Bonner
(G. Bonner, 1890) made experiments on the transplantation of mountain and lowland
plants, while Clements (F.E. Clements, 1904, b) studied the method of determining
the available water, using various plants. After transplanting several kinds of wild
plants in flower pots and putting them in a dark place or a sunny place, Hessemann
(H. Hessemann, 1904) made a comparative measurement of the amount of transpira-
tion, assimilation, and respiration of the leaves. Clements (F.E. Clements, 1905)
studied the structural variation of plants growing in dark places and in sunny places,
in the Rockies, and tried to clarify the adaptive types. He set wild plants in a
potometer and made experiments in regard to the response of plants in different envi-
nronments (by altitude). Sampson and Allen (A.W. Sampson, and L.M. Allen, 1909),
placing wild plants in a physical measuring apparatus set in a potometer, measured the
quantity of evaporation, in four different environment, and at the same time he com-
pared the quantities of evaporation caused by difference in place: dark or sunny, and
difference in altitude. McLean (F.T. McLean, 1917) established the basic concept in
which he regarded plants as synthetic recording machines and made every first value
of an experiment zero for the purpose of measuring the interrelations between the
growth of plants and the meteorological factors. He took soy beans as the standard
plant and used newly germinated plants in each experiment. He placed plants in two
flower pots filled with the same soil and put one pot at the sea-side and the other
on a mountain, and made comparative experiments on temperature, evaporation and
insolation at these two different places. From the results of his experiment he con-
cluded that temperature is the controlling factor of the growth of a plant for the
first two weeks and humidity, if high, have a strong controlling function for the
following two weeks. By making several experiments on saplings of woody plants,
Weaver and Thiel (F.T. Weaver, and A.F. Thiel, 1917) recognized that there were fairly great quantitative differences of evaporation among different types of plant communities. Sampson (A.W. Sampson, 1919) made an experiment on the influence of environmental factors, choosing beans, wheat and a species of Bromus as the standard plants. Clements and Goldsmith set three experimental fields on Pikespeak, one at the foot of the mountain, one on the mountain-side and one in the sub-alpine zone, during the period from 1918 to 1922. They carried out a detailed research on the adaptive faculties of plants, chiefly sun-flowers, to environment. The results of these experiments have contributed to the establishment of the concept of phytometer.

(b) The method by the phytometer

The establishment and the process of systematization of the idea of phytometer have been described above. The following chiefly concerns the methodological side of this idea. The fact that the phytometer was systematized by Clements was not by mere accident, for stimulus and response were placed at the center of his ecological viewpoint. He regarded all functional and structural changes of plants as the reflection of environment, so that the phytometer directly reflects his basic ideas in ecology.

The following have been employed in the phytometer method: the yield of seed, germination rate, the number of individuals, the rate of survival, the rate of reproduction and the difference of growth, as well as the size and structural changes of a plant. These characters indicate the responses of a plant to environment. Clements proposed several methods to indicate which character corresponds to which environmental factor. The free phytometer, in which plants in the field are used with no control, and the control phytometer, in which plants placed in certain pots are observed in predetermined environmental situations, are two of his fundamental patterns of phytometrical experiment. It is clear that he is taking the position of observing the effectiveness by fixing one and changing the other. In most cases soil and climatic conditions have greater influences on plants than other causes. Therefore the climatic phytometer, which, by adjusting the soil, detects the influences of climate, and the edaphic phytometer, in which the climatic elements are adjusted, can be admitted to be effective methods. We can establish single phytometer or group phytometer according to whether an individual or a community is made the subject of experiment. The former is tried to investigate the adaptation patterns of an individual plant and the latter, of a plant population.

In short, Clements aimed to treat a plant itself as an instrument and make it possible to clarify the synthetic causes and results which cannot be measured by the physicochemical measuring apparatus.

6) Comments on the phytometer method

Many scientists admit that the original idea of phytometer was ecologically very distinguished. Subsequent researches, however, along this line have not been very fruitful. We will discuss the reasons below. It was not a mere accident that Clements placed the idea of phytometer in the center of ecology. This is quite natural if we think of the fact that "stimulus and response" form the methodological basis of his ecology, and that his concept was born within the framework of the biology, especially the
physiological botany, of those days. Clements spent 40 years of his life in making field experiments to solve the problem, "What is adaptation?" The phytometer can be considered to be the stepping stone to clarifying his life work on adaptation. Clements undertook the research on adaptation in 1901. At that time the interest in evolution was centered on evolutional factors and not at the evolutionism. As found in the subtitle of his book "Adaptation and Origin in the Plant World" (F.E. Clements, E.V. Martin, F.L. Long, 1950) he tried to see "the role of environment in the process of evolution" by making clear the relation between environment and adaptation. In the method of his ecology, the phytometer was the fundamental concept in his experiments on adaptation.

(The phytometer means "plant measure". The Japanese word for it "Shyoukubutsu-kei" is certainly not a mistranslation, its content is not properly grasped if it is taken merely as a method of measuring environment by means of plants.)

The phytometer does not try to measure the physicochemical environmental factors by using plants. This is often grossly misunderstood, which is certainly due to the etymological meaning of the world, i.e. "plant measure". Originally Clements did not aim at a supplementary science of environment measurement like phenology, but he tried to find out what factors contribute to a certain response, and for this purpose he sought for the evaluation of environment by quantifying the living creature's response. (Geiger (R. Geiger, 1950) says that phenology is now making rapid progress as one of the important supplementary sciences of climatology. Schnelle (F. Schnelle, 1950) pointed out the close relation between plant phenology and climate or weather, and said that plants could be used as if they were apparatuses for meteorological observation.) Kira (T. Kira, 1951) criticized Clements' phytometer method as follows:

1. The response of plants to be observed, which ought to be one of the most important points, is not selected according to a fixed principle. Accordingly the original purpose of giving a consistent evaluation regarding the physico-chemically various environmental elements as an "ecological value" is not achieved.

2. The actual operations were analytical. That is, the adopted method was first to measure several responses at random while measuring at the same two or three environments, and then to examine the correlations between them separately. This clearly goes against the original purpose.

3. Although the result of the measurement can be shown in numerical figures, the import is quite qualitative, not quantitative.

4. Accordingly this method is useless for analysing environments precisely. Especially the distribution of environmental elements in a fixed time and space can not be grasped at all with his phytometer method.

Kira adds that the phytometer method has proved of no theoretical or practical use. Mitsudera (M. Mitsudera, 1952, a. 1954), too, once criticized it in a similar way. But if we read his "Adaptations and Origin in the Plant World" (F.E. Clements, E.V. Martin, and F.L. Long, 1950), published as the summary of the results of the 40-year experiments, we see that these comments are not strictly right. According to Clements, a plant is a response system due to environment, and the response appears first in its function. This we may call adjustment, while the response seen in structure is adaptation. From this we may say that Kira's accusation of the random way of
selecting the response to be measured is not justified. But his criticism is valid in so far as pointing out the lack of principle in deciding which to choose among the many functions a plant usually has.

Next let us look into KIRA's second comment on the actual operations being analytical and the way of measuring response being planless. If by "analytical" he meant the fact that several conditions must be changed in order to see the plant's response, this was inevitable as a matter of course in experimental operations. Nor can we wholly agree to his comment on the planlessness of CLEMENTS' response measurement. KIRA presents the metabolic phytometer to take the place of CLEMENTS' phytometer, and emphasizes the following three points in his method: (a) the response to be measured is limited to metabolic activity which is the most essential to plants, (b) the result of metabolic activity is grasped as the fluctuations of weight of dry matter and a more exact measurement is attempted than before, (c) it makes possible far more minute analysis as regards both time and space, by making the phytometer itself of as small a scale as possible. We will discuss below whether CLEMENTS' phytometer could be superseded by KIRA's method by virtue of the above three points. As to (a), we can say that the metabolic phytometer is far more backward than CLEMENTS' concept of phytometer, for it is not so much a matter on an ecological level as one on a physiological level. Concerning (b), we say that it may make an exact measurement possible, but it is no use in analysing a plant on the community level. As for (c), it must simply be said to be more analytic than CLEMENTS'. Then what are the weak points in CLEMENTS' phytometer method? If the purpose of this method is to make plants themselves tell of the environment, as CLEMENTS says, the first step is to let the control phytometer take the leading part in finding what elements in the environment generally reflect themselves to what degree in the function and structure of the plant. The second experiment shall make it its object to determine the value of the conclusion of the first experiment in the free phytometer. The third step is to clarify how many per cent of the phenomena in the field can be explained by the result obtained with the control phytometer, and to seek interpretation of those unexplained in the above way. CLEMENTS makes much of the experiment proposed by BACON, NAEGELI, KERNER and BONNIER as one of the keys to interpret the causal relations in a plant communities. The author, however, wants to point out that the actual operation of CLEMENTS' phytometer does not fully contain truly experimental procedure. As TANSLEY says, this must be one of the reasons why he failed to carry conviction with many people in spite of the numerous experiments of transplanting plants in various climates.*

Another questionable point is that CLEMENTS treats the free phytometer and the control phytometer separately. In the case of the control phytometer, he analyses the environment into factors and sets up a condition in which certain factors (to the exclusion of the others) are kept constant, and then he evaluates the effect of this condition. This may not be bad in physiological experiments. In ecological experiments, however, this is merely a process, and not a purpose.

In fact, researches on the phytometer have usually been no more than reports on a case study, which are far from the practical questions. Mitsudera (M. Mitsudera, * A.G. TANSLEY: Obiitary Notice, Frederic Edward Clements This was furnished by Mrs. E.S. Clements as one of the data concerning F.E. Clements.
1948) made an experiment on the relation between dryness and the rolling up of rhododendron (Rhododendron Metternichii) leaves. He could find out that there existed a high interrelationship between dryness in the atmosphere and the roundness of leaves. And at the same time the roundness of leaves had some relation with the quantity of soil moisture.

These experiments were founded on the control phytometer method of Clements, but the results could not be applied to a natural community. This leads us to think that controlled values are artificial and do not give us a faithful picture of nature. We have explained above how the idea was formed and what are the characteristics in method, concerning plant indicator, life-form, plant phenology and environment phytometer.

It is true that these four measures have it in common that plant figures are looked upon as reflecting the environment, but they are not integrated in one as measures of environment. In the subsequent chapters, we will deal with the problem of subjective measures by clarifying our fundamental position in the analysis of environment.

CHAPTER II

Basic Study on the Analysis of Environment

1. Blind spots of the traditional analysis of environment

Environment is neither a mosaic conglomeration of physical elements nor an extension of inorganic substance filling the physical space. It is a quantity which is vitally concerned with the life of living creatures.

The existing autecology (Boysen-Jensen 1932) (P. Boysen-Jensen, 1932) has not given due treatment to environment; both the structural aspect of the habitat and the functional relation between living creatures and their habitat have mostly been disregarded. Then, environment thus conceived is nothing more than an imaginary existence, and the dissected external world does not correspond to the realities of environment. True, light, water or temperature, for instance, are absolutely necessary for creatures to maintain their existence, but the quantity of these elements is a mere abstraction and therefore an imagined amount. As a primary requisite for ecology, environment should be actual and functional in every point.

Why has no contradiction been felt at all in adopting the method of physiological experiment? It is because that it has been falsely believed that in ecology it was possible for an individual to be picked up and separated from the habitat where it had the foundation of life. In fact, ecology without the idea of habitat is nothing but physiology under the name of ecology, though I do not mean to say that the knowledge of physiology is unnecessary for ecology. On the contrary, it plays a really important role in it. But we should put an end to the attempt to frame the methodology of ecology upon the model of that of physiology, i.e. laboratory experiment. In order to know the environment of living creatures, for instance, experimental ecology (autecology) conducts an experiment putting individuals under specific conditions. Surely, it does give quite objective results, but what does this really
mean? Suppose you have drawn some conclusions from experiments on the relationship between the growth of a plant and light, they are nothing but the results in some specific conditions. How can they be connected with natural phenomena of life? The results of such an experiment disregarding the structure of the habitat, are pertinent only to that specific case, and accordingly, the experiment of this sort lacks in universality in its practical application. Needless to say, the experimental method is a very effective weapon for the purpose of clarifying the structure of phenomena.

Synecology is far behind in introducing this method, but this science cannot afford to remain as it is indefinitely. Without sticking too much to chemico-physical experiments, we should trace the principles of experiment back to their origin, and introduce the achievement into the appropriate means of environment analysis. It was perhaps with this in mind that Clements (F.E. Clements, E.V. Martin, and F.L. Long, 1950) commented that the study of ecology always requires experiments of a new type.

2. Logical structure of the environment system

1) Environment system

The idea of ecosystem plays an important role in present-day ecology, as giving us a systematic point of view on the living creatures’ way of existence in space. This idea, however, is not satisfactory when looked at from environment analysis, and, as Numata (M. Numata, 1955, a) points out, lacks a clear view on levels. Miyadi and Mori* say, “We have the simplest ecosystem when we treat the individual and environment as one whole.” But Tansley’s idea of ecosystem was born of a criticism of the idea of biome of Clements and others, taking as its main target the combination of the biome and the physico-chemical elements of environment.

The present writer should like to explain here why the term “environment system” is used in this paper. While in an ecosystem the subject of the system, and therefore the levels, are vaguely recognized, Numata’s “Haushalt”-system has a clear view on levels in the sense of the level on which “Haushalt” develops itself. When the present author uses the term “environment system”, the following two points are to be noted: 1) the levels in the sense in which Numata uses the term are deliberately taken up, 2) the subjective method of measuring environment through the response of living creatures is resorted to, besides the objective method hitherto well known.

The studies conducted by the author were concerned with the population or community level, but of course the environment system can be valid on the individual level. That is to say, the author’s position, fundamentally, is very near to Umesao’s (T. Umesao, 1950) subject-environment system, but the term “environment system” was adopted to make the above two points clear in concrete analysis of the environment system of the plant. In a word, the author intends to analyse the environment of living creatures from the standpoint of the environment system.

2) Spatial Relations of the environment system

Since the object of plant ecology is the life phenomena of plants, we must often

deal with a population, or a community, which is a complex of populations. In this case the environment system is considered to be one of a higher order composed of the simple systems seen in the case of individuals. Needless to say, this is because we have to take account of various inter- and intra-species relations as factors of a higher order, unlike the case of individuals where only comparatively simple relations with the external world, i.e. inorganic matter, come into question. A community always occupies only a certain space, not extending indefinitely. It is spatially defined by the features of the environment system revealed by the relation to the living beings within the community.

3) Environment system and time

Plant life is defined by time as well as by space.

Every species of plant has its own life cycle, which is closely related with the process of succession. Therefore plant life cannot be well conceived apart from time and space. Since the subject changes with time and space, the environment system, which is revealed by its relation with living beings, cannot help changing.

4) Organization of the environment system

The population or community forms an environment system of its own. The population or community has an environment system qualitatively as well as quantitatively different from a mere group of the environment system of the individuals composing it.

Take up, for example, the formation of a bamboo forest. In its earlier stages we have little interrelationship between the species. We have only simple relations between individuals or populations and the external world. However, as different species come in, the environment system of the bamboo forest becomes unstable. [Instability means here the instability in time and space of the environment system, the natural succession having proceeded and the bamboo forest disorganizing itself.] But if the bamboo is predominant in its competition with other plants, the bamboo forest forms a stable environment system. This means that the organization of the environment system has well advanced.

3. Environment system and ecological quantity

1) What is ecological quantity?

By ecological quantity we mean the total amount of changes brought about by the living creatures in their living process. Generally, the term includes not only the amount directly measurable but also every amount of changes conceivable. But practically it includes such elements as amounts of internal chemical changes and of morphological changes, fluctuations in seeds and efflorescence time, or all the changes of phytosociological characteristics. In addition to these, categorical quantity is also included which is to be obtained through a particular treatment of life phenomena developed in polydimensions.
Let the ecological value within time \( t \) be denoted by \( y \), and the state of the environment system within \( t \), by \( S' \), then the relation between the amount of changes in ecological value and the environment system is as follows:

\[
\frac{dy}{dt} = F(S')
\]

Always reflecting the environment system the ecological quantity \( Y \) is in a functional relation with it. On the other hand, environment system \( S \) is composed, as mentioned before, of physical quantity \( E \), representing the external world, and the diagnosis quantity of living creatures \( P \):

\[
S = F(P, E)
\]

The ecological quantity \( Y \) is decided not merely by the living subject, but by the interrelation of the subject and the external world, which is denoted by \( S \). \( S \) may be considered to be composed of the subject and the external world, and the ecological quantity of certain period of time is accordingly to be shown by the interrelation of \( P \) and \( E \).

\[
Y = F(P, E)
\]

The ecological quantity is not influenced solely by the objective physical world, but is the result of the interrelation between the living subject and the external world. We cannot expect any satisfactory explanation of the growing process of communities, from a method of approach that simply adds up physical elements that are wholly irrelevant to the living subject.

2) **Organismic level of the environment system**

The ecosystem includes every level of integration, ranging from biotic society, community, “specie (specific synusia)” population, and individual to levels lower than individuals; and the “Haushalt”-system includes levels from biotic society to population. (M. Numata, ed 1959. b) Since there are levels observable with the living subject, we must find them in habitat. (M. Numata, 1956. M. Mitsudera, 1956. a) For example, we must notice that effective factors in the environment system are different according as we deal with individual bamboos or with bamboo forests. (M. Numata, M. Mitsudera, and K. Ogawa, 1957)

The lowest limit of temperature plays a decisive part in the northern or vertical limitation of the distribution of bamboos on the level of the species, while the amount of soil water makes the primary cause on the level of the population. This view of levels in the environment system is not based on a dualistic standpoint that maintains that different views reveal different structures of phenomena. It signifies much in elucidating the character of the unit in analyzing the ecosystem or life system concretely.

3) **Environment system and measures environment**

In the analysis of the environment system of a population or of a community, the required ecological quantity must preferably be shown as a quantity indicating the whole synthetic changes which take place in the system. Let us now see how useful
are the traditional measures of environment such as plant indicator, phytometer, life form, etc. in the new analysis of the environment system.

The plant indicator has been counted among the measures because it sometimes indicates a decisive factor among the constituent elements of environment. Yet it is not applicable to every case; although we can use it in classifying environment, it is of very little value in a more analytical approach. Life-form is also of very limited use, so long as it is an indication of a preliminarily given object. In this sense it is no better than the plant indicator.

Plant phenology principally reflects the whole body of climatic changes, and if properly approached it will offer us ample prospect of success in analysis of the environment system, though it is traditionally regarded as an auxiliary branch of meteorology and the changes both of individuals and areas are without discrimination dissolved into macroscopic climatic changes. (K. Kreeb, 1954)

4. Experiments of the environment system

According to Elton (C.S. Elton, and K.S. Miller, 1954) there are four stages in the method of obtaining general rules concerning the outdoor life of organisms, namely, 1) descriptive stage, 2) statistical stage, 3) dynamic stage and 4) investigation on productivity. It is true that ecology has historically developed in that process, but it is not indicative of further progress. The task that confronts us at present is to establish method of experiment suitable for each life level.

Take up, for example, the organismic level lower than the individual, and the population of individuals at the “Haushalt” level.

We can easily know that it is evidently meaningless to experiment about a population of individuals separating it from its habitat, while at the organismic level the habitat can be put out of consideration without depriving the experimental results of their meaning.

Experiments on the environment system are of course vitally concerned with the habitat. (This is, in a narrower sense of the word, “experiment in ecology”, and has nothing in common with “experimental ecology”.)

1) Levels of the object and the method of experiment

One of the methods of experiment in biology is one that makes much of exactitude in experiment and lays emphasis on indoor laboratory work.

Another takes the view that it is meaningless to analyze living things putting them under specific conditions because the object is alive and wholly organized.

There seems to be a confusion between these two methods of experiment. The former method lacks in insight into what exactitude in experiment ought to be, and the latter is apt to suppose that indoor laboratory work reduces life phenomena to mere abstractions and is therefore useless. They both discuss the apparatus of experiment, not the essential nature of experiment (T. Kitagawa, 1955. and M. Masuyama, 1950)

Here we re-examine the relative positions of experiments at the “Haushalt” level which is the object of ecological studies. Indoor experiments are conducted chiefly
at levels below the individual, while field experiments are conducted with the greatest effect at the “Haushalt” level of the population or the community.

2) **Indoor experiment** (laboratory experiment)

The current trend of laboratory experiment is towards different measures from those prevailing in the 19th century, owing to the appearance of the phytotrone (F.W. Went, 1957). The objects of laboratory experiment were hitherto limited to the levels which are irrelevant to place, or to cases where controlling many factors relating to place does not deprive the experimental results of their meaning. The appearance of the phytotrone enlarged the scope of the objects. Nevertheless, it is only a step forward in experimental technique; the limit to indoor experiment is still there.

3) **Field experiment** (ecological experiment)

Experiment in ecology, which is a science of the life phenomena of organisms, must always take the field into consideration. Needless to say, any experiment apart from the habitat signifies nothing, however precise and minute it may be. Ecological experiment, therefore, must give the primary place to field experiment (M. Numata, 1958).

Experiments has hitherto been all conducted in the laboratory, for laboratory has been believed to be the proper way by which we could control conditions with greater exactness and also ensure the validity of the result, so as to find out and examine a universal proposition.

Laboratory experiment has its advantage in that it enables us to conduct a highly minute experiment, that is, to make observation on specific data for experiment, within a specific framework of time and space, with specific apparatus and equipments. There are, however, some problems that call for our attention. First, we must consider what kind of experiment is needed to prove the thesis in question. This is the fundamental problem, and considerations of exactitude come after that. For instance, it is ecologically meaningless to repeat experiments about the relationship between the growth of a plant individual and temperature, without paying any attention to the habitat, if we are to find out and examine a general proposition about the habitat of organisms, however precise and minute the experiments my be. Secondly, we must not fail to notice two drawbacks which exact laboratory experiment is liable.

1) The result of a minute experiment objectivity and universality, because it is always conducted under specific limitations in time and space (G. Taguchi, 1957).

2) In indoor experiment the conditions must be kept as required, and this entails high cost. This is nearly impossible in ecological experiment, since it is performed in the open field.

These two weaknesses do not necessarily deny the value of laboratory experiment, but it can at least be said that ecological experiment must not be conceived on the same footing as mere indoor experiment.
As stated before, we consider that ecological experiment should be field experiment, not only because we can not control the conditions so freely as in laboratory work, but because it goes beyond the limits of laboratory experiment in having the field as its object.

4) Field of experiment

Ecological experiment can never be satisfactorily performed by a mere extension (by means of the phytotrone, for instance) of laboratory experiment for the reason just mentioned. Since ecology is essentially a science of the habitat, it simply cannot ignore the habitat. Therefore an experiment peculiar to ecology must deal with the field.

Granting that ecological experiment should be performed in the field, it is almost impossible in most cases to conduct experiment on communities as they actually are. Then only a part of them (the field of experiment) is to be subjected to experiment, and the remaining part can be considered as the field of application, where we may see to what extent the results hold true. (The concrete method will be given later).

5) Management of the field of experiment

It is impossible, for the above-stated reason, to conduct structural analysis of the environment system in the laboratory, but this does not mean that laboratory experiment cannot be applied to such ecological experiment. The author would like now to discuss how the field is controlled in field experiment, namely, how the conditions are managed in the field of experiment.

As has been discussed, the structure of the environment system is based on the interaction between living creatures and the external world, and its object includes upper life levels above the population of individuals. Then such things as the form and nature of individuals forming a population or a community, the historical process of the species and their actual conditions, make the major points of discussion. These are the main effective factors which cause changes in the environment system.

Among the means of control over these factors, stratification comes first of all. Even in this case, ecological quantity may fluctuate a great deal; that is, even if we stratify the plants by factors and measure the ecological quantity, yet the quantity shows an indefinite value. Thus, the spatial distribution of ecological quantity due to individuality cannot be grasped except as the mean quantity in the form of general scientific law.

6) Measuring ecological quantity

Quantification of the object is the first step in environment analysis.

As there are a great number of ecological quantities about the object, it is impossible, in most cases, actually to measure them out, although it seems theoretically possible. The first problem is therefore to determine what parts we should choose to measure. This choice must be made not arbitrarily but from a systematic point of view.
7) **Determination of ecological quantity**

Response of organisms to the external conditions comes out first of all in their function. Functional changes gradually develop into structural changes. By Clements this structural response was named adaptation, and the functional response adjustment.

In order to determine the conditions of plants through the ecological quantity as revealed in functional response, it is the first requisite to find a systematic method by which we are able to see how many independent functions plants have, what they are, how dependent functions develop from them and how these functions are subject to temporal or spatial fluctuation.

(a) Determination by factor analysis

Factor analysis is known to be a way of finding out the function which is used for re-analysis of many and various kinds of variables with fewer variables. No, the part measured for ecological quantities are extremely numerous, and these quantities are in many cases dependent upon one another. Factor analysis then ought to come in to reduce them to fewer variables. (This analysis of factors is also used in the field of psychology. It was originally invented for the purpose of simplifying the complex records of phenomena). The following will illustrate the method by factor analysis in regard to the determination of the parts of ecological quantity.

We had a test in the pasture belonging to the Research Institute of Agricultural Science in Chiba in August, 1958. We wanted to determine the conditions of ladino clover in the group of pastures with as small a number of ecological quantities as possible. One hundred individuals of ladino clover were chosen at random (this does not mean actually cutting them off), and seven kinds of ecological quantity of each piece were measured:

**Runner:** Internodal length

1) Length of the 1st and the 2nd node.
2) Length between the 2nd and the 3rd node.

**Thickness of inter node**

1) Thickness in the middle of the 1st and the 2nd node.
2) Thickness in the middle of the 2nd and the 3rd node.

**Stature:**

1) Height of the 1st stem
2) Height of the 2nd stem
3) Height of the 3rd stem

We measured the above seven ecological quantities. (It is needless to say that more ecological quantities are conceivable.) By calculating on these quantities by a method to be described later, we get the first factor load $K_{ij}$ and the second factor load $K_{2j}$ in factor analysis. The results are shown in Fig. 1. From these calculations we can see the relation of the parts performing independent function. As can be seen in Fig. 1.

The internodal length 1 and 2 can be made into one. As for the stature, it differs considerably from part to part, which shows that the function of stature
varies with the part. Also it can be seen that the thickness of the runner varies with the part.

The above seven elements can be grouped into three heads. The population of individuals was dealt with in the above. When a community is the object of research, we can make use of density, cover, and frequency as measures.

8) **Stratification and randomization**

Stratification is useful in order to understand the meaning of the variables concerning ecological quantity. We may mention, as factors of the environment system, geographical factors, meteorological factors, social factors, nutritious factors, time factors, treatment factors, observation factor and so forth. Different combinations of these factors bring about fluctuation in ecological quantity in the selfsame individual. Therefore, by grouping seemingly the same factors, we are enabled to see the variables of ecological quantity.

If there is still fluctuation in the factors, we classify them by stratification into several groups of phenomena so that factors belonging to one group may be equalized.

But they cannot always be regarded as quantities produced under the same conditions. Such factors of the environment system as properties of the soil, soil temperature, soil moisture, etc. have locally limited fluctuations. Climatic factors such as the amount of insolation, wind, temperature and fertilizers also vary locally. It is not always the case that even within a stratified group they are equally distributed. Then, even if we take measurement of an ecological quantity directly from the strata, its meaning does not become clear. It is true we can not make the conditions uniform as in indoor experiment, but random sampling from a sufficiently large number of individuals minimizes the possibility of individuals under specific conditions being exclusively chosen. Thus we are able to give a systematic “operation” concerning the measurement of ecological quantity, which is summed up as follows:

1) The response of a living being appears in most cases on its functional side. If we can perceive a high correlation among the many functions which a living being possesses, we can reduce the number of ecological quantities by integrating operation.

2) To stratify factor by factor the external conditions which make up the factors of the environment system, if there is much fluctuation among them.
3) To measure the ecological quantity of the parts determined in 1), of each
group or individual classified in 2). (In case of a community, first examine the
measures for a community by the method shown in 1), then, stratify by 2) and repeat
measuring at random by 3).

5. Analysis of environment system

The author would like to discuss the method of analysis of the environment sys-
tem from the view point of field experiment, and the objective method to be used in
synthesizing the results of analysis.

The structure of an environment system consists in an interrelational system of
an individual as a unit and the external world (K. YANAGIDA, 1950). Individual
organisms usually exist in a population or a community.

Therefore, concrete analysis of life cannot be achieved merely by analyzing the
individual, nor can it have ecological meaning if it puts the habitat out of considera-
tion. In such cases, we must devise a way by which we can extricate and grasp in
as pure a form as possible those of the factors which are the object of our research,
that is, which are predominant in the ecological quantity.

Behind the ecological quantity, there lie the factors working in a certain regular
way. Since it is the reflection of these factors, factor analysis must be an effective
method to comprehend its essential nature. The factors in the ecological quantity
that work through the environment system must, generally speaking, be inseparably
interrelated. And from among the possible factors, those that actually contribute to
the ecological quantity are taken up and clarified by this method.

Generally ecology has groups of factors which may be classified into climatic
factors, (A.G. TANSLEY, 1923) geographic factors, edaphic factors, biotic factors, etc.
In some cases, the constituent elements of these factors are known to us. (Take
climatic factors for instance: we can easily know that some elements like temperature,
amount of precipitation, sunshine, etc., are generally more closely concerned with the
ecological quantity than others such as atmospheric pressure, wind direction, wind
speed, etc. And also among edaphic factors the element of soil moisture content is
known to be the relevant element.) Thus when the particular factors are known to
exist, their participation can be studied through the ecological quantity.

Take the ladino clover for instance again. Although we measure the ecological
quantity of individuals in the same stage from a field which is seemingly under equal
climatic or edaphic conditions, yet there is still considerable fluctuation. Competi-
tion for nutrition caused by the density of growth, some micrometeorological changes
or so, may possibly be the causes. Then, what is the main cause? How much in-
fluence does the ecological quantity receive from each cause? The present analysis
ought to be able to answer these questions.

1) Analysis of the environment system (factorial experiment)

Factorial experiment is an effective method only when the participating factors
in the ecological quantity can be grouped according to their nature. Therefore it is
of limited use in analysis of the environment system, that is, it is not available unless a working hypothesis is already furnished. As Kitagawa (T. Kitagawa, 1948) pointed out, this analysis is not sufficient for the purpose of finding out the location of major factors. Hence factor analysis comes in to make up for this defect.

2) Analysis of the environment system (factor analysis)

As MITSUDEMA emphasized in the methodology of phytometer, this analysis is very useful for analyzing the environment system. Its effectiveness has also been proved by NAKAHARA and MITSUDEMA when they applied this method to analyzing the yield of the rice plant from the standpoint of agricultural ecology. Recently GOODALL (D.W. Goodall, 1954) adopted this for classifying plant communities. (In this case, emphasis was laid on classification of phenomena by means of factors rather than on analysis of environment.) By this method the system of factors concerning a phenomenon requires no previous knowledge, but it develops almost automatically by accumulation of measured data. It is for this reason that this method has acquired a wide currency of late years. As Kitagawa (T. Kitagawa, 1948) pointed out, it is noteworthy as a new way of phenomenon analysis. It was stated above that in a realistic study of the environment system, analysis must be performed by repeating the setting up of a hypothesis and making ecological experiments based upon it. And in this methodology, factor analysis in question seems to promise much in its first stage. Let us see how much help this method can offer in analyzing the environment system.

By factor analysis we mean a way to find out a function by which many and varied kinds of variables can be reduced to a small number as has been stated before. In other words, it is an attempt to replace numerous items for examination, as they are often dependent, with the smallest possible number of variables.

Results of test $S_{ij}$, $x_{1i}$, $x_{2i}$, $\ldots$, $x_{qi}$—show the size of factors.

Then, in general, function “$f$” utilizes the primary connection

$$S_{ij} = C_{1i} x_{1i} + C_{2i} x_{2i} + \ldots + C_{qi} x_{qi}$$

$C_{1i}$, $C_{2i}$, $\ldots$, $C_{qi}$ are called factor loads of individual factors in $j$ test.

Solutions in these forms tell that factor analysis is after all based on the theory of multiple correlation. There have been several ways of solution to this analysis, namely, the solution of bi-factor pattern, principal factor solution, centroid solution, averoid solution, oblique solution, etc. Originally this analysis is a mathematical one used in explaining the coefficients of correlation among several methods of test, but it is also valuable for practical use. For example, we can make a fruitful use of it in reducing a large number of plant ecological quantities, and also it is useful for examining by the ecological quantity what environment system a plant has.

True, factor analysis can tell nothing about what a particular factor directly means, but we can give it a deep significance as the axes of factors closely related to the test method by turning coordinate axes by a right angle, by conforming the solutions to already acquired knowledge in each branch of learning, by turning the axes by a right angle on the plane which determines the two factor axes (HOLZINGER
Factor analysis was originally a device to simplify complicated recording, and is theoretically founded on the idea of inferring the parameter, when a model of the phenomenon agrees to the actual data Kendall (M.G. Kendall, 1957). This is akin to the numerical experiment to examine how much a mathematical model corresponds to the atmospheric phenomena, to which no experiment on the ordinary scale is applicable Phillips (N.A. Phillips, 1958).

3) Procedure of environment analysis

The above is the gist of analysis of the environment system. Now we must take notice of the fact that there is a substantial difference between factorial experiment and factor analysis although they are both analytic means of investigation. In factor analysis, ecological quantity $X$ consists of two parts, that is part $IA$, $IB$, $IC$... which depend on several factors $A$, $B$, $C$ and part $Z$ which depends on the other factors. Then the formula of the analysis is:

$$x_{aj} = \sum_{k=1}^{p} a_{ak} F_{kj} + b_{a} S_{aj} + c_{a} e_{aj}$$

Individual $- W_{j}$; the ecological quantity $- x_{aj}$;

$F_{kj}$: Real value of factor $F_{k}$, common factor

$S_{aj}$: Real value of Factor $S_{a}$, special factor

$C_{a} e_{a}$: Error

$$E(\varepsilon_{aj}) = 0 \quad E(\varepsilon_{aj}^3) = 1$$

Such a mathematical formula as this resembles factorial experiment in the mode of thinking, but there is a great difference in the actual way of calculation. Factor analysis aims at analyzing the coefficients of correlation among the measured values, while factorial experiment tries to analyze fluctuation in the measured values. Moreover, factorial experiment gives a qualitative conclusion, such as concerns, for example, the meaningfulness of factors as hypotheses of operations, while factor analysis shows quantitatively the composition of factors that participate in the measured value, i.e. the ecological quantity.

Now, to conclude. We do not use the two methods independently, but as complement to each other.

As the first step of analysis, we stratify the external world by ordinary biological knowledge (for example, into such factors as meteorological elements, soil conditions, etc.), and thus obtain a qualitative conclusion by applying factorial experiment to each stratum. Next, if there is any significant difference observable in some layers, we use factor analysis so as to detect what kinds of factors are latent, which are the common factors and which the specific factors. (In using factor analysis to determine the ecological value, we must examine how many independent functions a living creature has, and according to the result of this, decide the parts to be measured.
Factor analysis as a method of analyzing the environment system is different in standpoint from the above, in that it is in a position to examine how the response seen in the determined part is connected with the environment system.

This is, after all, no other than the method of science in general, which proceeds from qualitative to quantitative analysis.

CHAPTER III

Applications of the Methodology

1. Re-examination of the phytometer method

The method of study concerning the structure of a plant's environment has been described above as a development of Clements' phytomer, together with some criticisms of this method. As an introduction to this chapter some studies of the author's own conducted by this method will be reported first.

The writer's present interest in the relation between plants and environment was motivated by the fact that the vegetation did not agree with meteorological conditions in Sado Island (soc of Presiclet of Primary School. Sado-Gun ed, 1935 M. Nakahara and M. Mitsudera, 1953) (Fig. 2).

The vegetations in Osado and in Kosado appear to be entirely the same at first glance, but, on minute inspection, we come to know there is unexpectedly much differences between the two. For instance, the southern part of Kosado abounds in warm temperate lowland vegetation, while Osado has a lot of mountain vegetation peculiar to the district of Oou (i.e., the northern most part of Honshū Island) and Hokkaido. This fact suggests to us such problems as: Is it possible to conjecture rightly the climate as plant environment from current meteorological observation?; Is it necessary to adopt more microscopic measurement in order to explain such phenomena?; or should we see here the limitations to the chemico-physical way of measuring, as Clements pointed out (M. Mitsudera, 1956, b). With the aim of settling these three problems, the author set about his research by careful examination into the range of climate in Sado Island. But we had to rest satisfied with the investigation of the dates of efflorescence of Prunus yedoensis throughout the whole island, for it is almost impossible to proceed with the examination on a larger scale, because such work would need much more observation stations and measuring apparatuses.

Fig. 2. Vegetation map of Sado Island
1. Alpine-Subalpine Vegetation (Subarctic zone)
2. Mountain Vegetation (Cool temperate zone)
3. Temperate lowland vegetation
4. Warm temperate lowland vegetation
Since the efflorescence date of cherry blossoms is known to fall around the day when the mean temperature is 10°C, the climatic variations over the island can be inferred from the distribution of the efflorescence dates (M. Nakahara, 1943). The author's survey of 70-percent flowering Prunus yedoensis was made in 1947 with the cooperation of some primary school teacher in the island (Fig. 3. A).

The author made a report on the results at a meeting of the Hokuriku Meteorological Club as the first report on applying the phytometer method (M. Mitsudera, 1947). Then and published it he sought for areas resembling in phenological phenomena by the use of phytometer method based on the data in 1947. Table 1 gives us the resembling areas from the efflorescence data obtained in 1947.

The author's next research was to find how the individual plant responds to climatic changes, based on the idea that the natural-growing plant is a reflection of climatic changes, under the leadership of Dr. Nakahara. He examined the relation between changes of the leaf form of Plantago major L. and humidity. Also, he examined the relation between the curl of the leaf of Rhododendron Fauriae and humidity. (1944)

Table 1: Phenological resembling areas (1947) (efflorescence of Prunus yedoensis Matsumura)

<table>
<thead>
<tr>
<th></th>
<th>Sado</th>
<th>Nakaoki</th>
<th>Negai</th>
<th>Urakawa</th>
<th>Kurohime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Date of efflorescence</td>
<td>April 18</td>
<td>April 26</td>
<td>May 10</td>
<td>May 14</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Whole country</td>
<td>Niigata</td>
<td>Akita</td>
<td>Sutsu Hokkaido</td>
<td></td>
</tr>
<tr>
<td>Date of efflorescence</td>
<td>April 18</td>
<td>April 26</td>
<td>May 11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As we see in the above table, the date of efflorescence in Osado is quite near those in Tōhoku and Hokkaido, while on the contrary southern Kosado shows a similarity in date to the areas south of Niigata.

This research proves that the climatic difference is reflected in the difference in vegetation reflects climatic difference (M. Mitsudera, 1948). (This was reported at a meeting of the Hokuriku Meteorological Club in 1948. Part of the report was also published in “Agriculture and climate in Sado Island” in 1953). The climatic difference was also discussed (M. Mitsudera, 1949) from the point of view of instability of the yield of rice.

The author's next research was to find how the individual plant responds to climatic changes, based on the idea that the natural-growing plant is a reflection of climatic changes, under the leadership of Dr. Nakahara. He examined the relation between changes of the leaf form of Plantago major L. and humidity. Also, he examined the relation between the curl of the leaf of Rhododendron Fauriae and humidity. (1944)
As a result it was found that there is a high correlation between the curl of new leaves of *Rhododendron Fauriae* and humidity. (Part of this research was published in the Japanese Journal of Ecology in 1954) (M. Mitsudera, 1954). We measured the curl of leaves of *Rhododendron Fauriae* which grows in each altitude (those which were on the flat ground had been transplanted).

It was found that the higher the altitude, the more curled the leaf is. The relation between them seems to be an exponential functional relation. It seems to show that on the flat ground there is a higher degree of moisture, and that it gets more dry with increasing altitude.

Since the curl of the leaf is also ruled by the moisture of the soil, it is doubtful whether it is an index of the humidity of the air. The author also examined the relation between efflorescence and acclimatization by observations as to the dates of efflorescence of *Rhododendron Fauriae* (transplanted from a 890-meter-high mountain 1939) every year since 1939. We see from Fig. 6 that it takes three or four years for the curve to show stability. (Not published yet).

However, part of this result was quoted by Numata (M. Numata, 1958, b). Throughout all those studies it was the author's aim to reconsider the phytometer method, for the many data by Clements or by Takeuchi do not indicate that the functional amount of variation of a plant always has interrelation with the external world, especially with the climate.

In order to clarify why this is so, stochastically examined, and to ensure an objective descrip-
tion and analysis (factor analysis as stochastics and multivariate analysis) of the response amount of the plant, the author developed the methodology of the phytometer (M. Mitsudera, 1952).

The study then was carried out from 1952 to 1953 on the polymorphism of *Erigeron annuus* under the leadership of Dr. Tsuyama (M. Mitsudera, 1952, b). In 1952, the author studies how the leaf form of *Erigeron* (*annuus*-type and *viridis*-type; especially regarding the distribution of serrations) changes through its life history. He further examined changes of the leaf form through process of growth, and developmental stages based on the time series and on the factorial experiment on the amount of vector.

In 1953 he investigated a community dominated by *Erigeron annuus* with the co-operation of Dr. Tsuyama as a basic study of the phytometer method in order to examine the method of community phytometer. He discussed the relationships between the density of individuals and environment, and discussed also the problem of environment evaluation by comparing community compositions, criticizing Kira's metabolic phytometer (M. Mitsudera, 1954).

At the same time, in order to see whether life form can be used as a phytometer, and whether it is a macroscopical climatic expression or useful for local climatic expression, he examined the relationships between life form and climatic elements on the basis of the already obtained data. He also made a study on the life form in Sado Island (M. Mitsudera, 1956).

Apart from the above studies, he also examined by the data of “Harvest Test” whether or not factor analysis is really useful as a phytometer. (The reason why we used the “Harvest Test” is because there were no pertinent data available) (M. Nakahara, M. Mitsudera, 1952, 1958).

Further a field experiment was carried out in regard to the effect of chlorate soda on the floristic composition of a weed community, (M. Mitsudera, 1957) and also the author took part in the field experiment of a bamboo forest arranged by Dr. Numata and others (M. Numata, M. Mitsudera, K. Ogawa, 1957). On the other hand Kawanabe et al. examined pasture to see if the method is proper (S. Kawanabe, M. Mitsudera, K. Takahashi, N. Tsuneoka, T. Yamada, K. Yoshihara, M. Ueno, 1959). In 1959 we made a survey at the Asama Pasture.

There was no proper method of measuring environment, especially regarding soil moisture, from an ecological point of view. (Since the study of the relationship between the curling of *Rhododendron Fauniae* leaf or changes of the leaf form of *Plantago major* L. and soil moisture, the author has been interested in this problem. But because no proper measuring apparatus was available, it was impossible to undertake the study). Therefore, Mitsudera et al. made a new measuring apparatus of soil moisture by heat conduction (M. Mitsudera, S. Agari, 1955. K. Tsukamoto, K. Takahashi, S. Tsuneoka, M. Mitsudera, 1959). They also designed a recording equipment for a continuous record of the amount of evaporation of a plant.

To summarize the above progress of the author's ecological studies, the following three stages are perceived: The 1st stage --- describing the relationships between vegetation and climate, the method being that of analogy.
The 2nd stage—studying the relationships between the function of plants and environment by the method of transplantation, i.e. transplanting a plant into a different the environment.

The 3rd stage—introducing multivariate analysis as a method of analysis to examine the relationships between changes of a plant community and environment.

These stages correspond to different views on environment. In the 1st stage, environment was treated as a fixed thing. In the 2nd stage, climate was viewed from the point of its effects on the plant, and also quantification of evaluation of environment attracted attention. It was found possible to quantify function but some inconsistencies in application were inevitable.

One of the problems that confronted us in the 2nd stage concerns the transplantation method, which proved inapplicable to a concrete plant community, since this method, though giving us a quantitative account of an element of environment, disregards the interrelation among the elements themselves. Putting the general structure of the habitat out of consideration, this method cannot be expected to give a satisfactory picture of the structure of environment. In the 3rd stage, then, it is necessary to establish a definite method of study by considering afresh what environment is. The first problem that posed itself was how to evaluate the part played by environment, and a definite method of research is necessary for resolving this problem.

Part of the methodology was published in 1952. However, since factor analysis as a concrete analysis of phenomena requires very complicated computation, it is not easy to manage without using an electronic computer as Masuyama (M. Masuyama, 1959) points out. Recently, however, the electronic computer is also available in Japan, and so we can fully examine the methodology.

2. Environment analysis of a bamboo forest

The author would like now to report on this investigation of a bamboo (Phyllostachys bambusoides. Sieb et Zucc) and a forage community, an example of woody and herbaceous plant respectively, which will serve as a fit illustration of his methodology of environment analysis. Usually perennial plants make a better subject than annual plants because of durability as a community, but when in doing experiment on them, they fail to satisfy his desire of having their response completed in a considerably short time. With these points in view, he chose a forage community, the easiest one to be managed of all the herbaceous plants, and also a bamboo among other woody plants. Bamboos seem to be highly desirable materials for experiment because of giving us quick and obvious results by means of annual birth of new bamboo-culms in spite of their modes of life as woody plants. He made use of the bamboo forest owned by the Chiba Prefecture (at Tōyama, in Narita City), which has already been subjected to field experiment conducted by Numata and others since (M. Numata, 1955 b). As we can find detailed accounts of this forest in Numata's research report, let it suffice it to depict only its outlines. This forest, after a part of which had been sold to private persons, still covers a space of about 50 ha. unusually large for one on the level ground. For his experimental purpose he borrowed two ha. of it, which had been miserably laid waste for a certain period of post-war days on account of the reckless deforestation during the war, but has now made some recovery.
Before proceeding to the structure analysis of the environment system of the bamboo forest, he must make a distinction between the two cases, namely the bamboo as a specific synusia and the bamboo as a population. That is to say, a considerable departure, in the order of participation of the environment system for example, is observed when the distribution zone of bamboo-culms is in question, from the case when a population formed in a particular area is the object of analysis.

Water and temperature are the primary factors in the geographical distribution of bamboos, while the depth of surface soil, the facility of draining, the relationship with the windbreak forest and the like seem to make factors of much importance in case of a population.

Now this relationship, i.e. between subject and levels of the environment system, has already been mentioned, he will here limit the discussion to the level of a population.

We must call attention to the fact that a population of and the specific synusia do not exist separately, but are of expressions for different approaches to one simultaneous-spatial distribution, the latter disregarding the individuals and concentrating on the distribution of the species, the former making much of the individuals and taking account of the quality and quantity of, say, each bamboo-culm (Phyllostachys bambusoides Sied et Zucc). If we look for the indexes to the environment of a bamboo forest in the bamboo-culm itself, we can mention the diameter of bamboo-culms, the height of the lowest branching, the number of bamboo-culms, the maximum internodal length, the desity of canopy, the degree of deterioration and so on.

The values measured by these indexes are called the ecological quantities of a bamboo forest, which are supposedly not independent, but for the most part related with each other. And the author's past experience teaches that the degree of recovery of a deteriorated bamboo forest first manifests itself in the increase in the number of individuals and in the height of the lowest branching, and then in the diameter of bamboo-culms. In the present experiment, he took up the size or diameter of bamboo-culms as the condition index, since the bamboo forest is not so extremely deteriorated.

1) Method of analysis

As for the field experiment on the bamboo forest in question, we made first a rough quantitative classification of the factors which are seemingly related with the environment system, and then examined the groups through the application of factorial experiment. Though this is useful in obtaining a qualitative conclusion, we can not expect this to afford us any knowledge about how much these factors affect the ecological quantity. For this reason, his next step was to adopt the method of factor analysis on the basis of the results of factorial experiment so that he might examine the relationships between the factors. The author's intent of using factor analysis consists not simply in checking the conclusion of the factorial experiment. (Factorial experiment takes up factors with a high probability of participation, but in most cases they are unknown).

Here, from the results of factor analysis, a working hypothesis will be proposed, which will be further examined.
2) **Establishment of the experimental field in the bamboo forest**

The bamboo forest under inspection belongs to Chiba Prefecture (at Tōyama, Narita), covering an area of about 120 acres. The growth process of this forest was reported by NUMATA. A field of experiment measuring 100 m × 200 m was set up in the forest, and the field was divided into fifty treatment blocks of 20 m × 20 m, each.

The arrangement of the five treatment blocks was determined by the random arrangement according to the Latin square.

A section of 10 m × 10 m was marked out for experiment in the center of each 20 m × 20 m block. (The arrangement of the blocks is seen in Fig. 7.)

The treatments in the experiment are as follows:

1. No treatment
2. Only new born bamboo-culms of 1955
3. Only three to one-year-bamboo-culms
4. Weeding (only three to one-year bamboo-culms)
5. Soil brought from outside (Ditto)
6. N+ weeding (Ditto)
7. P+ weeding (Ditto)
8. K+ weeding (Ditto)
9. N. P. K.+weeding (Ditto)
10. N. P. K. S.+weeding (Ditto)

Treatments from No. 1 to 5 aim at seeing the relations between the lumbering and the life space for each individual and those from No. 6 to 10 chiefly at seeing the effectiveness of fertilizers (M. NUMATA, 1959, c). Owing to the configuration of the ground, a random arrangement by Latin square was separately provided. Therefore the treatments 1-5 were subjected to environment analysis this time. The data obtained cover the four years from 1955 to 1958.

3) **Outline of experimental data**

According to the above-mentioned design of experiment, he reports here the result of four years' research from 1955 to 1958.

(1) The number of new-born bamboo-culms

Fig. 8 shows the percentage of the number of new-born bamboo-culms to each year's total number (namely, the percentage of the number of bamboo-culms in each treatment block to the total number of all treatment blocks). In Fig. 8 the axis of abscissas indicates the treatment (block) number and that of ordinates the percentage of the number of bamboo-culms.
No. 1 block (i.e. that of no treatment) shows a decreasing number in the first and the second year after the beginning of the experiment, but a tolerable increase in the third year. In spite of the physiognomy of the forest being so ruined, No. 1 treatment block does not seem to be so rapidly deteriorating, judged from the growth of new-born bamboo-culms in 1955.

In No. 2 block, we a large number of new-born bamboo-culms in the second year, but after that, it gradually returned to the incipient condition. One of the characteristics of this block was that almost all the bamboo-culms which came out after two years were slender.

In No. 3 block, new-born bamboos decreased in number after two years, but increased again next year.

In No. 4 and 5, the author has nearly the same results as in No. 3, and they showed an increase in number after three years.

Block No. 6 to 10 are fertilized blocks; therefore, they lie outside the object of the present experiment, and their outline will be given as follows; In No. 6 block (N) bamboo-culms multiplied in the first two years, but in the third year they decreased in number, showing a value less than that of the beginning. No. 7 (P) and No. 8 (K) showed a tendency toward reduction for the first two years, and then increased in the third year. No. 9 (N. P. K.) and No. 10 (N. P. K. Si) closely resembled No. 6.

(2) Breast height diameter of new-born bamboos

In Fig. 9 the abscissas show the treatment numbers and the ordinates the breast height diameter. According to this figure, the diameter in No. 1 block becomes smaller for the first two years. No. 2 block makes a fairly rapid recovery compared with No. 1, and attains far better conditions than at the beginning of the experiment.

In No. 3 and No. 4 blocks, the diameter becomes larger after the treatment, but there is little change in the value of diameter throughout the three years. No. 5 block has poorer marks than the other blocks, though the bamboo trunks attain to
some thickness in three years. In No. 6 block, the diameter size shows a sudden increase for the first two years, and then a decrease in the following year. In No. 7 and No. 8 blocks we can see no traces of treatment effect, in condition of the diameter gets even worse than that of "no treatment" block. Remarkable effect is seen in No. 9 and No. 10 blocks surpassing any other block.

(3) The height of the lowest branching of new-born bamboo-culms

In Fig. 10, the treatment number is given by the abscissas and the height of the lowest branching by the ordinate.

The figure shows the same tendency as that of the diameter, but it is noteworthy that there is a sharp fall in the third year especially in No. 6 block. No. 9 and No. 10 blocks tend to keep or make better the conditions of second-year-bamboo-culms. As for the height of the lowest branching, the position of the mode moves toward a larger value, while the frequency falls for No. 6, 9 and 10 blocks, thus showing exactly the good bamboo-culms and bad ones.

(4) Experimental factors and factorial experiment

As the ecological quantity of the population (experimental groups) in the field of experiment mentioned before, he took the measurement of the bamboo trunks. Factors which are considered to affect the ecological quantity may roughly be classified qualitatively into such groups:

1. time factor (Y)
2. treatment factor (B)
3. biological factor (D)

Factor Y means the total of the groups of factors which can vary with time. (Here climatic elements are actually considered).

Factor B is the total of the treatments No. 1 to No. 5, which were attempted to see the effect of the size of life space per individual.

Factor D is the whole body of individualities or characteristics of individual bamboo-culms that are the direct object of the experiment.

Data

Y: 1955 to 1958
B: treatments No. 1 to 5
D: thirty bamboo-culms, sampled at random.
The results of factorical experiment on the basis of the above are shown in Table 2.

<table>
<thead>
<tr>
<th></th>
<th>SS</th>
<th>DF</th>
<th>MS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
<td>1890.08</td>
<td>3</td>
<td>630.</td>
</tr>
<tr>
<td>B</td>
<td>2103.28</td>
<td>4</td>
<td>525.8</td>
</tr>
<tr>
<td>D</td>
<td>1383.64</td>
<td>29</td>
<td>47.7</td>
</tr>
<tr>
<td>Y×B</td>
<td>2137.86</td>
<td>12</td>
<td>178.2</td>
</tr>
<tr>
<td>B×D</td>
<td>3877.02</td>
<td>116</td>
<td>33.4</td>
</tr>
<tr>
<td>D×Y</td>
<td>2359.27</td>
<td>87</td>
<td>27.1</td>
</tr>
<tr>
<td>Y×B×D</td>
<td>8767.04</td>
<td>348</td>
<td>25.2</td>
</tr>
<tr>
<td>YBD</td>
<td>22518.19</td>
<td>599</td>
<td></td>
</tr>
</tbody>
</table>

\[H_0: \sigma_Y^2=0, \quad F_S=630/178.2=3.54^*\]
\[H_5: \sigma_B^2=0, \quad F_S=47.7/33.4=1.43\]
\[H_6: \sigma_{YB}^2=0, \quad F_S=178.2/25.2=7.07\]
\[H_5: \sigma_{BB}^2=0, \quad F_S=33.4/25.2=1.33^*\]
\[H_6: \sigma_{DY}^2=0, \quad F_S=27.1/25.2=1.08\]

The following is a summary of the results of Table 2. Time factor (Y) has a level of significance of \(\alpha=5\%\) (For the time factor he takes up climatic elements which vary considerably from year to year). This shows that the time factor can hardly be disregarded as a factor in the size of bamboo trunks. Biological factor (D) is also significant \((\alpha=20\%)\), which tells us that there are fairly small differences among the individuals. All this concerns the significance of treatment effects. The next step is towards quantifying the effect of those factors taking part in the ecological quantity which seem to be particularly effective.

Now let us begin with the problem of treatment effect, that is, how bamboo-culms are affected by various treatment conditions, or whether each treatment condition produces an effect independently or not. In order to examine these problems, we must apply the method of factor analysis.

3. The structure of treatment factors

The data used here are the average values for the unit area \((0.5 \text{ m} \times 10 \text{ m})\) in the area shown in Fig. 7. The average number of individuals measured was 100 for each treatment. On the basis of these data, factor analysis was tried. In studies like the present, we must center our attention on the ecological values obtained by following one and the same individual under various conditions. In factor analysis, on the other hand, the interrelation between the ecological quantity and treatment of population in a given time and the independence of each one of populations are discussed.

In this case, the structure of the factor in bamboo-culms is supposed as follows.
\[ x_{a,j} = \sum_{k=1}^{K} a_k F_{k,j} + b_0 s_{a,j} + C_a \varepsilon_{a,j} \]

- **x\_a,j**: \(\alpha\)-th quantity of characteristics (the diameter of the bamboo-culm) of individual \(W_j\)
- **F\_k,j**: the realized value of factor \(F_k\) (common factor)
- **S\_a,j**: the realized value of factor \(S_\alpha\) (special factor)
- **C_a \varepsilon_a**: the observational error

\[ E[\varepsilon_{a,j}] = 0, \quad E[\varepsilon_{a,j}^2] = 1 \]

When a treatment effect is very great, \(S_{a,j}\) (special factor) ought to become large. Next we will discuss the steps of the factor analysis by averoid solution (T. TAKAHASHI, T. KASHIWAGI, 1952).

**a. Normalization**

As we know by experience that the histogram of ecological values (diameter of bamboo-culms) ordinarily has a normal distribution, we didn’t do any special conversion. (But if the frequency curve is not coincident with the normal distribution, it is necessary to do some conversion, though the methods are quite conventional, and have no other meaning than normalizing the values).

**b. Standardization**

The values normalized in (a) of the sample means are symbolized by \(x_{T1}, x_{T2}, \ldots, x_{T_5}\) \((T_1, T_2, \ldots, T_5\) mean treatment numbers), those of sample variation fluctuation, by \(S_{11}, S_{22}, \ldots, S_{55}\), those of standard deviations, by \(S_1, S_2, \ldots, S_5\).

The same standardization of \(x_{a,j}\) is as follows:

\[ t_1 = \frac{x_{1i} - \bar{x}_{T1}}{s_1}, \quad t_2 = \frac{x_{2i} - \bar{x}_{T2}}{s_2}, \ldots, \quad t_5 = \frac{x_{5i} - \bar{x}_{T5}}{s_5} \]

The above formula means

\[ E[\varepsilon_{a,j}] = 0, \quad E[\varepsilon_{a,j}^2] = 1 \]

**c. \(C_{a\beta}=\text{covariance}\)**

**\(Y_{a\beta}\)**: Sample correlation coefficient between two treatments

\[ Y_{a\beta} = \frac{C_{a\beta}}{\sqrt{S_{a\alpha} S_{\beta\beta}}} \quad \alpha, \beta = 1, 2, \ldots, 5 \]

\[ \alpha \neq \beta \]

Table 3. The matrix of the correlation coefficients calculated with the sizes of bamboo-culms in 1956. For the correlation coefficients here, the average values within each block were used.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.123</td>
<td></td>
<td>0.081</td>
<td>0.093</td>
<td>-0.036</td>
</tr>
<tr>
<td>3</td>
<td>0.081</td>
<td>-0.102</td>
<td>0.166</td>
<td>-0.182</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.093</td>
<td>0.166</td>
<td>0.239</td>
<td></td>
<td>0.072</td>
</tr>
<tr>
<td>5</td>
<td>-0.036</td>
<td>-0.182</td>
<td>0.097</td>
<td>0.072</td>
<td></td>
</tr>
</tbody>
</table>
d. Calculation of the Factor Load

As previously stated, there are several methods of factor analysis. We will describe the calculation method of the factor load about the averoid solution. The factor load is calculated as the residual between $S_1, S_2, \ldots, S_5$ (sums of each line in Table 3) and the correlation coefficient. Let $T'$ denote the correction of the averoid solution, then the factor load $K_{ij}$ of the first factor is calculated by the following formulas:

$$T' = \frac{(n-1) T}{n}$$

$$T = S_1 + S_2 + \ldots + S_5$$

$$K_{11} = \frac{S_1}{\sqrt{T_1}}, \quad K_{12} = \frac{S_2}{\sqrt{T_1}}, \quad S_{13} = \frac{S_3}{\sqrt{T_1}}, \quad S_{14} = \frac{S_4}{\sqrt{T_1}}, \quad K_{15} = \frac{S_5}{\sqrt{T_1}}$$

In other words, it is calculated by subtracting the term of the first factor from the corresponding term in the original table of correlation coefficients.

In the above matrix, the term on the diagonal is $K_{ii}$ and the terms of the first row under the line are $K_{11} \times K_{12}, K_{11} \times K_{13}, \ldots, K_{11} \times K_{15}$, and so on for the following rows. Table 4 shows the process.

<table>
<thead>
<tr>
<th>Product matrix of the first factor</th>
<th>Residual matrix of the first factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>1</td>
<td>0.001</td>
</tr>
<tr>
<td>2</td>
<td>0.093</td>
</tr>
<tr>
<td>3</td>
<td>0.169</td>
</tr>
<tr>
<td>4</td>
<td>-0.014</td>
</tr>
<tr>
<td>5</td>
<td>-0.022</td>
</tr>
</tbody>
</table>

Sign-exchange

<table>
<thead>
<tr>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.122</td>
<td>0.012</td>
<td>0.076</td>
<td>0.022</td>
<td>1</td>
<td>0.122</td>
<td>0.012</td>
<td>0.076</td>
<td>0.022</td>
</tr>
<tr>
<td>2</td>
<td>-0.122</td>
<td>-0.104</td>
<td>0.163</td>
<td>-0.182</td>
<td>2</td>
<td>0.122</td>
<td>0.104</td>
<td>-0.163</td>
<td>0.182</td>
</tr>
<tr>
<td>3</td>
<td>0.012</td>
<td>-0.104</td>
<td>0.036</td>
<td>0.144</td>
<td>3</td>
<td>0.012</td>
<td>0.104</td>
<td></td>
<td>0.036</td>
</tr>
<tr>
<td>4</td>
<td>0.076</td>
<td>0.163</td>
<td>0.036</td>
<td>0.104</td>
<td>4</td>
<td>0.076</td>
<td>-0.163</td>
<td>0.036</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0.022</td>
<td>-0.182</td>
<td>0.114</td>
<td>0.104</td>
<td>5</td>
<td>0.022</td>
<td>0.182</td>
<td>0.114</td>
<td></td>
</tr>
</tbody>
</table>

$S_{2j}$: 0.232 0.245 0.266 0.053 0.422

$$T = 1.218, \quad \sqrt{\frac{1.218 \times 4}{5}} = \sqrt{\frac{4.872}{5}} = \sqrt{0.9744} = 0.987 = 0.987$$
The third factor can be calculated by the same process as is shown in Table 5.

Table 5. Product matrix and residual matrix of second factor

<table>
<thead>
<tr>
<th>Product matrix of the second factor</th>
<th>Residual matrix of the second factor</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>----</td>
</tr>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.058</td>
</tr>
<tr>
<td>3</td>
<td>-0.063</td>
</tr>
<tr>
<td>4</td>
<td>-0.013</td>
</tr>
<tr>
<td>5</td>
<td>-0.101</td>
</tr>
</tbody>
</table>

\[
S_{3j}:
\begin{array}{cccc}
1 & 2 & 3 & 4 & 5 \\
1.31 & 0.127 & 0.033 & 0.215 & 0.082 \\
\end{array}
\]

\[
T = 0.588, \sqrt{\frac{0.588 \times 4}{5}} = \sqrt{\frac{2.352}{5}} = \sqrt{0.4704} = 0.686
\]

\[
K_{3j}:
\begin{array}{cccc}
1 & 2 & 3 & 4 & 5 \\
0.191 & 0.185 & 0.048 & 0.313 & 0.210 \\
\end{array}
\]

The results of analysis of the 1st factor \((K_1)\), the 2nd \((K_2)\) and the \((K_3)\) on the bamboo-culms in 1956 are shown in Table 6.

Table 6 shows the degree of effect of factors 1, 2 and 3 on the five treatment blocks. Using \(K_1\), \(K_2\) and \(K_3\) as three rectangular axes, we can show the five treatment blocks as five points in the three-dimensional space. Fig. 11 shows this.

Fig. 11 shows that \(T_4\) and \(T_5\) have independent operational systems. \(T_1\) is affected by \(T_3\) and \(T_4\), and \(T_3\) by \(T_4\) and \(T_5\), so they are not perfectly independent. The author are afraid that the five treatment blocks might result in the same effect, but as was stated above, some treatments proved to have independent operations.

If they have some treatment factors in common, the communality ought to be fairly high, and if each block has its own treatment factors, the uniqueness of the factor ought to be high.
The values calculated by using the above formulas are shown in Table 7. The fact that $h^2$ is very small and $u^2$ large corroborates Fig. 11.

The above shows the degree of the effects of treating conditions upon each experiment population. “Factor score” in factor analysis is used to determine the degree of these effects on individuals.

If the factor score can be used in diagnosing and classifying the positions of individuals, the factor analysis is very effective in ecology. We will make calculation about the 1st factor.

Table 7. Values of communality and uniqueness.

<table>
<thead>
<tr>
<th></th>
<th>$h^2$</th>
<th>$u^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.169</td>
<td>0.831</td>
</tr>
<tr>
<td>2</td>
<td>0.096</td>
<td>0.904</td>
</tr>
<tr>
<td>3</td>
<td>0.187</td>
<td>0.813</td>
</tr>
<tr>
<td>4</td>
<td>0.468</td>
<td>0.532</td>
</tr>
<tr>
<td>5</td>
<td>0.200</td>
<td>0.800</td>
</tr>
</tbody>
</table>

The above shows the degree of the effects of treating conditions upon each experiment population. “Factor score” in factor analysis is used to determine the degree of these effects on individuals.

If the factor score can be used in diagnosing and classifying the positions of individuals, the factor analysis is very effective in ecology. We will make calculation about the 1st factor.

$C_1$: Factor score of the 1st factor

$C_1 = \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_5 x_5$

$\beta_1, \beta_2, \cdots, \beta_5$ are called $\beta$—weight. The simultaneous equations to obtain them are shown in Table 8.

From those equations mentioned above the values shown in Table 9 are obtained.
\[ \beta_1 + 0.123 \beta_2 + 0.081 \beta_3 + 0.093 \beta_4 - 0.036 \beta_5 = 0.278 \]
\[ 0.123 \beta_1 + \beta_2 - 0.102 \beta_3 + 0.166 \beta_4 - 0.182 \beta_5 = 0.005 \]
\[ 0.081 \beta_1 - 0.102 \beta_2 + \beta_3 + 0.239 \beta_4 + 0.097 \beta_5 = 0.335 \]
\[ 0.093 \beta_1 + 0.166 \beta_2 + 0.239 \beta_3 + \beta_4 + 0.072 \beta_5 = 0.607 \]
\[ -0.036 \beta_1 - 0.182 \beta_2 + 0.097 \beta_3 + 0.072 \beta_4 + \beta_5 = -0.052 \]

We will apply these values to the following formula,

\[ C = \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_5 x_5 \]
\[ C = 0.243 x_1 - 0.335 x_2 + 0.188 x_3 + 0.605 x_4 - 0.129 x_5 \]
\[ \beta - \text{weights of } K_1, K_2 \text{ and } K_3 \text{ are shown in Table 10.} \]

![Fig. 13. Normal and abnormal score of the first factor based on the rejection ellipse (\(a=0.05\)). The ordinates show the possession of the first factor in every fifty aerial shoots of bamboo by the factor score. The abscissas show the diameter (cm) of bamboo-culms.](image)

Using the above conclusion, we can discuss the structure, giving ecological values of the experimental community (sizes of bamboo-culms Rt) and the factor score of the 1st factor (F_1) as the axis of co-ordinates.

Here the values of Rt are obtained by sampling fifty at random from the experimented plants. In Fig. 13 Y-axis is F and X-axis is Rt (showing in deviation). The rejection ellipse is shown on the 5% level of significance.

Fig. 13 shows that in this experimental community, the values of the relation between Rt and F_1 are within a certain bounds except two values. This indicates that the increase of F_1 leads to the decrease of Rt.

These conclusions are obtained for the 1st factor only. We can determine the normal or abnormal zones of the other factors by separating the factor scores of the 1st, 2nd and 3rd factors using the discrimination function.

| \hline
| \( \beta \) | \hline
| \( \beta_1 \) | 0.243 |
| \( \beta_2 \) | -0.335 |
| \( \beta_3 \) | 0.188 |
| \( \beta_4 \) | 0.605 |
| \( \beta_5 \) | -0.129 |
| \hline

| \hline
| \( K \) | \( K_1 \) | \( K_2 \) | \( K_3 \) |
| \hline
| \( \beta_1 \) | 0.243 | -0.241 | 0.169 |
| \( \beta_2 \) | -0.335 | 0.001 | -0.019 |
| \( \beta_3 \) | 0.185 | 0.228 | -0.018 |
| \( \beta_4 \) | 0.605 | 0.008 | -0.270 |
| \( \beta_5 \) | -0.129 | 0.375 | 0.013 |
| \hline
We discussed the effects of treatment conditions of life space in the experimental community upon each individual, using factor analysis. Next we will discuss the structure of the time factor $Y$ on the basis of factorial experiment in Table 2, as $Y$ has an important effect on the ecological value (the diameter) of the bamboo.

The data were obtained from one hundred individuals sampled from the treatment blocks $T_1, T_2, \ldots, T_5$.

The analysis of the time factor is to measure the diameters of one hundred bamboo-culms from 1955 to 1958 and to study the changes.

Table 11 shows the matrix of the correlation coefficient of the treatment block No. 1, and its calculated amount of loads of the load of factors, and $\beta$-weight.

<table>
<thead>
<tr>
<th></th>
<th>1955</th>
<th>1956</th>
<th>1957</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>-0.184</td>
<td>-0.005</td>
<td>0.354</td>
<td>-0.265</td>
</tr>
<tr>
<td>$K_2$</td>
<td>0.017</td>
<td>0.237</td>
<td>0.075</td>
<td>-0.098</td>
</tr>
<tr>
<td>$K_3$</td>
<td>0</td>
<td>0.271</td>
<td>-0.161</td>
<td>0.097</td>
</tr>
<tr>
<td>$K_4$</td>
<td>0</td>
<td>0.233</td>
<td>0.117</td>
<td>0.508</td>
</tr>
</tbody>
</table>

Table 12. Result of treatment “2”.

<table>
<thead>
<tr>
<th></th>
<th>1955</th>
<th>1956</th>
<th>1957</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>-0.184</td>
<td>-0.005</td>
<td>0.354</td>
<td>-0.265</td>
</tr>
<tr>
<td>$K_2$</td>
<td>0.017</td>
<td>0.237</td>
<td>0.075</td>
<td>-0.098</td>
</tr>
<tr>
<td>$K_3$</td>
<td>0</td>
<td>0.271</td>
<td>-0.161</td>
<td>0.097</td>
</tr>
<tr>
<td>$K_4$</td>
<td>0</td>
<td>0.233</td>
<td>0.117</td>
<td>0.508</td>
</tr>
</tbody>
</table>

Table 13. Treatment “3”.

<table>
<thead>
<tr>
<th></th>
<th>1955</th>
<th>1956</th>
<th>1957</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>-0.184</td>
<td>-0.005</td>
<td>0.354</td>
<td>-0.265</td>
</tr>
<tr>
<td>$K_2$</td>
<td>0.017</td>
<td>0.237</td>
<td>0.075</td>
<td>-0.098</td>
</tr>
<tr>
<td>$K_3$</td>
<td>0</td>
<td>0.271</td>
<td>-0.161</td>
<td>0.097</td>
</tr>
<tr>
<td>$K_4$</td>
<td>0</td>
<td>0.233</td>
<td>0.117</td>
<td>0.508</td>
</tr>
</tbody>
</table>

Table 14. Treatment “4”.

<table>
<thead>
<tr>
<th></th>
<th>1955</th>
<th>1956</th>
<th>1957</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>-0.184</td>
<td>-0.005</td>
<td>0.354</td>
<td>-0.265</td>
</tr>
<tr>
<td>$K_2$</td>
<td>0.017</td>
<td>0.237</td>
<td>0.075</td>
<td>-0.098</td>
</tr>
<tr>
<td>$K_3$</td>
<td>0</td>
<td>0.271</td>
<td>-0.161</td>
<td>0.097</td>
</tr>
<tr>
<td>$K_4$</td>
<td>0</td>
<td>0.233</td>
<td>0.117</td>
<td>0.508</td>
</tr>
</tbody>
</table>
4. Considerations on the time factor

We will proceed to consider the time factors in each treatment on the basis of the above results.

Treatment 1.

In Fig. 14 the relative positions of factors in each year are shown by rectilinear coordinates with $F_1$ as ordinate and $F_2$ as abscissa. If, as can be seen from the two figures, 1956 and 1957 are considered to have appeared in one independent factor system, the effect on the ecological value was positive in 1956, and negative in 1957. 1955 and 1958 were not in simple relation, but they show mutual relation to the second factor.

### Table 15. Treatment "1." 

<table>
<thead>
<tr>
<th>Year</th>
<th>1955</th>
<th>1956</th>
<th>1957</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>−0.060</td>
<td>−0.020</td>
<td>0.061</td>
<td></td>
</tr>
<tr>
<td>1956</td>
<td>−0.060</td>
<td>0.040</td>
<td>0.064</td>
<td></td>
</tr>
<tr>
<td>1957</td>
<td>−0.020</td>
<td>0.040</td>
<td>0.069</td>
<td></td>
</tr>
<tr>
<td>1958</td>
<td>0.051</td>
<td>0.064</td>
<td>0.069</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Load of Factors</th>
<th>1955</th>
<th>1956</th>
<th>1957</th>
<th>1958</th>
<th>$\beta$-weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_1$</td>
<td>0.053</td>
<td>0.298</td>
<td>0.235</td>
<td>0.149</td>
<td>$\beta_1$ = −0.038</td>
</tr>
<tr>
<td>$K_2$</td>
<td>0.044</td>
<td>0.213</td>
<td>0.075</td>
<td>−0.021</td>
<td>$\beta_2$ = 0.280</td>
</tr>
<tr>
<td>$K_3$</td>
<td>0.023</td>
<td>0.192</td>
<td>0.006</td>
<td>0.017</td>
<td>$\beta_3$ = 0.215</td>
</tr>
<tr>
<td>$K_4$</td>
<td>0.000</td>
<td>0.186</td>
<td>0.000</td>
<td>0.000</td>
<td>$\beta_4$ = 0.119</td>
</tr>
</tbody>
</table>

Fig 14. Factor system of Treatment "1"  
Fig. 15. Factor system of Treatment "2"

Treatment 2.

In Fig. 15 we find three independent types of functional factors: in 1957; 1956; and 1955 and 1958. The functional factors in 1957, 1958 and 1955 belong to the first
factor system, and that in 1956 belongs to the second factor system. There is a converse correlation between the result obtained in 1957 and that of 1958 and 1955.

**Treatment 3.**

When we rotate $F_1$ and $F_2$ by 45° (Fig. 16) the relative positions of each year become clear. The results obtained in 1955 and 1956 belong to the system of action of $F_1$, while the results obtained in 1958 and 1957 are found on the axis $F_2$ and belong to the system of $F_2$. There is a converse correlation between the results obtained in 1958 and 1957.

![Fig. 16. Factor system of Treatment “3”](image)

**Treatment 4.**

Although the factor system in Fig. 17 is not clear the results can be roughly classified into two factor systems when we rotate the axes of $F_1$ and $F_2$ by 45°. The results obtained in 1955 and 1957 are included in the system $F_1$ and those obtained in 1958 and 1956 are included in the system $F_2$.

**Treatment 5.**

Here, as Fig. 18 shows, one factor system covers all the results except for 1956. That is, the results obtained in 1955, 1957 and 1958 are included in one system and only the result obtained in 1956 is affected by the interrelation between $F_1$ and $F_2$.

The characteristics of the factor system of those treatment will be concluded as follows: The treatments 2 and 5 have only one factor system ($F_1$), and the treatments 3 and 4 have two factor systems. The treatment 1 must constitute another type, though it may be included in the first type as $F_1$ has a greater load of factors.

Fig. 19 represents the structure of the first, second and third factors of the treatment 1 in three-dimensional space.
We calculated $K_1$, $K_2$, $K_3$ and $K_4$ as time factors and made table of them for each block (Tables 11-15).

Except for a few special cases $K_1$ and $K_2$ have predominantly large loads of factors, while $K_3$ and $K_4$ very small ones.

We have calculated time factors block by block from the microscopic point of view. Now we are going to see what is the overall structure of factors, including the treatments 1-5.

Table 16. The matrix of the correlation coefficients (the original table)

<table>
<thead>
<tr>
<th></th>
<th>1955</th>
<th>1956</th>
<th>1957</th>
<th>1958</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td></td>
<td>-0.086</td>
<td>-0.035</td>
<td>0.022</td>
</tr>
<tr>
<td>1956</td>
<td>-0.088</td>
<td></td>
<td>0.023</td>
<td>-0.011</td>
</tr>
<tr>
<td>1957</td>
<td>-0.035</td>
<td>0.023</td>
<td></td>
<td>-0.013</td>
</tr>
<tr>
<td>1958</td>
<td>0.022</td>
<td>0.011</td>
<td>-0.013</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>$K_1$</th>
<th>$K_1$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1955</td>
<td>-0.270</td>
<td>-0.034</td>
</tr>
<tr>
<td>1956</td>
<td>0.227</td>
<td>0.051</td>
</tr>
<tr>
<td>1957</td>
<td>0.132</td>
<td>-0.012</td>
</tr>
<tr>
<td>1958</td>
<td>-0.086</td>
<td>0.014</td>
</tr>
</tbody>
</table>

Table 16 shows the results of the author’s examination of the time factors by obtaining the values of the bamboo-culm of the average individuals for each year. (The average individuals were selected according to the distribution shown in Fig. 7, the unit area being 50 m x 0.5 m).

Looking at the relative positions of the factors on the rectangular coordinates of $F_1$ and $F_2$, we see that all the values of 1955 to 1958 (Fig. 20) belong to the first factor system.
The above results show that the first factor system holds, as a time factor, the dominant place in this bamboo forest. But it is not clear from the calculation what this really means. Therefore we must make an experiment to find out what is the first factor, (i.e., what is the actual factor working singly as a time factor on the size of bamboo-culms).

5. An experiment concerning the time factor

According to the above results, the sizes of bamboo-culms greatly change every year and the factor seems to have a single operation system. On the basis of the knowledge hitherto obtained, we must now seek for a working hypothesis on what the first factor actually is, and examine how far the experiment supports it.

1) Hypothesis

Bamboos, unlike forest trees, grow rapidly in a short period of time. UEDA (K. UEDA, 1955) points out that the growth period of bamboo-culms (Phyllostachys bambusoides) is several dozen days and they become mature and cease growing by the time summer comes. The growth period of the species which we took up for experiment is said to be something between 25 and 40 days after the young shoot first came above the ground. One of its characteristics is that the main trunks never grow after this period. Taking this characteristic into consideration, we can regard the meteorological elements during the growth period as one of the chief factors which have influences upon the sizes of bamboo-culms.

It may be true that the meteorological elements not only during the growth period but also after, that is, during the period of the growth of the subterranean stem, must be taken into account. But here, for convenience's sake, we take up only the growth period.

As the meteorological elements which affect the growth of bamboo-culms, temperature (including soil temperature and air temperature) and the amount of rainfall may be first mentioned (on the assumption that fertilizers and soil conditions do not change with time). Although temperature and the amount of rainfall are equally important, they affect the growth of bamboos differently. (It is needless to say, in this case, that both work as factors not in dependently but in close relation to each other, though, of course, one may predominate over the other in some cases).

We know by experience that temperature has the effect of advancing the date of the sprouting of bamboos. (For instance bamboo sprouts come out along the isotherm of 17°C–18°C in spring). But temperature cannot be a direct affecting factor of the...
growth of bamboo. The author mean by this that the amount of the changes in weather and temperature in the field of experiment is not sufficient to explain the amount of growth. In considering the amount of rainfall, too, we should not ignore temperature as one of the average conditions of the field. On the contrary, the amount of rainfall during and around the growth period is experimentally admitted to be a directly working factor. We will discuss the problem taking up the amount of rainfall in June as a single and actual factor in determining the size of bamboo-culms.

2) The first factor and the amount of rainfall in June

If, for the reasons above, we take up the June rainfall as the time factor $F_1$, what correspondence to the factor load calculated in Table 20 can we find? This is the problem that now confronts us. (The growth period of the bamboo begins in May, but meteorological data oblige us to choose only June rainfall.)

In Fig. 21 the axis $Y$ shows the value of $F_1$ (factor load) and the axis $X$ the amount of rainfall in June (yearly ratio). We used the values of the amount measured at the Tokyo Central Meteorological Observatory, for this seemed more proper than adopting those of the Choshi Meteorological Observatory.

As Fig. 21 indicates, the values of $F_1$ coincide well with the changes of the yearly ratio of the amount of rainfall in June. When the amount of rainfall decreases, the value of $F_1$ negatively becomes greater, and when the former increases the latter increases positively.

But the relation of the two is not simply linear, for as the rainfall amount exceeds the yearly mean, the value of $F_1$ slows down its rate of increase.

$$Y=0.2\{1-e^{-0.0579(X-50.568)}\}
$$

$X$: the amount of rainfall in June

If the first factor exactly shows the amount of rainfall in June, the time factor in this community is satisfied with a rainfall of 200-300 mm in June. (The average rainfall in June here is 166 mm. Kyūshū, which is known as the zone suited to bamboo, has an amount of rainfall more than 300 mm).

The above consideration leads us to think that if this hypothesis is correct, this community must be lacking in water. Accordingly we have to make an experiment on the quantity of water which an individual needs a day, and on the total quantity of water which an individual consumes through the growth period.
3) The method of experiment

The results obtained above still remain hypothetical. They must be proved through an experiment. A discussion of the water economy for a bamboo is required from the reasons stated above.

(1) Water economy of phyllostachys bambusoides

To aim at a complete measurement of the water economy of the bamboo we have first to measure the amount of water consumed by it during its growth period and in other periods, and next make a research on the relation between the evaporative quantity and the meteorological elements.

There is no method to measure the water economy under natural conditions, and forest physiology (T. Satoo, 1958) employs the cut-shoot method, water culture method, etc. Water economy resulting from life phenomena can not be measured by these method. The author designed an evapori-meter which makes it possible to measure water economy under conditions as natural as possible. See Fig. 22 and Photo 1.

(2) The experimental apparatus

A in Fig. 22 shows a soil tank, B het meter of soil moisture devised by Mitsudera
and AGARI, 150, C the water level adjusted in the soil tank, and D an equipment to regulate the water level. F indicates a magnet valve, G the part recording the evaporating quantity, H a reservoir tank, I the electric circuit for E, and J and K the meters for B. The operating procedure is as follows. Give water to the bottom of D and A from H through F. There is a float within D, and above it an electric connecting part E, which automatically makes electricity flow when the water level comes down.

![Graph](image1)

**Fig. 23. Automatic recording by the transpirometer**

![Graph](image2)

**Fig. 24. Characteristic curve of the measuring apparatus for the soil moisture**

![Graph](image3)

**Fig. 25. Automatic recording for soil moisture**
Suppose that water has been given to the soil tank A up to the level C. When the water is consumed and the change in C makes E operate (but 2 seconds after), the secondary circuit is closed, and the closed magnet valve F operates to open the water canal from H. Then the water is sent to D and A from H. Thus we can trace the change of the water level, and keep it constant automatically. By recording the change of the amount of water, the amount of consumption of water is known immediately. The soil surface in the soil tank is covered by a sheet of vinyl as shown in Fig. 21. When the distribution of soil moisture in the soil tank is not equal, the recording contains experimental errors. Therefore we ought to record after ensuring a uniform distribution of soil moisture by the soil moisture meter. The record (Fig. 23), the characteristics of the soil moisture meter (Fig. 24), and the amount of soil moisture obtained by automatic recording (Fig. 25) are shown here.

4) The results of experiment

The above described apparatus was installed in the bamboo forest which was the object of the experiment. The measurement was started in August, 1958, to be continued for one year. We failed, however, to get exact data because of the imperfect management of the field of experiment. We made a second attempt from August 7 to 13, 1959. The bamboo-culms selected were the new-born ones of 1959.

Fig. 26 is the record measured on August 8 (fine weather, average wind velocity 3 m/sec). Before the author begins the experiment, he checks the inclination of soil water in the soil water in the soil tank (The measurement must be made when the water level gets stable
at a certain point. In his experiment it took about two days). See Photo 2.

He could see that one bamboo culm consumes 1000 cc of water per day according to the data measured in the experiment made on the 9th. (In this case he cut off some of the roots of bamboo culms because a drum-can was used as a soil tank. Therefore this amount must be less than that of natural ones). In our experimental community the density of the bamboo-culms was 1.6/m². The necessary amount of water per day, then, is 1.6 l, and the necessary amount of water per month becomes 48. On the other hand the amount of rainfall in June is 160 mm, which is equal to 160 l/m².

A fundamental formula* of the water economy is generally shown as follows:

$$M = R - (E + F + G)$$

where

- $M$: the increasing quantity of soil moisture
- $R$: the amount of rainfall
- $E$: an evapotranspiration quantity of water (evaporation from each + the quantity of transpiration)
- $F$: the quantity of surface runoff
- $G$: the increase in the quantity of underground water

According to this formula, the incomings and outgoings of water at the bamboo forest in June are as follows:

- $R = 160$ l/m²
- $E = 105$ l/m² + 48 l/m²
- $F = 0$
- $G = 48$ l/m² (Calculated as 30% of the quantity of rain water during one month)**

So,

$$M = -48$$ l/m², which distinctly shows a lack of water.

In this calculation evaporation from the bare ground is more than twice as much as that from the surface of water (Soc. Agr. Met. ed 1954), but we are not concerned with the bare ground in this case, so evaporation here was obtained by multiplying the value of evaporation from the water surface by the number of days.

Damages of roots are not allowed for in the above experiment. If they were, want of water would be more distinctly shown. In some other parts of this bamboo

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* Handbook of Agricultural Civil Engineering, Tokyo, Maruzen, 1957
** Dictionary of Agricultural Meteorology, Tokyo, Yokendo, 1954
forest, the bamboo trunks, the levels of which are twice to three times as heavy (whole fresh weight being about 13,000 gr.) as the specimen examined, grow as thick as, or even thicker than it in the author experiment. In this case want of water will be far more distinctly seen. Considerations given above are based on the mean value of the normal rainfall in June. But as is shown in Table 8 each rainfall except in 1957 is below the average, and so the hypothesis that the rainfall in June is the first factor becomes the more probable.

From the relation (Fig. 21) between the first factor \( F_1 \) and the rainfall in June, we have seen that 200-300 mm of rainfall in June will be sufficient so far as the time factor is concerned. \( 41 \text{ l/m}^2 \), which was shown to be the amount of water insufficiency, is equal to 41 mm of rainfall. This is, then, the amount necessary to keep the water economy in a balanced state, and this fact supports the author’s hypothesis.

6. Summaries on the environment analysis of the bamboo forest

1. The results of the factor analysis upon some treatment fields show that the environment structure of the bamboo forest is extremely complicated. But when we consider the conditions of the treatments in the abstract the functional systems of factors in the analysis of overall experimental plots have proved simpler than we expected.

2. To know what the unique and definite factor is, the author set the amount of June as a working hypothesis, on the basis of our knowledge and experiences upon the varying tendency of the loads of factors.

3. The results of the experiment seem to confirm the hypothesis that the ecological value, the diameter of the bamboo-culm, is much affected by the insufficiency of the soil moisture in June.

4. Besides, the results of the factor analysis show the possibility of analysing the concrete structure of the time factor, though the amount of rainfall in June is not the only factor in the changes of the ecological value (the size of the bamboo-culm).

5. As the above results, the author think he can prove the high usefulness of the field experiments (the ecological experiments) in solving practical problems as a method of structure analysis upon the plant environment.

7. Environment analysis of a forage community

1) Methods of analysis

In this paragraph we describe the environment analysis of the artificially ladino-clover \((Trifolium repens L. \text{ RACE GIGANTUM})\) cultivated in the Institute of Agricultural Technology, Feed Crops Section. First we discuss how the inter nodal length of ladino clover which is cultivated in four small sections, each about 1 m × 5 m in area, is affected by the structure of environment. If the soil, the climate (i.e. microclimate), and the cultivating conditions are uniform, the value of the common factor in factor analysis ought to be large. On the other hand, if they are not, the unique factor will be large.
From the four blocks 100 individuals were chosen as average individuals with the distributions shown in Fig. 27, and the ecological value was measured, taking the length inter node from the second node to the top as object. The results were then subjected to factor analysis. Fig. 28 shows the relative positions of the factors using the first factor \( F_1 \) and the second factor \( F_2 \).

![Fig. 27. The arrangement of the blocks](image)

![Fig. 28. Factor system of a forage crop (ladino-clover)](image)

In this figure, the four sections are seen to be almost independent of each other, and especially the sections 3 and 4 show practically perfect independence. Although the sections 1 and 2 have some similarity, between them, their relative positions are different. From this the hypothesis above, which claims that the kind of seeds, soil and climatic conditions the four sections are the same throughout, is very doubtful. Therefore the author examined the origin of the seeds of the four produced. The seeds in the section 1 were the first crop gathered in the Institute of Agricultural Sciences after their importation from U.S.A.

The seed of section 2 were the kind which were imported by Iwate Livestock Breeding Farm from U.S.A. in 1951, and the plant is cultivated for 3 years, the seeds of which, in 1954. The same number of seeds was used in both sections.

The seed used in the second 3 were like those in section 1, but were obtained from individuals of a presumably different type. In section 4 the author showed which were originally imported from the U.S.A. in 1952 by Hokkaido Kami-Nopporo Livestock Breeding Farm and gatherd them in the same way as in the sections 1, 2 and 3. Though it is not possible to conclude immediately from the above that the seeds of the four sections are hereditarily different, from each we may presume that their past histories make their characteristics different enough. Accordingly, if we assume that the soil and the climate are the same (in this case, the quantity of seeds diffused is the same in each section), the situation of each section in the co-ordinates of the first factor and the second might be different from each other.
2) **The structure of environment factors**

Now let us examine the relation between the factors and the yield of the seeds which have outwardly different characteristics.

As is noticed in Fig. 29 their relation is such that as the factor increases positively the yield increases. It does not at once follow from this that the first factor depends on the characteristics of the seeds, but it is possible to think that this will provide us with a working hypothesis (weight per 20 cm was used here).

In the above case the author made an experiment in an extremely small area. He made then an experiment on ladino clover in Asama pasture in Gunma prefecture.

He chose 8 sections, each 1000 m apart from the others, for the purpose of experiment, but this time only the sections 1 to 4 and 6 were employed. Each experimental section is of 10 m 5 m in area. The ecological quantity which is used here is indicated by the thickness of the widdle part of the second inter node from the top of the runner.

The author measured one hundred average individuals which were sampled out of the above five sections by means of the arrangement in a distribution as shown in Fig. 30, and tried factor analysis on the results.

The relative connection thus obtained between $F_1$ and $F_2$ is show in Fig. 31. This figure shows the relative positions when $F_2$ is rotated by 45° on its axis. From this figure, we can see that all the sections are situated nearly along the $F_2$ axis. Accordingly, the factor in relation to the thickness of the node is considered to be of a single system. Let us examine what it actually is.
Table 18. The matrix of the correlation factors

<table>
<thead>
<tr>
<th>Ra_{ij}</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-0.102</td>
<td>0.102</td>
<td>0.236</td>
<td>0.187</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>0.102</td>
<td>-0.102</td>
<td>0.202</td>
<td>-0.003</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-0.102</td>
<td>0.010</td>
<td>0.070</td>
<td>0.072</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>0.236</td>
<td>0.020</td>
<td>0.070</td>
<td>-0.392</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0.187</td>
<td>-0.030</td>
<td>0.072</td>
<td>-0.392</td>
<td></td>
</tr>
<tr>
<td>S_{ij}</td>
<td>0.423</td>
<td>0.129</td>
<td>0.050</td>
<td>-0.066</td>
<td>-0.186</td>
</tr>
</tbody>
</table>

Table 19. The load of factors

<table>
<thead>
<tr>
<th>Ra_{ij}</th>
<th>K_{1}</th>
<th>K_{2}</th>
<th>K_{3}</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.803</td>
<td>0.710</td>
<td>0.654</td>
</tr>
<tr>
<td>2</td>
<td>0.244</td>
<td>0.156</td>
<td>0.146</td>
</tr>
<tr>
<td>3</td>
<td>0.094</td>
<td>0.053</td>
<td>0.056</td>
</tr>
<tr>
<td>4</td>
<td>-0.125</td>
<td>-0.061</td>
<td>-0.072</td>
</tr>
<tr>
<td>6</td>
<td>-0.351</td>
<td>-0.058</td>
<td>-0.025</td>
</tr>
</tbody>
</table>

Fig. 31. Factor system of ladino clover stand

Fig. 32. Relationship between the second factor and the depth of surface soil

Fig. 33. Factor structure of ladino clover stand
In this case it is clear that the soil and the climate are more or less different, from section to section, because the experimental section are arranged ranging over several Km. Here the author examined the relationship between the depth of surface soil and $F^2$ of each experimental section, since the growth of grass is empirically known to differ in the depth of surface soil. The result is shown in Fig. 32.

As seen from the figure, the value of $F_2$ and surface soil are positively correlated. It also agrees with our experience that the surface soil is the factor. (Fig. 33 shown the structure of factors three-dimensionally by the values obtained in Table 19). The author should carry on the same experiment here as he did on the bamboo forest, but here he confines himself to showing to what extent factor analysis is useful as a method.

8. Summary of the environmental analysis of the forage community

In the analysis of the bamboo forest the author took up the more effective factors, ignoring its individual character, i.e. the past histories of the individuals. In the case of the forage community, it was made clear that one of the factors which influence the environmental system under fixed external conditions, differs with the characters (past histories) of the seeds. And as a result of the experiment in the Asama Pature, It was found that the structural factor in the environmental system, in case of leaving the past histories of the seeds out of consideration, is greatly affected by the soil factor.

CHAPTER IV

Ecological Meaning of the Methodology Environment Analysis

1. Position in ecology of the methodology of environment analysis

It would be needless to develop the methodology here if environment analysis only aimed at an analysis of chemicophysical quantity. The ecology of today, which is called an ecosystem ecology, is no longer an autecology, which treats an individual as a unit, nor synecology, in which we treat a plant community in a closed system. Its chief object is to study the structure of the field, as a science of the life field of organism.

The concept of environment as completely enclosing an organism is now out of date. It is impossible to explain the actual state of life phenomena from a fixed, preconceived view of environment. Each physico-chemical element has no meaning in itself. For it to have any meaning, it must be grasped and evaluated in its actions on and reactions from the living organism.

Synecology has not paid due attention to the structure of environment. The experimental ecology also was apt to ignore the structure of environment. This was largely due to its methodology which considered experiment impossible without neglecting many factors in the habitat. It is true the in an ecosystem ecology the viewpoint on the life phenomena of organisms showed great change from previous ecology, and
took up the idea of ecosystem, but no satisfactory method was found to comprehend the actual structure of it. That is to say, the unit of the system and the way of evaluating environment were not clearly understood. The method of gradient analysis of Whittaker (R.H. WHITTAKER, 1951) is one way of interpreting environment. However, it is available only when environment is primarily determined by a specific element. Plant indicator or life form is useful in the sense of classifying the habitat by the specific conditions determined through the living subject; however, they are useless when you are to treat the more dynamic aspects of the habitat system. In other words we can make use of life-form or plant indicator only when it is considered that the environment system is unchangeable by the time factor.

It is needless to say that the methodological basis of environment analysis is the phytometer method. The ecological meaning of the phytometer was explained and the comments on Clements' phytometer method were presented above. The theory that environment should be evaluated through plants, however, is very important in today's ecology. Several people made attempts to develop this idea of Clements' but they have failed to establish convincing methods. (M. NUMATA, 1947. a.b. M. NUMATA, T. KATO, 1949, T. KIRA, 1951)

The reasons why Clements' phytometer method has been of little use in actual environment analysis are as follows: it lacked the theory about the habitat; it was not clear about the relation between experiment and application; it stood upon the physiological point of view for the basis of experiment (contradictions between laboratory experiments and field experiments), and we could obtain knowledge on the individual but none on the habitat.

The above method of environment analysis is based on the idea of phytometer, but it is fundamentally different from Clements' in that it took up not the individual but the group as the object of experiment. (The experiments by Clements were done in the field, yet the basis of his thinking could not go beyond the bounds of laboratory experiments. For instance, the transplantation phytometer is typical of this, and the community phytometer makes use of the growth and transpiration of the plant community as an index. As for growth it is mainly calculated with the cutting method, and transpiration is measured by the sodcore method. It is clear that he deals with individual plants as separated from the original plant community. From these experiments we can not grasp the dynamic phase of "Haushalt"-system nor can we clarify their structure.)

2. Meaning of phytometer in methodology

Clements made an experiment to connect the reaction quantity with a specific condition. In this paper the author tried to clarify the relation between the overall conditions in the field life and the reaction quantity. This is a great departure from Clements, though in both cases the phytometer method is followed. The response quantity of plants (ecological value) should be considered as the whole of conditions which constitute the field of life. It is disregarding the actual conditions to consider it as depending on a specific condition. Experiments done along these lines will produce merely imaginary results and have no actual effectiveness.

The phytometer method should be a method of environment analysis through the actual life patterns. Accordingly the main point of this method should be an analy-
sis using an ecologinal quantity (a reaction quantity) which is measured under natural conditions. Since ecology treats the habitat, we can not rest satisfied with indoor experiments, which separate the plant from its habitat and makes it impossible for us to follow its changes in time. In view of these characteristics of ecology, a new type of experiment must naturally be devised. Here, in place of laboratory experiments we adopted ecological experiments in which stochastics and multivariate analysis were introduced.

As seen from the above, the author’s methodological basis lies in the phytometer method, which in this case, did not remain in a method of analyzing environment but provided a basis for functional treatment of plant ecology. (For instance, we have J.A. Major’s (J.A. MAJOR, 1951) relative equation between a plant community and a group of factors

\[ V = f(C_l, P, R, O, T) \]

where \( C_l \): climatic factor,
\( P \): edaphic factor,
\( R \): topographic factor,
\( O \): biotic factor,
\( T \): time factor

In this case, however, the value of \( f \) can not be determined). In factor analysis as a method of multivariate analysis we can discuss it concretely by a model experiment (numerical experiment).

3. Functional approach to plant ecology and its methodology

Supposing there are \( m \) factors as variables of ecological value, it is possible to indicate to what extent we can explain with these factors. For instance, take \( Z_j \) for an ecological quantity and the sum total \( \sum_{a=1}^{m} a_{aj}^2 \) of the square of the load amount of the factor \( a_{aj} \) will be 1. But in the actual case, because it includes the unique factor, it will be smaller than 1.

Communality : \( h_j^2 = \sum a_{aj}^2 \)

Uniqueness : \( u_j^2 = 1 - h_j^2 \)

The formula to show the degree of the average contributing rate will be

\[ f = \sum h_j^2 / K \]

In summing up on the method of analyzing environment described above, the author can mention the following as the salient features of his method: the method of analyzing environment was based on the phytometer; field experiments were resorted to for concrete analysis; the method of multivariate analysis was introduced. By means of the above procedures plant ecology can begin to be quantified.

The author should like to emphasize, especially, that the ecological quantity has been determined in a consistent way as the basis to find an environment system and that he can proceed with analysis through the ecological quantity, so long as the life phenomena can be, as Major and others say, represented as the functional relations between plants and the external world. Accordingly the structural functional relationship may be considered to occupy an important place in the ecological law.
Conclusion and Summary

Let us arrange the points of argument on the structure of plant environment:

1. It is true that environment has been considered to be a very important problem in ecology. The attention has been centered upon measuring the external world objectively in its actions on the living organism, while the measurement of the action subjectively, i.e. through the response to the part of the organism, has mostly been neglected. The present author attempted to analyze environment from the point of view of environment system.

2. The method of environment analysis which has hitherto been employed was that of comparing various combinations of physical elements. This can not be a direct proof concerning environment, nor was analysis conducted in a consistent way.

   The author has established the method of field experiment and showed the possibility of analysis in a consistent way through the ecological quantity.

3. As for the environment structure, he made it clear quantitatively, though it is different with the organismic levels of plants. At the same time he showed that it is possible to clarify the time and spatial structure of the environment system concretely.

Summing up further the above three points, we can say that the plant ecology has hitherto been mostly regarded as an explanatory science or an extension of plant physiology, because it lacked a methodology of environment analysis of its own.

   In the author’s experiment he could take one step forth in the methodology of environment analysis on the basis of the phytometer method.

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植物の環境構造

三寺 光雄

環境把握の方法として示されたClements の phytometer method の批判を試みることによって、ある程度環境の数理的解析の方法を示した。そして、この方法が具体的にどのように役立つかマダケ林と牧草群落について適用した。
その結果
1. 本実験の対象となった千葉県成田市遠山におけるマダケ林では、竹の生長に関する制限因子は蒸発期における土壌水分の不足であることがわかった。
2. 牧草群落 [浅間牧場における] の生長に関する制限因子は気候的要素ではなく、表土の厚さが早い程生長が良好となることを確かめることができた。