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GROUPEMENT D'ETUDES ET DE RECHERCHES POUR LE DEVELOPPEMENT DE L'AGRONOMIE TROPICALE

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by

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PREFACE

In producing this methodological specification, the authors have attempted to bring out the results learned in nine years of multidisciplinary experience passed in countries as various as Madagascar, Mali, Upper Volta, and Niger. For reasons of conciseness, only the general principles leading to the idea of « Operational Ecology » are worked out here, examples of the application being described elsewhere.

By creating the Programme of Interdisciplinary Research on the Locusts and Grasshoppers of the Sahel (P.R.I.F.A.S.) with the assistance of the Aid and Co-operation Fund of the French Republic (F.A.C.), the Study and Research Group for the Development of Tropical Agronomy (G.E.R.D.A.T.) (*) has given to the team of which the authors form a part, the opportunity of applying, on a really large scale, the principles of operational ecology. The authors wish to express their gratitude here for this opportunity.

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INTRODUCTION

The study of the relationship between organisms and their environments has made real advances starting at the moment when Man has begun to disturb his surroundings seriously. Ecology has therefore become a science of the first importance involved in day to day life. The most important result has been making the public aware of the problem of nuisance, of pollution, of the unchecked degradation of the « environment ». In trying to preserve the natural habitat of Man, ecologists have denounced with conviction and sometimes even with violence the excesses of various agricultural, forestry, or industrial enterprises, and the senselessness of certain developments.

As it happens, economists and developers are those most exposed to criticism since their work consists precisely in modifying the environment according to economic, financial, political, or social criteria. Placed, rightly or wrongly, in the place of the accused, they have developed a certain reticence as concerns ecology, as this science appears to them to be in general a further restricting factor. The few attempts that have been made to associate this discipline to their plans of campaign have been discouraged because of the impossibility of making the necessary research fit in with the urgency of the execution of the programmes. Moreover, too often, ecologists have endeavoured to understand the mechanism of ecological systems, from the basis of studies of the micro-surroundings, a scale on which it is difficult to integrate the interaction of the many factors involved in a satisfactory manner.

In a semi-arid tropical zone, the unsuitability of ecology to economic realities seems partly due to a methodological deficiency which it is necessary to remedy by reconsidering the type of approach to the organism/environment relationship. The term organism is used here in its widest meaning and indicates the various living beings and the communities that they form. The subject treated is limited to studies carried out in a semi-arid tropical zone (the Sahel of West Africa) although the basic principles that will be mentioned have a general validity.

The developing countries have limited food resources dependant on ecometeorological conditions. The equilibrium existing between the human populations and the supply of food is precarious, and constitutes a limiting factor for economic development. The prospect of hydro-agricultural developments in the naturally priveleged areas such as the valley of the River Senegal, the flood plain of the Niger in Mali, the Middle Niger, or the Lake Chad has naturally beguiled the countries concerned, who have seen the possibility of increasing their agricultural production, and of preserving it at least in part from the meteorological hazards by means of control of water over large areas. Each experiment carried out on a large scale is characterized by a first euphoric period giving rise to the greatest possible expectations. Later on problems linked to diseases, crop pests, or in the human context, considerably reduce these hopes, and in some cases, the situation becomes so critical that the investment is no longer profitable because the cultivated land is devastated by insects, rodents, and birds, to mention only a few of the pests. International aid sometimes manages to contend with these pests by financing protective and preventative measures, but it must be recognized, on the one hand, that these are not always effective, and on the other, that they cannot be borne financially by the farming community and that they contribute to the disturbance of agrosystems. It becomes clearly indispensable, therefore, to consider the application of a protective strategy for the developments based on precise knowledge of the ecological equilibrium of the regions concerned.

To emphasize the wish of promoting an ecology directly usable by the planners, the expression « operational ecology » has been chosen. It means the perfecting of a new method of investigation based on the latest ecological concepts, and capable of providing the best guarantee of obtaining results that can be employed by developers in short, medium, and long term. It is in this sense that the term operational should be understood. This form of ecological approach implies a rigourous choice of objectives and of methods of operation to attain them.

The development of a territory with a view to its agricultural improvement consists in replacing a more or less ancient and well adjusted ecological equilibrium, not considered sufficiently favourable for economic and social development by a new equilibrium better adapted to the present and future needs of the human populations. Before any development is started it is essential to acquire a sufficient knowledge of the pre-existent system in order to define the objectives that it is possible to reach by a transformation of the surroundings, the means to be employed, and the protective measures to be envisaged (BOUR et al. 1974). The vigilance of the ecologists and the flexibility of the project must be maintained until the new ecological equilibrium has been reached and stabilized.

Operational ecology is founded on a sufficient knowledge of the ecological entities to be able to draw from it lessons directly affecting the potentiality of the development. The principle of the ecological analysis proposed is experimental observation, an idea that needs to be defined. The aim pursued is to arrive as quickly as possible at an ecological synthesis by the expedient of the theory of the ecological optimum and the domain of the survival of species, a synthesis that should lead to the forming of a model opening up the prospects of planned development. This type of study, to be well carried out, demands an integrated research team in direct contact with the economic realities.

In a later part of this document, the problem of crop pests will be taken implicitly or explicitly as an example to introduce various ideas useful to the definition of a new strategy for ecological research. It is none the less true that the principles set forth have general validity and that a simple adaptation will allow possible users to treat the problems with respect to their specific interests.

1. ECOLOGICAL ENTITIES.

1.1. *Basic ideas of biogeocenosis and of the ecosystem.*

In ecology, the reference unit is the biogeocenosis (SUKACHEV, 1954). This idea is relatively simple to define on the theoretical level : it consists of a group of plant communities (phytocenoses) and animal communities (zoöcenoses) and of their environment, between which more or less close relationships exist that constitute the ecosystem in the sense proposed by BOURDU (1968).

In practice, the delimitation of biogeocenoses becomes delicate, because they are all interlaced to varying degrees in a vast world wide continuum : the biosphere. Such a statement is not very heuristic in its immediate application, but it should be kept constantly in mind by the ecologist (PRENANT, 1934).

At present, the terminology of this discipline in course of development is far from being fixed, and if different terms often cover closely related concepts, it sometimes happens that the same name is given to differing concepts. Biogeocenosis (ecosystem of LAMOTTE and BOURLIERE, 1978 or in a more restricted sense, ecobiocenosis of MOLINIER and VIGNES, 1971, following ODUM, 1959) is generally the reference element in ecological studies. It is convenient to give it a modular structure, in the interior of which four fundamental units can be distinguished :

— the surroundings,

— the communities of autotrophic organisms,

— the communities of heterotrophic organisms,

— the ecosystem.

For methodological reasons in investigation, three sub-units are identified within the heterotrophic communities :

— the microconsumer communities,

— the macroconsumer communities, from which are separated,

— the human communities, because the action of man is not only to be found at the macroconsumption level, but is also a factor in the surroundings, that influences the other species significantly.

A diagrammatic representation of the biogeocenosis is given in Figure 1.

The study of biogeocenoses is undertaken by two complementary approaches, one described as structural and founded on autecology and synecology, the other described as functional, covering the cenological studies.

Cenological studies aim at analysing the ecosystem belonging to each biocenosis by determining the operational balance for the various elements of the biogeocenosis (LAMOTTE and BOURLIERE, 1967). The complexity of the ecosystems generally compels researchers to work on relatively simple functional units (trophic levels, for example). The ultimate goal is to know the importance of each species within the biogeocenosis. This work has great theoretical interest, and important practical consequences can reasonably be expected in the medium and long term. Additionally, this type of approach deserves to be continued, for excellent results have already been achieved on this theme (DUVIGNEAUD, 1974 ; LAMOTTE and BOURLIERE, 1978). It corres-

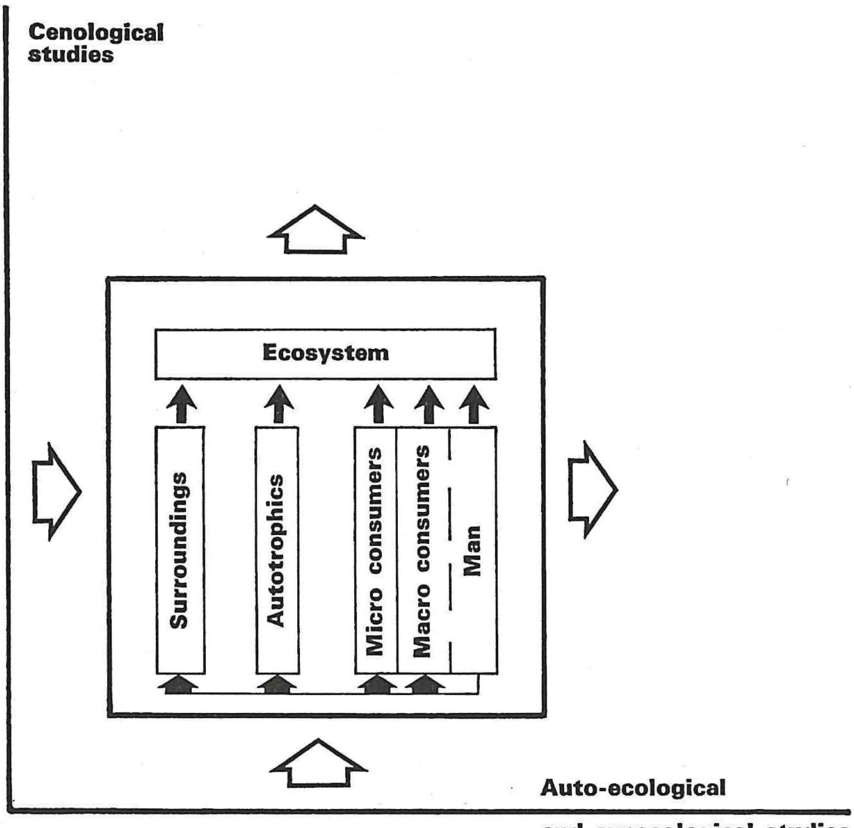

Figure 1. — Diagram of a biogeocenosis.

ponds, however, to an ecological integration which at present has no direct connexion with the type of understanding required for development in the short term. It is for this reason that the emphasis is put on other forms of ecological approach to introduce the idea of operational ecology.

Structural studies consist of breaking down the biogeocenosis into elementary communities belonging to the same system : plant associations, ornithological associations, locust and grasshopper communities... In each community, the ecological behaviour of the various species is then analysed, and the entirety of the researches enables the general structure of a biogeocenosis (or of a constituant community) to be built up on the basis of the ecological constitution and of the population dynamics of the species involved. Structural study enables the level of the investigation and the integration of the data obtained to be chosen as a function of the required results. The choice of the dimensions and the number of biogeocenoses is a decisive factor for success. As the conditions of generalization are clearly laid down from the sampling selected, in consequence, it is very suitable for regional studies. The limits of the biogeocenoses are established by relying on the existence of natural dividing lines. To bring out basic ecological entities, the quickest method consists of identifying the plant communities which are known to reflect the totality of the ecological conditions in which they exist by their physionomy and their floristic composition. MOLINIER and VIGNES (1971) propose the ecobiocenose as the « ecosystem unit ». It is defined on the basis of the limits of the individuals of plant associations. In practice, it seems preferable to adopt a more flexible strategy adjusted to each object of study, whilst retaining the idea of the biotope whose limit corresponds to that of one or several plant associations (VERDIER and QUEZEL, 1951). The systematic use of delimitation of biogeocenoses according to the limits of the individuals of associations provides a high level of reliability to the required observation generalizations since the factors of space and time are taken into consideration.

1.2. *Basic ideas of the environment and its inhabitants.*

The environment indicates the totality of the ecological conditions which affects the organism : plant species, animal species, or community of species. This concept is relative : the environment is only significant as it concerns the organism inhabiting it. At the extreme, with no inhabitant organism, there can be no environment (GUINOCHET, 1973). There is only a space described on the basis of arbitrarily chosen criteria, whether physical, chemical, or biological. Each organism lives in its own special environment. To take an example, the environment of a locust is different from the environment of the plant association in which it develops. Information on the biogeocenoses obtained by study of the plant communities must therefore be adapted and completed in order to describe the environment of the locust but they form a homogenous work basis.

The environment of an organism is the resultant of a number of factors whose conditions evolve in time and space. These factors can be grouped together in two fundamental components :

— static components,

— dynamic components (DURANTON, 1975, 1976 a).

The static components correspond to stable conditions, or those that evolve slowly, in the environment. For a plant association, this could be the type of soil and the climate, for a phytophagous animal, it would be the distribution of the plant groups. The idea of the relative stability of these components which integrate in the medium and long term the instantaneous variations of the environment must be emphasized. These historical conditions, also called integrating conditions are noticeable at the level of the species as they determine their distribution.

The dynamic components indicate the fluctuating conditions of the environment, those that are sufficiently instable to be noticed immediately at the level of the individual. They have direct effects on the population dynamics (LAUNOIS, 1974 a, 1974 b) and, in the last analysis, they are essentially eco-meteorological conditions. Their historical resultants are integrated at the species level.

Each year a space/time mosaic of dynamic conditions superposed on the static conditions occurs in the distribution area of each species. This seasonal change of the environment is particularly great in semi-arid tropical zones on account of the alternation of the dry season and the rainy season, and more so as the rainfall is the more irregular. The organism must rely on some part of this mosaic to ensure its existence and the perenniality of the species. Some species move away, others have some form of resistance that allows them to survive in difficult conditions (LECOQ, 1978).

An effective study of the environment must take into account the two components which have just be considered. Different types of environment can be identified and characterized by using the plant groups as the reference elements (REY, 1967) reflecting the static conditions. Their description is specified by frequentative studies of the seasonal variations of dynamic conditions.

1.3. *Listing the types of environment by the study of the groups plant.*

The physionomy and above all the floristic composition of the plant groups are linked to the static conditions of the environment. A particular combination of these conditions that can be assimilated to a type of environment corresponds to each plant community. *Vice versa,* each type of environment is characterized by a particular plant community (GUINOCHET, 1973).

A plant community is a collection of species brought together within a homogenous structure. The plant group takes on a different signification according to the criterion chosen to define homogeneity. It is for this reason that it is necessary to distinguish plant formations from plant associations. Plant formations are groups physionomically homogeneous, whilst plant associations are groups with homogeneous floristic composition. Associations enable a more accurate analysis to be made for completely different associations can have similar physionomies and because of this belong to the same formation. The floristic composition of a savanna varies according to its geographic origin. Moreover, within the same formation, different associations can coexist, making up particular phytocenoses according to the plant species of which it consists. In this way, the phytocenoses of a savanna with trees can be formed of several associations :

- — a woody heliophile association,
- — a grassy heliophile association,
- — a skiaphile grassy association,
- — possibly a termitophile association,
- — and several cryptogamous associations.

The elementary floristic group is the association. Not all plant associations have the same ecological significance, depending on whether they are extensive or specialized (DURANTON, 1975).

Extensive associations occupy considerable surfaces and are in ecological equilibrium with the conditions of the meso-ecology. They enable regional types of environment to be characterized and localized.

Specialized associations in general cover restricted surfaces. They only receive the effect of regional ecological conditions indirectly because they depend on particular conditions occurring locally : hygrotrophy, rocky outcropping... Their identification leads to an understanding of the types of environment within a region.

The chorology of extensive associations therefore enables the zones submitted to the same meso-environment to be localized. Surfaces ecologically homogeneous are called natural regions. Their ecological complexity is easily discovered by making a list of the specialized associations which occur there.

Simple mapping of the plant associations enables the diversity of types of regional environment to be determined qualitatively and quantitatively. The upper level phytosociological units decide the grouping of natural regions in floristico-ecological domains. In West Africa, the division into large eco-botanical domains until now carried out on essentially physionomic bases (CHEVALLIER, 1900 ; AUBREVILLE, 1949) ought now to be specified by a systematic floristic study of the plant associations so as to bring to light the particularities of the various natural regions of the zone.

The phytosociological analysis of the plant cover enables the list of types of environment to be put together rapidly by basing the study on the floristic composition of the groups found there. This objective approach has the advantage of being available with small material means.

The recommended method of specifying the types of environment having been described, it only remains to identify them by exactly defining the ecological conditions relating to each of them.

1.4. *Identification of types of environment.*

In the first place, it is convenient to mark, on a suitably scaled map the limits of the surfaces colonized by the various plant groups recognized as a result of the phytosociological analysis. Each group is thus placed in space (localization, area affected). This is the first phase of identification.

In the second place, all the ecological data on the environment available in the bibliography are grouped together in complex ecological factors (climate, hydrology, pedology, human influence...) and mapped separately on the same scale as the plant communities.

By proceeding in this way, the total of available knowledge can be used by a simple superposition of maps to bring out the common or differentiating characteristics of the various types of environment specified.

The number of criteria taken into consideration should be great enough to characterize each natural region without ambiguity. In extreme cases, an identification key of the dichotomic type will underline both the common points and the differences and allow a layman to recognize each type of environment.

These general data act as a basis for the definition of the environment of each species and to make their ecological situation clear.

This initial balance sheet has the advantage of integrating the totality of the previously acquired knowledge in very varied domains, and to add recent observations to it. It compels the research worker to search each region in a homogeneous manner, inaccuracies or lacunae being unmistakeably indicated at the moment when the maps are put together.

Starting from this general study, it is possible to construct a research programme designed to specify the characteristics of a natural region, in general one that will be the subject of development, by knowing in what context the subject is treated. The types of environment relative to the plant communities will act as the basis, whatever the circumstances, to the study of the special environments of the organisms concerned. Then it is possible to have recourse to more sophisticated methods giving very exact information for the most important cases (LONG, 1974, 1975).

2. ECOLOGICAL ANALYSIS : EXPERIMENTAL OBSERVATION.

2.1. *Choice of the scale of the study.*

No ecological survey should be undertaken unless the scale of the study has been clearly defined from the beginning (LEMEE, 1978). This basic selection should take into consideration both the objects to be achieved and the means disposed of. This initial choice is most important because it conditions all the concerted methods of approach. The scale of the study ought to allow an overall approach to the problems that is in agreement with the use which it is intended to make of the results, by taking up a position as close as possible to the local realities without, however, losing oneself in a set of ecological anecdotes. The compromise must be made according to the required exactitude of the results and not according to an apparent, but often illusory, accuracy.

Ecological studies are conceived on three scales :

— the micro-scale,
— the meso-scale,
— the macro-scale.

These conceptions have a relative meaning, and they depend on the object of the study.

The micro-scale is adapted to a study at the level of the individual. The accuracy obtained is very great, but the sampling is not usually made on a great enough number of individuals to allow of correct extrapolation. Starting with very accurate data, it is only too easy to draw incorrect conclusions when they are put into a more general context. The final value of the results depends on real possible circumstances for producing generalizations.

The meso-scale corresponds to studies at the level of populations. Of course, the accuracy of the measurements is lower, but the results have a more general application.

The macro-scale is found at the level of the totality of populations belonging to the same species or to the same ecological entity. In general, this type of approach is inadequate if not supported by solid investigation at the meso-scale level.

A particular environment level and suitable methods of approach correspond to each of these scales. They allow different thresholds of understanding of phenomena, often interwoven with each other, to be achieved. As far as development problems are concerned, operational ecology is most paying in the short term at the meso-scale level. The macro-scale serves to place the results in a more general context, and the micro-scale helps by clearing up in some special cases, as in a study of the behaviour of certain pests or local phenomena of factor compensation.

As a first approximation, it can therefore be concluded that studies in operational ecology are made at the meso-scale. Extensions, as necessary, can be added by studies at the macro-scale and the micro-scale, when the objectives warrant it.

2.2. *Basic ideas of experimental ecological observation.*

To anyone capable of observing, Nature forms a vast laboratory, where significant ecological experiments are being carried out on a really large scale. The research scientist must therefore adapt his methods of investigation to the material that he is studying. From this point of view, random sampling techniques are frequently banned in favour of opportunist sampling ; that is, exploiting the special natural ecological situations (LAMOTTE and BOURLIERE, 1969 ; GOUNOT, 1969). All the cases observed are regarded as being so many priveleged situations, allowing the interpretation of more general situations. In this way, by a study of pests in a given place, facts can be deduced that are able to explain events on a continental scale. This has been demonstrated on a number of occasions as far as locusts and grasshoppers are concerned (LAUNOIS, 1973).

Each year, the static and dynamic components of the environment combine to make up a space/time mosaic more or less favourable to each species. The scientific approach consists of observing the behaviour of the species faced with very varying ecological situations arising simultaneously or consecutively in its area of distribution so as to obtain as much information as possible in order to bring out the ecological constitution of the species.

Experimental ecological observation consists of the simultaneous study of the environment and of the populations present at a given moment, describing the environment by the characteristics significant for each species. A complete observation takes into consideration the precarious equilibrium observed in the present and, if possible, in the recent past to judge the availability of individuals. All the observations carried out in ecological situations as different as possible are then brought together so as to bring out the positive and negative correlations. The processing of the data can be made by proceding by analogy and cross-checking. New techniques of data analysis (correspondance factor analysis, analysis by principal components, discriminatory analysis, automatic classification methods...) are very valuable tools because they make it possible to expose the profile of the phemomenon starting from observed facts.

Experimental ecological observation makes the supposition that the observer is capable of describing the environment on the basis of complex ecological factors which have a strong probability of affecting the plant or animal species and that a certain equilibrium will arise temporarily between the surroundings and the living creature (GODRON et al., 1968 ; DURANTON, 1976). To limit the number of observations, the natural situations that seem simplest should be given priority in study, those that are more complex or that have a transitional character being reserved for verification of the conclusions reached following the examination of the first series of measurements.

The systematic examination of instantaneous natural situations from an experimental angle allows rapid definition of the constitution and behaviour of species on a qualitative basis at the first approach, and then on a semi-quantative basis by ponderation of the effect of active factors (LAUNOIS, 1974, 1977).

It is advantageous, in some cases, to create the natural experiment by intervening to simplify the problem. For example, a new clearing can be opened in a forest, or an irrigated area can be installed in an arid zone to establish the speed of colonization of potential pests, or individuals can even be marked to estimate their daily time employment (CHARLES-DOMINIQUE, 1978). The interventions should always be as discreet as possible, the form as neat as possible and the results compared with those of control checks. In general, the conclusions must be drawn with circumspection, since the cases observed are restricted in number. Furthermore, secondary phenomena are always possible, as experiments that can be carried out on a really large scale are exceptional. However, experiments in natural conditions afford a powerful determining weapon for someone who knows how to use it wisely. It has its place, therefore, as a complement to the results obtained by experimental ecological observations without intervention.

2.3. *Investigatory methods.*

The methods of ecological investigation are to be adapted strictly to each object of study. After the choice of the scale, the second priority in research is to discover or to put into operation as quickly as possible the most rewarding methods of study and to choose amonst these those whose ratio of cost to result is the best. No one should decide *a priori* that such and such complex method will give better results than some other simpler one ; only the facts can make the final decision. The fundamental criterion that should guide methodological research is the obtaining of usable results in the minimum of time with the minimum of effort.

In very general terms, the methods of investigation are differentiated into intensive studies and extensive studies ; the two types of approach are complementary, and both are concerned with the environment and its inhabitants.

Intensive studies are carried out on a restricted number of sites that are ecologically complementary. The establishment of the sites depends on the ecoclimatic zones represented in the area under study and the importance of the local gradients, especially the hydro-gradient. In the plots decided on as sampling points, the population dynamic is noted at regular intervals so that it can be correlated to the local evolution of the environment. On this subject, the importance of phenological studies (DURANTON, 1976 b, 1976 c) must be underlined. A comparison of the behaviour of the species is then made, using the results obtained at the various sites.

Extensive studies are carried out at critical periods of the year, when, for example, the diversity of species reaches a minimum or a maximum. They are carried out in relatively short periods and cover considerable surfaces. Priority is given to the space factor. In principle, this type of study enables the conditions of generalization of intensive studies to be specified. It can also give rise to a re-examination of the establishment of the sites for the intensive studies, in order to improve the representativity of the biotopes selected when these are not strictly subordinate to the developed zones.

The employment of the data is done in a determinedly statistical spirit. Each event is regarded and described in terms of probability and not in terms of averages (BENZECRI, 1973), as the organism has to adapt itself to real fluctuating conditions and not to artificially weighted conditions. This is why progressive comparison, case by case, is far more determinant than the collection together of individual cases into a supposedly representative average case. This does not prevent the general profile of a phenomenon's being brought out by successive comparisons provided that it is possible to describe all the variations known or foreseeable in this way. It is not recommended in any case to try to integrate observations to a theoretical model by introducing successive correcting parameters. The best approach to investigation is based on ecological observation leading to a hypothesis validated by other observations carried out in the field. Several successive cycles of observation

— reflective study — hypothesis confirmed or invalidated are sometimes necessary to understand a phenomenon. The depth of understanding of an event can be judged when it is possible to forecast it with a co-efficient of certainty better than 80 % taking into consideration the elements entering into the description of the ecological context, including its inhabitants.

The combination of intensive studies and extensive studies leads to the exposure of discriminatory ecological factors and conditions for the organism studied in a very short time. It then becomes possible to describe objectively what can be taken as a favourable or unfavourable element for the species or community of species. At this level, the ecological factors studied are normally complex, even if their expression is simple. More exact studies, for which it is desirable to make sure of the opportuneness before undertaking them, can lead to the breaking down of complex factors into simple factors (elementary factors), but this is not generally necessary in the case of a study at the meso-scale level (DURANTON, 1976 a).

After producing discriminatory ecological factors for the species under consideration, it is desirable to examine which are the paths that are the most effective for building up an ecological system that enables the research worker to understand in what manner the existing ecological equilibrium will be upset by the developments and possibly to specify the levels of human intervention to correct the foreseeable disadvantages.

3. ECOLOGICAL SYNTHESIS : THEORY OF THE ECOLOGICAL OPTIMUM AND OF THE DOMAIN OF THE SURVIVAL OF SPECIES.

An ecological synthesis consists of an attempt to integrate all the available data into a coherent whole of the discursive type leading to a correct interpretation of the natural situations and to a statistical forecast of the behaviour of the species under study in a particular environment.

3.1. *General.*

Every living being expresses the maximum of its potentialities in clearly defined ecological circumstances (PAULIAN, 1948). When conditions, well known to be very favourable, arise in the surroundings, this corresponds to the optimum for the species. The ecological optimum is not defined by a unique value for the various ecological factors in which the species lives. It can only be achieved if none of the environmental factors is limiting, so that the only restriction on development and growth is of a genetic type (endogenous limit) (LE BERRE, 1976).

In fact, this idea is somewhat theoretical, since there are often several ways in which the ecological optimum can arise, as a result of the compensation of factors (DAJOZ, 1975). Furthermore, when the environment has values that are approximating to the optimum, the animal species can often reach it, by actively exploiting the biotope (behavioural adaptation). From the viewpoint of this study, the ecological optimum of species is considered as having been achieved in practice when none of the key factors is limiting at the meso-scale. This combination of factors known to be favourable changes at the micro-scale in a certain number of micro-environments at whose level the species can in fact find the conditions necessary to reach its upper biological limits for speed of development and the intrinsic survival limits. For certain species, in the definition of their ecological optimum, the presence or absence of non-climatic destructive factors (diseases, parasites, predators,...) must be taken into consideration.

From the moment when one of the environmental factors no longer reaches the optimum value for the species, development is slower and mortality higher, and the more so as the limiting factor is more marked or the number of limiting factors is great (exogenous limit for the development of the species). The domain of survival includes the ecological optimum and all the conditions compatible with the survival of a fraction of the population. When the limiting factors become restrictive to the point where the perennity of the species is no longer assured (ratio of offspring to parents less than 1), the ecological conditions can be interpreted as being incompatible with the tolerance of that species.

An ecological optimum and a specific domain of survival exist for each species. To be able to define them on a qualitative level is to be on the way to defining the value of the environment and to express what ought to be understood when favourable or unfavourable conditions, or effective or indifferent conditions, are spoken of. The whole difficulty lies in the manner in which an objective definition is to be obtained, in its formulation so that it shall be easily employable. The choice of the accuracy comes up again, and the correct application of methodological principles leading to an ecological synthesis depends on this.

3.2. *Methodological principles.*

To apply the theory of ecological optimum and the domain of survival profitably to species of economic importance, such as crop pest, for example, it is necessary to proceed by successive stages.

The main guiding principles are as follows (LAUNOIS, 1974 a) :

1. Study of the ecological optimum and of the domain of survival of the species. This is a matter of giving definitions that are as simple as possible to these two concepts. To do this, it is necessary to know the vulnerability of the species and the forms of resistance to the

environment which it can develop in certain conditions : embryonic diapause, imaginal diapause, reduced life tempo, removal...

2. As each type of environment can be objectively qualified as favourable or unfavourable by, if necessary, introducing other shades of meaning (optimum, compatible, within the threshold of survival), a time/space study of the evolution of the environment makes it possible to describe the surroundings in terms of its significance for the species. The instantaneous potentialities of its habitat area are thus established without ambiguity and without subjective interpretation.

3. To the degree that the responses of the species are known, quantified or semi-quantified (speed of development of each stage, importance of forms of dissemination...) in the presence of an environment that is itself characterized according to the potentialities that it offers, a reconstitution of the biological cycle of the species in its habitat area can be undertaken. This attempt at ecological modelling can be validated by comparing the deductions with past or present situations, or by a bibliographic comparison. When the model is accepted as conforming to the reality, and for that it may be necessary to introduce other factors, the operational simulation becomes possible.

4. By operational simulation, the reconstitution of the behaviour of a species in the presence of a defined environment, which may even be imaginary provided that it is ecologically feasible, is understood. This method enables statistical prediction of the possible responses of the species to modification of the surroundings following the expected development to be made.

3.3. *Analysis of the environment by discriminatory factors for the species.*

The exposure of discriminatory factors for a species can only be made if a number of observations of its reactions to environmental modifications exist. Intensive studies and extensive studies as described previously must therefore be utilized. In certain circumstances, the records are too sparse to be employed statistically. This deficiency can sometimes be partially remedied by calling together the pest supervision and control experts for the species under consideration, and making use of their empirical knowledge. For this purpose, it is necessary to organize meetings for comparison, and by concerted action to bring out little by little the semi-quantified model on which complete agreement can be reached. This procedure will obviously only provide working hypotheses, hypotheses that can nonetheless be confirmed later by verification of some amongst the conclusions that it has been possible to reach through them. Even through empiric, this preliminary survey should not be excluded from research of the operational type. The human mind is able to integrate unconsciously a vast number of parameters that, little by little, enable the man of experience to predict the behaviour of such or such a species without necessarily being able to explain clearly the reasons for his opinion. This flair displayed by experienced scouts is by no means infallible but its effectiveness is sufficiently well proven for scientists to take it into consideration in order to produce working hypotheses. Gross errors of sampling amongst the principal pests could be avoided by preliminary enquiry about the populations. The locust control scouts are capable of recognizing the sites where each species lives in a single glance, so astonishing the less knowledgeable. In fact, they have implicitly taken into account different factors which they evaluate, such as the height of the vegetation, the overall cover, the basic cover, the density of the trees, the state of turgescence of the plants, the formation and the texture of the soil... As soon as it has become possible to define the significant criteria that are the basis of the prediction clearly, knowledge becomes transmittable.

Five to ten complex factors are generally sufficient to characterize the environment of a species (of a pest, for example) at the meso-scale, 10 appearing indeed to be the maximum (HOLLING, 1963, 1964, 1965, 1966). These factors may be photo-periodic, thermal, water distribution, vegetation, availability of space, or access to the area. The exposure of these discriminatory factors is deduced from the comparison one to another of the various experimental ecological observations made. The comparison can be made manually or by computer. It is then necessary to put these factors in hierarchical order of importance by an evaluation review technique : factor 2 is only operative if factor 1 is favourable and so on. The gradation depends on the sensitivity of each species but it will be noticed that very often the conditions are interrelated (ecoclimatic conditions linked to the inter-tropical front, for example).

The conclusions of these analogue studies are always for the verification of a certain number of real situations to establish whether the ecological factors considered are sufficient in number to explain the nature of the biological events observed, with a satisfactory prediction certainty.

3.4. *Establishment of tables of correspondance between the environment and its inhabitants.*

Up to now, the study has been directed towards the definition of the criteria to be taken into consideration to characterize each environment. It remains to seek the characters at the level of the species which should be examined in order to judge the effect of the surroundings. In general, rapid development, accompanied by a low mortality are considered as being very favourable for the species. In practice, it becomes necessary to express slight differences and to adapt the model to the object of the study. At the same time, it is recommended to use a result index taking account overall of the time factor and the survival rate if a general understanding of the responses of the species is required. Whenever possible, the tables of correspondance between the environment and the inhabitant should be established by breaking down the responses of the species according to its principal stages of development. For a plant, these would be germination, first shoots, flowering, fruiting, dissemination of seeds... For an animal, birth, development of the young, sexual maturity, death...

In practice, the first operation consists in establishing a list of the discriminatory factors ecologically feasible. To avoid having too great a number of possibilities, those that seem to be very significant are selected (creation of classes) according to the response threshold responses of the species. When this first inventory has been made, it then remains to codify the types of response of the species faced with each environment described. In the majority of cases, it is enough to reproduce the results of experimental observations. Where the situations have not been observed, it is possible to interpolate the responses of the species provided that they are sufficiently well-known. It is legitimate to reconsider these hypotheses if the results obtained do not agree with the reality.

The chart established should take account of all the ecological situations that the species encounters in its distribution area and on its fringes. The time scale considered can be monthly, ten-daily, or daily according to the subject of the study.

3.5. *Operational model forming and simulation.*

Ecological model forming is intended to represent schematically the responses of the species to the variations of its environment over the whole of its habitat area. Graphically, the procedure is as follows : the time factor is set on one coordinate, covering, for example, the period of a year, whilst on the other coordinate the space factor, described in terms of longitude and latitude, is set. At each meeting point in space/time, a particular environment is found, defined by a third dimension grouping together the values of the various discriminatory factors.

If it is a matter of a statistical study, the descriptive elements can be extracted from general works. To predict the response of the species, it is enough to take the graph that has been drawn up already, and to examine the correspondances established. The instantaneous responses of the species on the whole of its area are then discoverable.

In a semi-arid tropical zone, the starting point for the study is generally taken to be the start of the rainy season. The first event following on the production of the conditions objectively described as favourable depends on the state in which the species is found. In any case, a revival or at least an acceleration of development is observed. As from this moment, the progressive reconstitution of the biological cycle of the species, possible removals, the number of generations, are predictable (LAUNOIS, 1974 a, 1974 b ; LECOQ, 1974). It even becomes possible to redefine the domain of existence of the species when the nature of the ecological barriers opposing its dispersion are known. This result is usually simple to verify on the basis of past reports. Here, there is a means of checking the agreement of the model with the reality.

When the accumulation of direct and indirect proofs enables the proposed model to be considered as satisfactory, the next step is to proceed to an operational simulation. By simulation, the theoretical reconstitution of determined types of environment is meant, and by operational, the practical character of these operations.

Most frequently, a start is made by establishing the general plan of seasonal population evolution of the species in the whole of its area of distribution for a year climatologically « normal » (statistically speaking). The main characteristics of the population dynamic are brought out. On every occasion when it is possible, a bibliographic comparison is carried out to check whether any known fact is opposed to the general plan.

Next, the variations between years are examined over the longest possible time scale. The so-called exceptional years are always very interesting. Some of them have shown abnormal pullulations of pests. Since it is these pullulations that have an economic effect, it is therefore essential to know the laws governing them. The study of the variations between years completes the general plan and enables the variations within the employed space to be better understood. Lastly, operational simulation can predict the responses of the species in the event of modifications to its environment following on development. This is where the ultimate aim of the model forming is to be found. It should supply the elements necessary to ecologists for predicting the consequences of disturbances and protect the investments and the anticipated agricultural production.

3.6. *Applications.*

The applications of the theory of ecological optimum and of the domain of survival are very important as regards research, training, supervision, and control.

3.6.1. Research.

The methods used in operational ecology, even if they are applied to classic subjects, give novel results. Above all, they offer the possibility of having a synthetic view of ecological problems with very short delay. The overall understanding of the operation of an ecosystem enables research programmes, well adapted to the realities of semi-arid tropical zones to be designed. This system of investigation gives the best possible guarantee of short and medium term results. It in no way encumbers the future, as all new facts should be added to the model in the perpetual desire to improve the accuracy of the prognostics. This new form of ecology, called operational, compatible with all the others, is very efficaceous for practical use by developers concerned about agricultural yields.

3.6.2. Training.

The very simplicity of the intellectual process that has led to the creation of operational ecological models and the obtainment of a general plan made significant by knowledge of its variations, makes up an ideal unit for training purposes. Each interested party : research, supervision, and control knows into what framework his effort fits and how his action is beneficial to developments of the agricultural system.

3.6.3. Supervision.

The establishment of a supervisory system is a logical consequence of the discursive methods of operational ecology. Its setting up, its structure, and the necessary means are determined scientifically in accordance with the objects pursued. It is possible to convert it into a real early warning system at small cost by using operational simulation, while at the same time retaining a close liaison with the conservation and crop protection services.

3.6.4. Control.

The results of operational ecology make it possible to tell where, when, and sometimes how the control of pest that threaten developments should be carried out, since the most vulnerable stages of the pests will be clearly shown. At this point, a junction with the ideas of METCALF and LUCKMANN (1975) concerning the planning of control operations has been reached. The start of a control operation takes place after action concerted between research scientists, scouts, and developers.

Thus, the anticipated applications are many. It should, however, be noted that medium and long term prediction depends on meteorological forescasting in these semi-arid tropical countries, which at present cannot be safely relied on for more than a few days. This, therefore, touches the limit of the prognostic and is why it is necessary to speak of warning and not of prediction.

4. MULTIDISCIPLINARY AND INTERDISCIPLINARY CONCERTED APPROACH.

The execution in practice of operations of the operational ecology type justifies the formation of integrated research teams devoting all their efforts to a particular problem over a limited period (DURANTON, LAUNOIS, LUONG-LAUNOIS, LECOQ, 1977). It might appear unnecessary to linger over the meaning of the word « team », as this term is widely employed, especially in ecology (KUHNOLTZ-LORDAT, 1956). In reality, however, it must be admitted that different definitions have been given to it, and that which is included in the idea of operational ecology offers a certain originality which it is as well to underline.

4.1. *Composition and organization of an integrated team.*

A team is a group of specialists speaking a common scientific language, whose different works combine to achieve clearly defined objectives. The principle of multidisciplinary action thus forms an essential part of the basic structure of the ecological team. However, its functional structure is more of the interdisciplinary type, that is to say, that bridges for the circulation of knowledge between the disciplines involved are established by the specialists, who are themselves directed by an organizer. The role of the latter is to maintain the cohesion of the team by integrating into a vast group all the special work. The application of the theory of ecological optimum and of the domain of survival constitutes a priveleged theme as a meeting place for research scientists, as each one amongst them knows exactly the place occupied by his work in the final synthesis and his own contribution to the research of his colleagues. The state of mind existing in a integrated team is that of perpetual and fruitful emulation and not of rivalry. All the members are directed towards the same single end and must from the first adjust their work to the master plan. In these conditions, ecological synthesis presents no difficulties for all the necessary elements have the required form for their integration into a harmonious whole without lacunae. Many ecologists have attempted to work in the reverse direction. They have endeavoured to group together special studies carried out seperately. This method is obviously inefficient, as the pieces of the jigsaw were not designed to fit into the final plan. It is not only a matter of concertation at the level of the definition of the subject of the study and of the synthesis of the results, but the whole of the work must be organized step by step from beginning to end to make the transdisciplinary approach efficient.

A team is a functional group created so as to have a more effective approach to problems too vast to be undertaken successfully within a limited time by a single research worker. This is not to say that personal initiative is in any way reduced ; it is only canalized towards a common objective, the importance of which is recognized by all. A living team consists of responsible research workers determined to provide a real contribution to an ecological synthesis with the full time support of an organizer whose role is to simplify the integration of their work into an interdisciplinary whole.

There are some who find this plan too idealized to be operational. The experience of the last nine years proves that it is by no means so, and, provided that men suitable for this type of research can be found, an integrated team is a reality in the present state of affairs. There are two ways to set about creating operational ecology teams :

— the first consists in bringing together research workers of good will, with sufficient affinities between them for the cohesion of the team to be ensured automatically. The co-ordinator is simply an organizer, the person who guides the entirety of the work towards its final objective. His authority and his competence must be recognized by everyone and accepted without reservations, his existence being justified by the necessary distribution of duties. As a scientist, he must be able to identify himself with all the domains touched in order to maintain the bridges between the disciplines, to set up concerted approaches, to find new links between domains hitherto separated. He must be a general scientist gifted with the spirit of synthesis, a perpetual source of new subjects of reflexion for the research workers. This formula enables durable teams to be formed, but it presupposes a strict selection amongst the candidates both on the professional level and on the personal level. Only specialists pre-adapted to this type of integration can take their place in a group of scientists chosen to carry out, in a limited time with defined material means, an exact task under the direction of a leader. Each agent is indispensable for the final success.

— The second way of forming teams is to proceed by control. This is the most economical method and for this reason it is often used. It consists of collecting together a certain number of specialists who have never yet worked together as a team and orientating their actions by the intervention of a study director whose role is to canalize the individual characters towards a common end. The lack of selection at the beginning is compensated for by the authority of the co-ordinator who, little by little, builds up the team spirit, starting from a potential often somewhat heterogeneous. The efficacity of this group can be good or moderate according to the personality of the organizer. He impresses his own ecological ideas on the research workers from the start of the operations to avoid dispersion of effort, and he can only leave more freedom of action to the agents progressively, when they have become impregnated with the basic methodological principles of concerted action. Such teams can produce good results, but their success depends entirely on the personality of the project director. When he no longer exercises his influence, it is common to see the break up of the team, the efforts at co-ordination having borne fruit finally for a single operation.

To the extent to which the idea of operational ecology achieves the development that it deserves, it will be useful to provide special training for the experts who hope to take part in this type of approach. In fact, the concepts brought into play are very different from those usually taught, and a professional and psychological preparation appears to be as necessary at the candidate level as at that of their selection. It is clear that certain persons can never fit themselves into this system, which to them is a restriction, their single handed work being nevertheless of value. It is even complementary to that considered here. As from the time when some supplementary training preadapts the research workers to integrated multidisciplinary work, it will be possible to form « variable geometry » teams, that is, teams whose exact composition depends on the subject of study. There will always be a central core of experts around a co-ordinator making up a very homogeneous group, then collaborators at various levels, limited in time and space. This plan should suit all the individual aptitudes. This formula takes account of the necessary evolution of structures and transitional stages which it is essential to respect.

4.2. *Preparation of an « operational ecology » operation.*

The clear definition of the objectives of an intervention of the « operational ecology » type is made during meetings for concertation between developers and ecologists, with the participation of the organizations that will benefit from the development. As far as possible, the objectives of the operation, the time allowed for trying to achieve them, and the financial resources are set from the beginning.

The « operational ecology » intervention begins by the formation of a team, whose basic structure is closely adapted to the problem posed. Adjustments are always possible during the course of the work. Under the direction of the co-ordinator, the agents undertake an exhaustive bibliographic search on what is known on the subject of study. Each research worker evaluates the knowledge in his own field of competence, extracts the essential, and prepares one or several statements intended for the information of his colleagues. The co-ordinator intervenes to emphasize the interdisciplinary links between the statements and makes the essential syntheses. This preliminary bibliographic balance sheet has several advantages. Each specialist has to make the effort of thought necessary for making a clear synthesis, lively and attractive. In endeavouring to make his knowledge accessible to other specialists, he clarifies his own ideas and defines his vocabulary. At the team level, the benefit is obvious ; a base of general knowledge has been acquired. The common language enables everyone to put his queries in the correct terms and to understand his own future work's place in the projected whole. Moreover, the organizer finds the opportunity to encourage the spirit of co-operation when standardizing the bibliographic notes and the glossaries.

When this first stage has been passed, the organizer applies himself to the definition, with the research workers, of the material means to be employed. For that, he prepares a plan of operations and proposes his budget within the framework of the overall financial plan prepared for this operation. The approach by the scientists to problems of organization and financing will be assisted by responsible consultants, who understand how to make adjustments according to the inevitable material restrictions. Ideas of participation and responsibility will be developed. Consideration should always be given to the possible use of the results, if any, of each research theme. By taking an overall view, a selection of the fundamental themes can be made. The plan of operations remains nevertheless open to any changes that might permit some perceptible progress.

Two types of study are in hand at once : the first calls on proven methods, with no risk of failure, whilst the second is innovatory. The mixed formula has the advantage of not limiting the system by restricting the domain of ecological intervention by the methods employed. The most recent technological discoveries can be adapted in the field if the occasion presents itself, but they will be judged by their results and put into competition with the old style techniques.

4.3. *Planning of an agricultural development operation.*

The study of the environment can be the subject of two approaches : one overall, the other specialized.

The overall approach is intended to show the ecological entities according to the methods previously described. The entities intended for development are the object of an ecological analysis deepened by the expedient of experimental observations.

The special approach is concerned with the developments themselves and the nature of the disturbance to the environment factors that they entail at the meso-scale. It is essential never to limit the ecological investigations to the developed zone, but to situate the latter in the totality of the natural entities to which it belongs, if only to define its uniqueness and its relationships : contribution to pest populations, meteorological activity centre affecting it...

These studies compare the pre-existent environment and the development projected, causing the restrictions to appear. The fundamental restrictions are linked to the positioning of sites : photoperiod, rainfall distribution, temperature averages... and can be little altered. The developer must therefore observe them when selecting the varieties of plants to be cultivated, for example. Supplementary restrictions may appear : water shortage, social pressure... but it can be hoped that some of these may be modified. In addition, the ecological synthesis made tries to define to some extent how the situation is going to develop, and, in accordance with these warnings, the developer can adapt his programme so as to make the investments as profitable as possible for the countries concerned. The watchfulness of the ecologists should never be relaxed since new problems, not predictable *a priori* may arise. That is why the operational ecologist should intervene at the level of development protection, by organizing supervision and control on a rational basis. The new ecological system created must achieve a certain equilibrium, even if that entails some periodical human intervention. If this equilibrium cannot be achieved, the risk of the development programme's failure is very great.

4.4. *Conjunction between research, training, and diffusion of information.*

In any project that is linked to economic development, the requirements for training are considerable. Research workers are often advised to undertake this training, a legitimate suggestion from some points of view, but one that also presents serious inconveniences :

— employment of experts on a task for which they are not prepared,
— reduction of the time devoted to research,
— no full time occupation for the students,
— unsuitability of the structure.

To protect the research scientists work and the ensure at the same time the training of local agents, it is recommended that someone entrusted with the training, with teaching background, should be attached to the team : he must be interested in research, in complete intellectual harmony with the research scientists, and his duty will be to devote himself full time to the students entrusted to him :

— basic courses,
— directed work,
— practical work,
— conferences and seminars with the participation of the project research workers.

A separate budget should be devoted to supplying the lodging of the students, the class rooms, the teaching aids, and means of transport. The training officer will pass on the information acquired during the project in his instruction, and assist with his teaching knowledge in the preparation of popularized publications. The number of students should never exceed 10 in each class, several classes during each year being possible, according to the level of aptitude.

GENERAL CONCLUSION.

Ecology is by definition the study of the relationships existing between an organism and its environment, organism being taken in the widest sense. The new term « operational ecology » emphasizes the wish to bring ecology and development closer together by undertaking multidisciplinary activities to proceed with scientific analysis of problems of development or organization. The example given here concerns the rational organization of hydro-agricultural developments in a semi-arid tropical zone. A chart of the synthesis of the various operations entering into the framework of operational ecology is shown in Figure 2.

Until now, the ecologist has not been greatly interested in agricultural development plans. His principal role has been that of exposing the inconveniences of unconsidered modifications of biogeocenoses and drawing up an account of the damage caused by developers. This first stage, described as critical examination of economic activities, was justified by the necessity for sensitizing the responsible parties to the problems of the environment. The end pursued being considered as achieved, it would now be wise to bring developers and ecologists together so that the catastrophic errors which have occurred in past years may not be repeated. There is a need for a radical change of attitude on the part of the ecologist, a revision of his methods of investigation, and a desire to be effective in the short and medium term so as to arrive at the formulation of practical recommendations immediately applicable by the developer. On these terms, operational ecology has a legitimate place in improvement plans directly connected with the realities of land development.

In general terms, the study of the environment and the analysis of the phenomena should be carried out by as efficacious methods as possible, new if necessary, choosing the scale of the work carefully so as not to confuse precision with exactitude. All the analytical studies are worked out against a background of short term ecological synthesis. The systematic applications of the theory of ecological optimum and of the domain of survival are given with the related methodological principles.

The set of methods of study recommended leads to the conclusion that a new strategy of ecological research is possible with the means existing. Its application certainly depends more on a conversion of the intentions of the research than on technical or financial possibilities. In fact, operational ecology is an applied science which uncovers fundamental facts, a discipline which controls the future whilst concerning itself with short term results. The classic distinction between pure and applied science is hence meaningless in this type of approach. Furthermore, it is perfectly possible to undertake research in the field with the scientific rigour of research carried out in the laboratory, or again, to proceed to experiments in the laboratory to interpret natural events. For this reason, the second intellectual barrier tending to separate field from laboratory also seems to be artificial. The strategy of research in operational ecology recommended is intended to acquire, with little delay, an adequate overall knowledge of the relationships between the environment and its inhabitant to be able to predict the evolution of the problems in relation to the disturbance caused to the biogeocenoses. Finally, the intellectual process is very similar to that of a doctor who proceeds from diagnosis to prognosis and then to treatment.

In order to put these new methodological concepts into practice as effectively as possible, it is essential to create transdisciplinary teams so as to be able to carry out quickly all the ecological analyses needed to work out the final synthesis from which model forming and operational simulation become possible. At present, the training necessary to provide the integrated research workers is given nowhere. There are, naturally, isolated individuals whose natural aptitudes fit them for useful work in this type of team. However, since their number is clearly inadequate as compared with existing requirements, it can be logically concluded that it would be wise to create a new type of teaching to follow after the traditional training. In this way, ecology could find its true place in the plans for economic development of, for example, the hydro-agricultural type, and developers could only look favourably on such a collaboration that would guarantee the future of their labours.

This new form of ecology, known as operational ecology, is in no way opposed to the classic concepts of ecology. It is even complementary to them because it takes account of the past to explain the present and to predict the immediate future. Its creation simply responds to new demands which must be recognized, and which offer to the ecologist the position of an effective adviser which belongs to him whenever there are human modifications to the ecosystems. Therefore, the critical spirit developed until now *a posteriori* to pass judgement on developments will have the opportunity to operate of development plans and to influence them by assuming all the responsibility that belongs to it.

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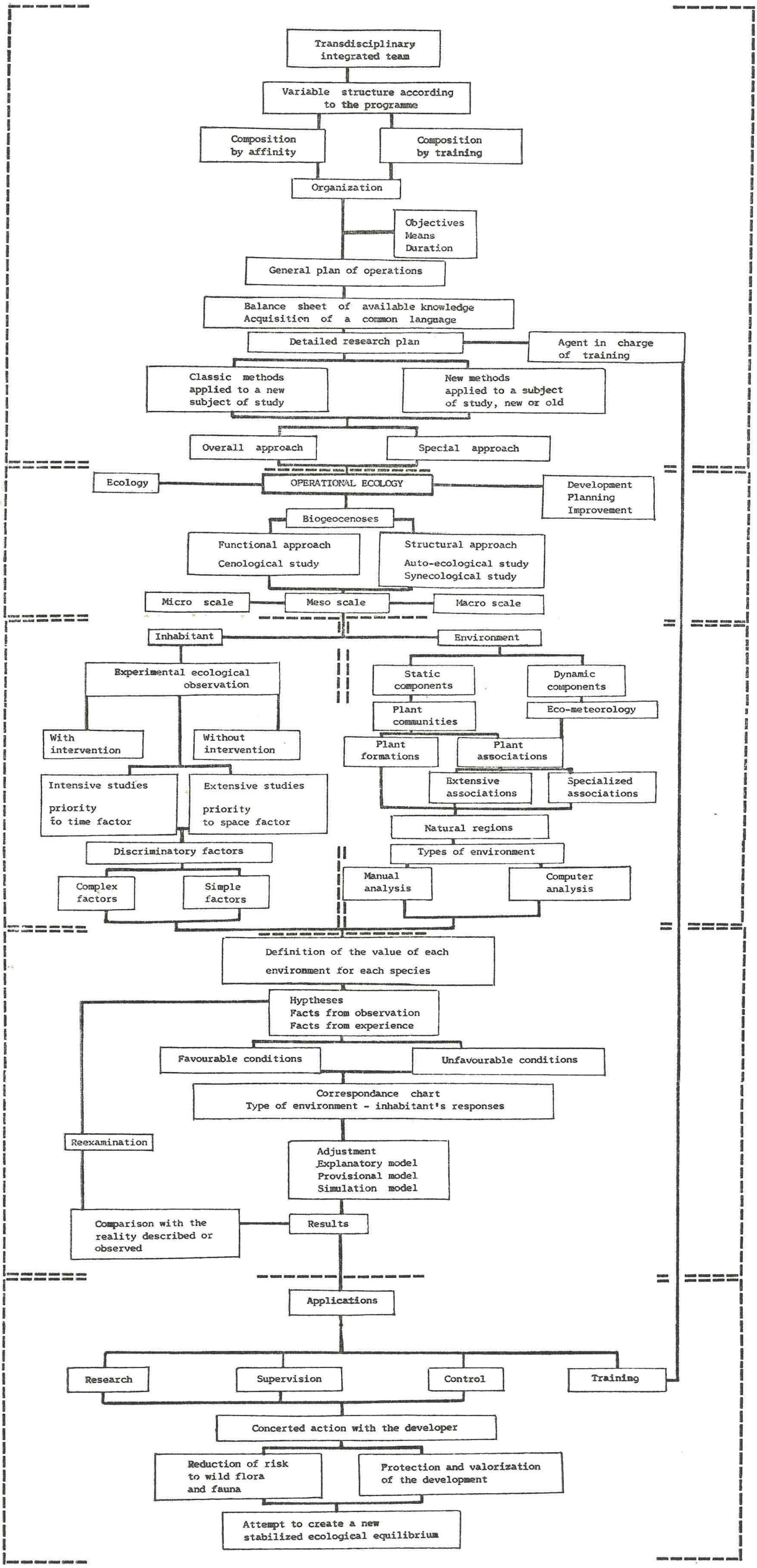

Figure 2. — Flowsheet of synthesis in operational ecology.