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Integration in land research for Third World development planning: An applied aspect of landscape ecology

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Abstract

In the practical application of landscape ecology to development planning it is essential that there be interdisciplinary collaboration. Three ways of developing this collaboration are discussed. These are (1) use of environmental concepts which directs specialists to focus on landscape interrelationships; (2) geomorphic differentiation to provide a common framework for analysis and **(3)** a unified methodology based on mathematical modelling, hypothesis testing, and application of statistical theory. Broader implications to policy and administration are also examined.

Introduction

Land is our most precious asset. It is the hub of the natural environment: the complex of primary resources – soils, vegetation and surficial water features – upon which the existence of all terrestrial animals, including *Homo sapiens*, is dependent. In addition, its constituent rocks and deposits provide essential raw materials for diverse industries and human needs. The exploitation of land resources, therefore, has been a dominant factor influencing the development of all nations. However, Third World development problems are the chief concern in this article, though many of the issues to be raised are relevant everywhere.

Achieving the most beneficial use and management of land, especially for agriculture, is of the utmost importance in Third World development planning. A high rate of economic expansion is impossible without the revitalization of agriculture, for most of the labor force and capital are invested here. Hence general economic growth requires that agriculture must proviae not only large increases in production but also major contributions to the labor and capital needs of industry and other sectors of the economy. And an urgent priority is the need to expand food supplies at a minimum rate to match that of population increases. All depends, therefore, on making the best use of land.

A fundamental reappraisal of traditional agriculture is thus essential as part of any development program. However, scientific knowledge of land use potential and its controlling factors, which is a necessary prerequisite for this reappraisal and development planning, is grossly inadequate in most areas. Interdisciplinary collaboration is crucially important in the required land evaluation process. This has long been recognized (Zonneveld, 1968, 1979; Wright, 1972). Nevertheless, despite the attention it has received both in the literature and at a number of scientific training centers – notably including the International Institute for Aerospace Survey and Earth Sciences (ITC) in the Netherlands – interdisciplinary effort in land research and development planning is still relatively uncommon in Third World countries.

It is because of this, and the ever-increasing need to make the best use of land in developing countries – not least to avert even greater problems of food supply there (Dudal, 1982) – that the present article has been written. The subject matter dictates that land must be viewed as a mosaic of habitats and their interacting organisms which sustain human life on earth. From that view point, therefore, land evaluation for development planning is one of the most important applied fields of landscape ecology. This article is concerned with problems involved in mobilizing the interdisciplinary research needed for such evaluation. Reasons why interdisciplinary research is so vitally necessary are first outlined below; then some of the problems arising in its integration and implementation are discussed.

Interdependence within science

Agricultural land use is governed by diverse interrelationships involving environmental conditions – especially the intrinsic characteristics of the land itself – crops and man. In Third World countries, mainly in the tropics, environmental conditions have posed major constraints ranging from soil fertility problems, plant pests and animal parasites, to irregular water supplies, flooding and erosion. Traditional agricultural systems have been evolved to adapt to these conditions whereby human subsistence needs are commonly the overriding priority. In addition, however, these systems reflect a multitude of social and economic factors, including religious beliefs, dietary preferences, genealogical ties, attitudes to territory and land tenure, marketing structures, lack of incentives for innovation and of capital for new technological inputs.

Interdisciplinary research is needed here because the potential use is determined not by any one land characteristic operating alone but by many acting in combination. There is the allied need for economic evaluations of the various use possibilities in terms of production and marketing costs, and likely returns; so the use-potential research must be closely co-ordinated with practical trials and pilot-farm projects incorporating alternative management practices. Social studies must be planned in conjunction with the basic scientific and economic work so that potentially useful forms of production can be assessed in human terms also.

Numerous disconnected specialist investigations of these research and planning problems lead to much duplication of effort and technical facilities. They are thus wasteful of time, expertise and money in Third World countries where these are at a premium. Moreover, as the results of the different investigations are arrived at independently from each other, it will be difficult to apply them collectively to overall planning needs. Indeed, those seeking to utilize one set of results may be unaware of the existence of other, related ones dispersed in a variety of reports and institutions. In contrast, by avoiding duplication and dissipation of effort and technical facilities, interdisciplinary collaboration enables research and development problems to be tackled more speedily and more economically. Also, by bringing an integrated range of expertise to bear on any problem, it reduces the possibility of unprofitable avenues of research, thus preventing much costly and time-consuming work from being wasted. Collaboration also leads to a synthesis of the various specialist contributions, oriented towards their jointly designed objectives, and the results will thus be more readily applicable to the development problems which governed those objectives. In these various ways, therefore, optimum use can be made of the staff, resources and funds available for research and planning purposes.

There is an even more fundamentally important justification for interdisciplinary collaboration: it not only mobilizes the most effective applications of science but is also likely to promote its advancement. History provides countless instances of new discoveries in one scientific field stimulating advances in others and of the interconnections between science and technology. Many of the early technical advances, up to about 1850, especially in engineering and industry, were not greatly dependent upon existing scientific knowledge; though science sometimes profited from technology, as in the case of thermodynamics which developed partly from the study of the steam engine (Mason, 1953).

After 1850, however, applications from many scientific fields became an increasingly important factor in the growth of industry, and during the present century most of the outstanding technical discoveries have stemmed mainly from scientific researches, including such universally essential tools as electron microscopy and digital computing. These and further technological innovations are also needed for the most effective land research and development planning in the Third World. The discovery and application of successful ones are inherently more likely as a result of interdisciplinary scientific research because, to be successful, they must be specifically adapted to the distinctive combination of environmental factors which governs land use possibilities in any locality.

Despite the manifest interdependences between different scientific fields, however, since the mid-nineteenth century there has been increasing specialization in science and fragmentation of knowledge. The resultant subdivisions are largely artificial compartments within a particular field or between cognate disciplines. Inevitably each has evolved its own theories, techniques and terminology, and considers its own sphere of interest in its own terms which may be largely incomprehensible to other specialists. Furthermore, the exponential growth of published literature has made a comprehensive grasp of any scientific discipline beyond the capacity of any one individual. Equally, it is no longer feasible for one specialist to examine in its entirety a specific practical problem, such as those arising in land use, because the necessary knowledge is dispersed among different scientific subdivisions.

For these various reasons, therefore, it is imperative that the increasing isolation of scientists within their separate compartments be reversed. This applies emphatically to the many disciplines needed in land research and development planning. The way forward is clear from the example of those fields with a greater tradition of practical achievement, for in their case the links between cognate disciplines have either never been severed, as in engineering and industry, or have had to undergo reconstruction, as in medicine. Similarly, the development of landscape ecology as a practical discipline could be instrumental in counteracting compartmentalization, and in stimulating unifying themes, within the earth and environmental sciences.

Integration

The International Institute for Aerospace Survey and Earth Sciences (ITC), in the Netherlands, has for many years been at the forefront in the provision of training to meet the practical needs of scientists and planners in Third World countries. Such training for land resource surveys in their various aspects, including management, integration and emphasis on landscape ecology (Zonneveld, 1981), is organized by the Department of Land Resource Surveys and Rural Development. The problem of integration in multidisciplinary projects has always received special emphasis (Zonneveld, 1968, 1979) and, in their reviews of this feature of the work of the ITC, Nossin (1975) and Luning (1985) stress the distinction between ‘internal’ integration and ‘external’ integration. The first of these refers to the combining together of the results of the various scientific, social and economic researches in multidisciplinary surveys. In addition, however, the broader context in which these surveys are carried out necessitates ‘external’ integration also, to incorporate the needs of all interested parties (including planners, policy-makers and potential beneficiaries) so as to ensure that surveys are designed and findings are presented in forms suitable for general planning and decision-making. The present article is concerned primarily with internal integration, in that it deals mostly with the scientific aspects of interdisciplinary land research.

It is important at the outset to emphasize the difference between a truly interdisciplinary study and other types of multidisciplinary projects. The former involves various specialists working as an integrated team towards jointly planned objectives, influencing one another’s activities at all stages, and attaining a careful synthesis of their findings. There are other sorts of projects where different specialists may likewise attempt a collaborative investigation. But in this case they may still operate more or less independently, each dealing with his own aspect of the project with the ultimate intention of combining their various findings. The respective contributions in such an approach lead to a series of separate results, which inherently can only be loosely related to each other. This further complicates the already difficult problem-solving and planning process by creating further problematical and potentially wasteful exercises of collation and interpretation in attempting to apply the separate results to development planning. Thus, because of the contrasted backgrounds of the various specialists, their respective findings may not only differ widely in scope, organization and presentation, but also lack connected features and vary in their relevance to planning needs.

For such reasons, interdisciplinary collaboration requires much more than simply bringing together a range of specialists to examine various parts of a problem, viewed in their traditional scientific compartments, and then 'pooling' the findings. In reality it necessitates a framework of unifying features to ensure the close teamwork which is imperative if a more superficial multidisciplinary approach is to be avoided. Three such features are advocated below: conceptual, spatial and methodological.

Environmental concepts

Land has traditionally been perceived as a number of distinctly separate components: rocks, soils, landforms, plants, water features and so forth. A corresponding variety of scientific disciplines has been evolved, each largely independent of the others and with its own theories, methods and terminology. Hence most land research in the past has comprised specialized investigations of these individual components. There is, however, a complex interdependence and interaction between all living things and between them and the inorganic constituents of the environment. This involves, for example, continual transfers and transformations of matter and energy in biogeochemical cycles, such as those relating to carbon, nitrogen and phosphorus, which govern plant production and hence the survival of all terrestrial life. Consequently, proper understanding of land and its use potential must be based on knowledge of the structure and functioning of such environmental systems. The natural processes involved in plant growth and crop production, for example, reflect complicated flows and transformations of energy, nutrients and water in which atmospheric, ground surface and subsurface conditions, plants and animals are linked inseparably.

Recognition that land characteristics are interacting elements within dynamic environmental systems – a basic tenet of landscape ecology – thus provides unifying concepts in mobilizing interdisciplinary effort. It provides the different specialists with a common purpose by directing them to develop their work *in the context of its environmental relationships,* not in their traditionally disparate compartments. Further, it *compels* their close collaboration and mutual assistance because it is manifestly evident that, without this, proper understanding of land, its use potential and management is impossible. Clearly, because of these dynamic natural systems, evaluation for sound land-use planning requires understanding of the functional interactions governing land productivity so that the effects of human activities may be predicted and management planned accordingly. Only in this way can suitable land-use methods be devised to ensure sustained increases in productivity, with prevention, let alone effective treatment, of such widespread hazards as soil erosion, salinization, impoverished nutrient levels, soil and plant diseases. Such an approach is vitally necessary if development projects are to succeed in Third World countries, mostly in the tropics, where ecologically unsound land-use practices commonly have drastic environmental repercussions.

There is an appropriate comparison here with medicine and allied sciences which for many years saw over-specialization and the increasing isolation of cognate fields. However, this trend had to be reversed with recognition of the need for a synthetic approach drawing upon different kinds of knowledge. In physiology, *e.g.* (Singer and Underwood 1962):

'The study has become synthetic because organs have been studied not so much in and for themselves as in relation to other organisms. There has been, in fact ... an increasing consciousness of the integration of the organs into one organic whole, the entire process being under the control of the nervous system, the various parts of which are themselves integrated, and of the endocrine system.'

Such integration and 'systems' functioning – the essence of nature – is analogous to the dynamic complex which is land. Similarly, it underlines that integrated effort from a range of scientific disciplines is required if land research and development planning are to be effective.

Spatial framework

Land characteristics and associated environmental factors vary continuously in space. Hence local heterogeneity in ecological conditions is a major consideration in land evaluation. Furthermore, evaluation and development planning are required for vast areas in Third World countries, therefore much groundwork is imperative before time-consuming and costly projects are embarked upon, because staff, funds and facilities for research are strictly limited in these countries, so ensuring their most efficient use must be a top priority. Social factors also vary in conjunction with these environmental changes and are an inseparable consideration in development planning. This emphasizes further the importance of spatial variability, for planning is unlikely to succeed unless local conditions are taken into account.

A common spatial framework is thus needed in which to plan the deployment of research effort, co-ordinate field observations and experimental work, view findings synthetically and extrapolate results. Detailed spatial analysis commonly requires a regular or random sampling design of relatively closely spaced observations. This kind of sampling is neither feasible nor necessary over larger areas, however, for which it is more appropriate to devise a purposive mapping framework followed by detailed analysis of selected parts as required. There is much evidence that geomorphological differentiation can provide a basis for such a landscape ecological framework for the investigation of land resources (see *e.g.*, Verstappen, 1983; Wright, 1984), as outlined below.

The form of the ground, in detail and regionally, is expressive of underlying parent materials and the nature and duration of land-forming processes. Detailed slope characteristics reflect the rate of development of weathering products relative to their removal. In any particular climatic setting, therefore, each lithology tends to have a characteristic range of slope forms and gradients. There are similarly close associations on a regional scale, with changes in rock structure and stratigraphy being etched into major relief forms. Surface configuration is also closely related to land-forming processes, as implied above. The relationship is reciprocal, for ground shape is not only the product of earth materials, land-forming processes and time, but is also an important factor influencing the achievements of these processes. Thus the vigor of many of the processes is a function of slope angle, and the latter, together with the orientation, microrelief, local elevation and position in 'toposequence' of a slope influence incident solar radiation, humidity, ground temperature and moisture conditions, water-table relationships, surficial water movements and drainage.

In these ways, landform variations are associated with local and regional changes in earth materials, rainfall run-off and infiltration relationships, ground climate and the nature and intensity of weathering, eroding and transporting agencies. Such associations underlie the close links between landforms and soils. **A** slope and its soil share common parent material and processes of development. In particular, local weathering variations are associated with geomorphological differences and, just as slope character is a function of the rate of development of weathering products relative to their removal, so this relationship governs the nature of cantemporaneous soil formation. Hence geomorphological variations tend to be accompanied by changes in important soil properties, such as depth, texture, profile development, moisture relationships, erodibility and nitrogen content. These variations thus exert an indirect but powerful influence over vegetation response, because of their soil, surface stability and ground climate relationships.

There are numerous practical implications. There is a long tradition in many cases, for instance, of crops and cultivation practices being closely adapted to their landform setting. Geomorphological process systems have been manipulated to increase productivity. Slopes have been corrugated or trenched to improve drainage; streams have been controlled or diverted for irrigation, with regrading of the cultivated slopes where necessary; surfaces have been terraced and ditched to reduce erosion, conserve soil, increase infiltration or disperse potentially damaging run-off. Similar adaptations to, and manipulation of, geomorphological conditions are well-established in other spheres of land use, including diverse engineering practices, and in environmental management generally.

For such reasons, geomorphological differentiation of terrain units can provide the necessary spatial base for a landscape ecological framework whereby environmental variations may be viewed synthetically and interdisciplinary land research effort can be co-ordinated to ensure its integration. There are methodological advantages too, because landform features are more readily perceived, measured, mapped and interpreted than other land characteristics. It is not proposed here to discuss various possible approaches for this differentiation – principles rather than techniques are the main concern. However, an approach based on the identification of small slope units, termed geomorphological 'sites', has proved to be effective (Wright **1972, 1973).** These are delimited along detailed, measured slope profiles as segments of uniform shape internally, regularly curved or near-planar, and separated by relative discontinuities in gradient or rate of change of gradient. They are equivalent to the primary units, or taxonomic 'individuals', needed in systematic land classification. On this basis broader terrain units can be delimited at different levels of abstraction, built-up systematically from within by aggregation of the classified individuals.

The use of airphotos and other forms of remote sensing is important here. They provide an integrated representation of ground surface conditions, the constituent tonal and textural differences reflecting variations in vegetation cover, detailed surface configuration and, indirectly, bedrock, soil, ground climate and surficial water conditions. Furthermore, such airphoto differences are commonly expressive of changes in the interactions between these various elements of the ground, rather than just the elements individually. Consequently, airphotos are another means of facilitating integration in interdisciplinary collaboration, by providing a common base for terrain interpretation and mapping by different specialists, and by directing attention to environmental interrelationships (Wright **1971;** Nossin **1975;** Dunford ***et al.*** **1983).** They are an essential tool in the site-analysis approach because, even where subtle geomorphological site differences on the ground may only be apparent on measurement, they are commonly expressed in tonal and textural variations on airphotos, reflecting the associated vegetation and soil-surface relationships. Correlation of site characteristics with the airphoto image thus permits site data to be extrapolated between the measured slope profiles. The use of airphotos also underlines the potential unifying role of geomorphology in interdisciplinary land research because geomorphological interpretation of airphotos is a traditional feature in many fields, including geological surveys, hydrological investigations, soil mapping, vegetation surveys and terrain evaluation for engineering purposes (Zonneveld **1979;** Verstappen **1983;** Wright **1984).**

Application of the approach referred to above has demonstrated that geomorphological site variations are of primary importance ecologically – even in gently sloping plainlands – being associated with changes in soils, vegetation and natural process systems. Hence differentiation of sites and their spatial groupings provides a useful framework for interdisciplinary land research and development planning. **As** ecological units (Vink **1982)** they constitute a common base for diverse studies. They also serve to indicate the limits of application of information derived from these studies, by the extrapolation within site assemblages of knowledge gained about particular site types. In this way the land resources of large areas may be assessed more rapidly than would be possible otherwise.

Unified methodology

The diverse specialists involved in land research differ greatly in their working methods. Hence a unified scientific approach is logically needed to provide a methodological framework for integration. The essential requirement in this integration is to be able to organize collaborative effort which is carefully planned to answer specific questions, and to provide results that are readily applicable to the project's objectives. A joint approach must be based on mathematical procedures – which constitute a common 'language' for interdisciplinary teamwork – including numerical measurement, modelling and data manipulation for predictive purposes. It involves clearly-defined hypotheses being formulated and tested against appropriate data. The application of statistical techniques is an integral part of this hypothesis testing, so suitable sampling methods and measurement procedures must be designed beforehand.

The particular need for such applications in the present context is underlined by some distinctive features of the ground surface environment. All land characteristics vary continuously in space, and many vary through time also. Quantification and analysis of this variability is thus of fundamental importance, with many practical implications in land evaluation and development planning. Statistical treatment has special value here. For instance, the variability can be expressed in terms of probability distributions, from which mathematical models can be developed for the specified objectives of analysis or prediction. Moreover, any land characteristic is interrelated with many other land and environmental variables forming interacting elements within natural process systems. Statistical handling of these interrelationships, supported by computerized techniques, is essential if the complexity is to be properly understood. Appropriate models can be applied to examine the interacting variables, and statistical tests used to evaluate their relative importance.

Modelling is thus of central importance in this approach. The creation of conceptual models is an integral feature of the scientific method, and indeed of the human intellect generally. Such a model is an analogue of reality: a set of assumptions about some observed phenomena, together with an analysis of the logical consequences of the assumptions. In mathematical modelling the assumptions are expressed in mathematical form. This is a notable refinement of all other kinds of conceptual models. It enables the structure of the model and the relationships between its components to be defined more clearly, precisely and concisely. A diversity of mathematical treatments is then available to derive logical deductions and arithmetical results. The results can be tested against observations of reality and, if they are thus verified, the model is held to 'explain' reality. It is in this predictive capacity that mathematical models have great practical value. Further, the mathematical consequences of a model quite commonly lead to predictions about the observed phenomena which were not known previously, or only poorly understood, on the basis of experimental studies.

This modelling requires first evaluating patterns of numerical variation in the phenomena under investigation, usually in terms of probability distributions as noted above. These are then used to construct a mathematical framework, or model, for examining particular features of the phenomena for specified objectives, commonly the investigation of hypotheses. This involves applying the model to test the hypotheses against observable facts. Clearly, the formulation of the model is the prime consideration, so it is essential in the data manipulation to ensure that the mathematical assumptions of the model are confirmed. Such validation and testing of a model, possibly leading to its refinement or replacement, are vitally important. Initially, especially in the investigation of natural processes, which is a major application of modelling in science, the inherent complexity of the problem may have to be greatly reduced to derive a model which is sufficiently simple to study. Even so, this can permit better understanding of the main factors and relationships. Then, given this understanding, the model can be made more realistic.

A group of models particularly relevant to interdisciplinary and environmental problems falls under the general heading of systems analysis, which is concerned with the interactions between the connected parts of complex wholes. Thus the structures and dynamics of natural or man-made systems may be viewed in terms of constituents linked by flows and transformations. Where the latter are continuous, 'deterministic' models are used, but more complicated probabilistic, or 'stochastic', models are required where the underlying processes involve random events. In this way, quantitative models can be developed for the analysis of complex phenomena, including both natural systems such as soil erosion, population dynamics, nutrient cycling and other ecological processes, and man-made ones as in systems engineering and policy analysis for planners and administrators. Both types of application have features in common, though one is concerned with greater understanding of natural processes and the other with the planned functioning of organizational structures, including logistic, economic and management problems.

Such modelling of dynamic systems is greatly facilitated by computer simulations. They represent another integrating element for interdisciplinary work, providing a common data-processing and storage facility for use by teams of scientists. And the increasing availability of cheaper, miniaturized hardware makes it no longer necessary to depend on large, costly installations. Dangers are inherent in the use of computers, especially in the uncritical adoption of program 'packages' and inadequate attention to their underlying assumptions. As with any scientific technique, repeated experimentation and appraisal are needed with, above all, continual critical review of the advantages and limitations of computer-based methods.

The development of geographical information systems (GIS) warrants special mention. These are computer-based systems for storing and manipulating very large quantities of spatially-indexed data. By reference to points, lines or areas on the ground surface, spatial variations in diverse types and forms of landscape data, and their interrelationships, can be viewed synthetically and interpreted using computer-assisted analysis and remotely sensed image-processing techniques. GIS are thus potentially an important means of integrating interdisciplinary collaboration, lying as they do at the intersection of many disciplines and with a wide range of users such as land and resource managers, administrators, planners and policymakers (Coppock and Anderson, 1987).

The previous emphasis on methodological considerations is particularly relevant in this context. Firstly, for instance, a preliminary mapping framework will be needed in most cases, though this can eventually be refined within a GIS on the basis of combinations of different sets of data and the relationships identified between them (Aalders 1980; Meijerink 1985; Drury 1987). Among other things, the preliminary mapping will be required in planning the deployment of more intensive research effort and in the design of detailed spatial sampling, because in utilizing GIS in land research and development planning it will invariably be both too costly and unnecessary to attempt complete coverage of the areas under investigation. Secondly, in view of the complexity and the very large quantities of the data which can be handled by GIS, all depends upon a methodologically rigorous approach to data analysis and interpretation, including the application of appropriate statistical procedures combined with, *e.g.*, progressive modelling of the landscape characteristics of those areas and their associated natural process systems.

The following provide a variety of illustrations of some of the points raised in this section: Cochran and Cox (1957, Flagle *et al.* (1960), Jones (1970), Bartholomew (1973), Grossman and Turner (1974), Bailey (1977), Wright and Wilson (1979), Marble and Peuguet (1983), Smith *et al.* (1987).

Implementation

This paper has emphasized the need for interdisciplinary collaboration in land research for development planning, but also that it cannot be truly interdisciplinary without specific, integrating concepts and methods. Basic principles have been the chief concern, rather than technical details, for the latter will vary greatly from one situation to another. Many broader issues arise, however, if such collaboration is to be implemented in Third World countries. Some of the more immediate ones are as follows.

Considerable changes are desirable in the present machinery for land research and development planning. Government backing would be required to initiate these changes by modifying the traditional, specialized departmental structures of government and other institutions. Closer collaboration involving existing research institutions would undoubtedly be facilitated by their reorganization. Indeed, some of their personnel and facilities, supplemented by others as feasible, would probably be utilized to better advantage if re-deployed to create new interdisciplinary groups. This suggestion is also justified on other grounds because, where the evaluation of very large areas is involved, it is desirable to work on a regional basis by establishing a number of research and planning centers. The new interdisciplinary groups would provide appropriate staff for these centers. Initially, the number and location of the latter must be governed by available resources and existing regional policies. Ultimately the aim should be to evolve a network for effective coverage nationally, which would necessitate much greater government investment in scientific research – and in science training. But such regional organization and investment are essential prerequisites if development plans are to succeed in meeting the quite distinctive needs of different parts of any country. It is not proposed to elaborate on the range of evaluation and planning activities needed at these centers (Wright **1972).** However, some implications of points raised previously can be illustrated with reference to a few of them.

An initial requirement in the evaluation process is for preliminary surveys of natural resources. These depend on interdisciplinary collaboration, with the actual combination of specialists being governed by local priorities. Their aim is to systematize spatial variations in natural resources and their interrelationships in order to provide the essential environmental information for planning the intensive experimental and assessment work needed in land evaluation. **A** geomorphological framework can facilitate the necessary integration of research effort, as explained earlier.

A subsequent priority in the more intensive work is to investigate the biological and physical possibilities of crop, pasture and animal production, associated with appropriate management studies and leading to practical tests and socio-economic assessments. These intensive investigations can only be extremely localized, so their design and spatial deployment warrant careful consideration. *E.g.*, they could be organized to examine the range of most frequently recurring habitat conditions in the planning region, by being linked to the dominant site types in an appropriate range of mapping units delimited in the preliminary survey. Similarly, the results of these localized investigations have to be extrapolated into extensive tracts of country. This would necessitate numerical analysis of spatial patterns of variation in appropriate variables, and likewise the mapping units of the preliminary survey would provide the necessary 'stratified' framework for such analysis.

This latter problem of extrapolation, and design questions in all stages of the interdisciplinary land evaluation, relates back to the importance of unified methodologies. It follows that mathematical, statistical and computational advice is an essential requirement. This cannot be over-emphasized, for it would be dangerously short-sighted to expect the various other specialists to develop the high level of expertise needed in these fields. Without this professional advice, much costly and time-consuming research may be seriously limited or indeed wasted. Consequently, the advisers must collaborate closely in the interdisciplinary teamwork from the beginning to the end of any project: in the initial research design, in re-appraising the design as data are obtained, interpretations are made and new problems arise. This involvement is not only an essential part of the problem-solving process, but also ensures that the activities of the various specialists are co-ordinated most effectively, each activity being progressively adapted to any modification of the design as required by the overall development of the project.

The interdisciplinary research and planning activities must operate in a hierarchical structure extending from the broader, policy-making levels of national ministries – for agriculture, economics, education and so forth – through the corresponding regional administrations, incorporating or closely linked with the regional research centers advocated here, to local activities including experimental farms, other development projects, agricultural 'extension' work and similarly important liaison with the people working on the land. The organization and efficient running of such a hierarchy is a complex problem, for there are diverse interconnections laterally as well as vertically within it. Total costs of the research and planning activities are great, so careful organization is essential to make optimum use of staff, facilities and funds. This applies particularly to the interdisciplinary programs advocated here which in the Third World would need to draw upon all available scientific resources, in University departments as well as Government institutions, and include a variety of pure research, applied research, liaison work and development projects.

Hence, much planning is needed to co-ordinate the efforts of these varied and – if land research and development problems are to be solved – mutually dependent activities and institutions. The interdisciplinary integration required, therefore, extends far beyond the basic land research and evaluation, but also presupposes sound organizational structures in which the complex administrative and technical services are planned to function effectively. It is for such reasons that the ITC places much emphasis on the importance of 'external' integration (Luning **1985).**

In a different but analogous context, Bailey **(1977)** has argued that operational research, the scientific study of administrative or executive problems, provides an appropriate basis for planning such complex organizations and managerial decision-making. In addition to variants of systems analysis, or systems engineering, this could include the use of decision theory which has considerable potential value in the quantitative appraisal of administrative procedures, especially as computers now facilitate the intricate mathematical operations that are involved. Similarly, he draws attention to the use of queuing theory, mathematical programming, simulation and operational gaming in providing a suitably scientific approach to the investigation of organizational problems. There would be considerable difficulties, both theoretical and practical, in applying such an approach. Nevertheless, its potential value must not be ignored, least of all in Third World countries, if best use is to be made of the expertise and resources which are available.

Finally, there are important educational implications. The traditional boundaries between scientific disciplines need to be reshaped to permit the growth of interdisciplinary links. New 'integrating' courses of study, incorporating landscape ecology, *e.g.*, must be devised to facilitate interdisciplinary training and research projects. New attitudes and modified faculty structures are needed in the Universities to permit this. To these ends, greater emphasis should be given to practical methodological considerations, based on appropriate mathematical training, in scientific education. The necessary training should be incorporated within the various fields of study, not simply an incidental subject. It should commence in the schools at a suitably elementary level, to be subsequently developed progressively, rather than being a once and for all course on 'scientific method', or some such, as at many Universities.

Thus many problems have to be overcome to establish the breadth and diversity of interdisciplinary collaboration which is required for land research in the Third World: political, scientific, organizational and educational. This necessitates fundamental changes in attitudes and standpoints in science, education and government policy-making. Without such collaboration, however, the more serious and pressing obstacles to agricultural development, and hence to general economic growth, cannot be tackled effectively.

Summary

In the practical application of landscape ecology to land research for development planning, interdisciplinary collaboration is essential to deal effectively with the complex problems which influence development possibilities, to make the most efficient use of staff and resources, and to promote the advancement of scientific knowledge. Three ways of integrating this collaboration are advocated: environmental concepts which direct the different

specialists to focus on landscape interrelationships; geomorphological differentiation to provide a common framework for spatial analysis; a unified methodology based on mathematical modelling, hypothesis testing and the application of statistical theory. Broader implications include policy-making and administrative questions, and the need for educational changes.

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