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SUSTAINABILITY AND NATURAL RESOURCE MANAGEMENT

The *MESMIS* Evaluation Framework

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FOREWORD

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Sustainable systems of production are those that realize the total potential of their underlying resources, *i.e.*, they provide environmental, social and economic opportunities to present and future generations alike. The conventional management paradigm of maximizing profit and economic return has proven insufficient for describing sustainable systems and should embrace a more holistic development objective, one that both optimizes as well as balances productivity with social equity, economic viability and conservation of natural resources. Any attempt to evaluate the sustainability of natural resource management systems (NRMS) should effectively integrate strategies for productive stability with socio-cultural compatability, environmental protection and economic improvement.

MESMIS is a novel methodological framework that captures the holistic complexity of natural resource management. As a methodology, MESMIS derives indicators to accomplish two goals: first, to reflect the behavior of the most critical aspects of a particular NRMS; second, to demonstrate how the characteristics of a particular NRMS may achieve the multiple objectives of sustainable systems. These characteristics include:

- Maintaining or improving productivity and reducing risks.
- Increasing ecological and socio-economic services.
- Protecting the natural resource base and preventing the degradation of soil, water and agro-biodiversity.
- Achieving economic viability.
- Existing in a form that is socially acceptable and culturally compatible.

With this methodology, agents of development will be able to monitor any changes in resource quality as well as in the relative efficiency of input or resource use. Within this framework, each sustainability indicator can be analyzed in turn, as well as be integrated within a broader matrix of indicators. One of the most important aspects of MESMIS is that, apart from a comparative assessment of the system's present condition, MESMIS proposes modifications that optimize each component or key factor through proposing distinct alternatives for agroecologic management.

For individuals and organizations working in agricultural and forestry development projects, MEMSIS provides a clear and effective methodology that comprehensively and systematically evaluates the state of a NRMS, by monitoring the impact of different interventions and by indicating appropriate changes for improvement.

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Despite the extensive discourse on sustainable development, there have been few consistent and systematic attempts to transform the general principles of sustainability into operational practices within actual field conditions. Traditional analytical approaches (*e.g.*, cost-benefit analysis) have proven insufficient or simply inadequate at incorporating constraints - such as the existence of non-aggregate or non-quantifiable variables, or the integration of biophysical parameters within social and economic processes - into analyses of sustainability.

In order to address these difficulties, research has been directed towards implementing different conventional techniques as a sort of *ad hoc* combination of strategies, which have proven inadequate for addressing the holistic complexity of systems analysis. Given this inadequacy, practical and conceptual formulations that are qualitatively distinct from former conventional techniques are required for an in-depth analysis of the sustainability of resource management systems.

Particularly in the context of Third World peasantry, there is presently no appropriate theoretical framework to evaluate the sustainability of NRMS. This is not to say that progress in this area has not occurred; on the contrary, substantial progress has been made in the measurement of biophysical indicators, particularly for specific subsystems under controlled conditions (*i.e.*, sustainability indicators for soils or for a given crop). There has also been substantial development within a wide range of economic indicators, mostly for application in commercial agricultural systems. However, there have been few attempts to incorporate social and institutional criteria into sustainability evaluation schemes, and there has been little progress in tackling complex NRMS (*e.g.*, farming-forestry-livestock systems) and long term management systems (*i.e.*, forestry).

The basic problems are thus: existing appraisal methods for sustainability are usually either too general and vague, designed for *rapid* appraisals, or so elaborate that they may only be applied under experimental situations. More research is needed to develop evaluation strategies that are both based on a rigorous appraisal of sustainability, and effective in field conditions.

Furthermore, assessing sustainability tends to result in a mere *qualification* of productive systems (*i.e.*, simply assessing whether the systems are sustainable or not). Up until now, no sustainability assessment framework exists for the specific purpose of improving both the social and environmental profiles of the NRMS or the technologies that they investigate.

OBJECTIVE OF MESMIS

The Indicator-based Framework for Evaluating the Sustainability of Natural Resource Management Systems (in Spanish, *Marco para la Evaluación de Sistemas de Manejo de Recursos Naturales Incorporando Indicadores de Sustentabilidad,* MESMIS) is a methodological tool that:

- Assists in evaluating the sustainability of natural resource management systems (NRMS), with an emphasis on small farmers within the local context (from the level of the farm to the village).
- Improves the likelihood of success for any proposed alternative NRMS as well as for already existing NRMS being evaluated. MESMIS attempts to generate a *process of analysis and feedback*, which would avoid a simple ranking of management systems in terms of a *sustainability index* or scale.
- Seeks an integral understanding of the opportunities and constraints for the sustainability of NRMS that are forged by the intersection of environmental processes and socio-economic conditions.
- Evaluates the *comparative* sustainability of management systems, either by comparing one or more alternative systems with a system of reference, or by observing changes in the properties of a particular system over a period of time.
- Promotes an evaluation process that is systemic, participatory, multidisciplinary, and flexible, which can adapt to different levels of data availability and local technical and financial resources.
- Constitutes a tool for development, in which the experience of applying the methodology will improve the very model on which it is based. In this sense, it should be understood that MESMIS functions as a method for *organizing* a discourse on how to make the concept of sustainability operational in the field.

Audience Addressed. MESMIS is geared towards research institutions, non-governmental organizations (NGOs), and organizations of producers involved in the design, development and diffusion of NRMS.

Linkages with International Efforts. The MESMIS structure is designed to be compatible with the Framework for Evaluating Sustainable Land Management (FESLM), a program internationally promoted by FAO (FAO, 1994).

ACKNOWLEDGEMENTS

This document is the fruit of intense collective labor; many people have contributed towards its completion either in specific stages, or throughout the entire process. First, we wish to acknowledge the constant and continued support of Rubén Puentes. His comments, criticism, and methodological contributions were key factors in the successful completion of the project.

We owe special acknowledgement to MESMIS case study participants. Their support and collaboration brought many generic concepts 'down to earth', by providing us with useful feedback for the development of the methodology and by making us aware of the practical limitations of our proposed approach. We would like to specially thank the sustainability assessment groups created in the *Unión de Ejidos Majomut*, in the Southern state of Chiapas; the *ERA-UZACHI* project in Oaxaca; the joint *INIFAP-Universidad de Chapingo* project in Southern Sinaloa; the *Unión de Productores y Ejidos de la Zona Maya*, in the state of Quintana Roo; the group *GIRA A.C.*, in Michoacán, and the *Grupo Pachuca* in several states of Southeastern Mexico.

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PREFACE

Transforming the discourse on sustainable development from mere academic or political rhetoric into a more substantive operational practice requires conceptual frameworks and practical tools that define in explicit terms the principal fundaments of sustainability.

The development of the Indicator-based Framework for Evaluating the Sustainability of Natural Resource Management Systems (MESMIS) is the result of an ongoing effort that seeks to address this issue. Two of the authors drafted a preliminary framework for deriving sustainability indicators as graduate students at the University of California Berkeley in 1992. Their efforts were concretized in a methodological framework made possible through collaboration with the Rockefeller Foundation's *Natural Resource Management Program*. Late in 1993, the non-governmental organization GIRA A.C. assembled a team to work on evaluating the sustainability of NRMS using the frameworks previously developed. Their work on alternative methodologies for these evaluations was initially systematized through a series of workshops, and a year later, they made their first specific attempt to develop the MESMIS framework and to apply it in several case studies.

In 1996 the first version of MESMIS appeared as a working paper under GIRA A.C., and since then it has undergone extensive theoretical and practical review. The document was initially distributed to a large number of experts in both social and natural sciences, whose valuable comments and suggestions greatly contributed to the work.. Later, MESMIS was applied to the field through various case studies throughout Mexico. During this time, several workshops were held, in Mexico and in other parts of Central America, in which a wealth of new ideas and useful suggestions emerged that enhanced the operational and methodological aspects of MESMIS. Finally, MESMIS was incorporated to the graduate program in biology at the *Universidad Michoacana de San Nicolás de Hidalgo,* which further expanded its content.

This latest version of MESMIS, published in book format, is the natural result of the rigorous processes of feedback and review described above. It represents an ongoing effort towards a synthesis of methods to evaluate sustainability, in which the application of MESMIS to a wider range of case studies will ensure its continued evolution. This document focuses on the fundamental methodological aspects involved in evaluating sustainability. As such, it essentially presents a framework for organizing assessments, and is not a complete field guide for carrying them out.

As we have said, our work is by no means complete: MESMIS is an evolving process. Nonetheless, we feel that this document includes the fundamental organizing principles that overcome several of the limitations and omissions of previous work on sustainability. You as the reader will have the final word on the matter. We hope that our efforts will be useful to all those interested in establishing alternative, sustainable development practices, particularly among farming systems in developing countries.

The MESMIS project on evaluating sustainability. This project on *Evaluating Sustainability* is a multi-institutional effort coordinated by GIRA since 1995, in collaboration with other research centers, like the Autonomous University of Chapingo, the National Institute of Forestry and Agricultural Research (INIFAP) , and the Institute of Ecology of UNAM, as well as various NGOs, such as the Union of Majomut Commons and the Organization of Forest Producing Commons in the Mayans. This project was funded through the Rockefeller Foundation's *Natural Resource Management Program* and is geared towards the development, dissemination and application of methodologies to evaluate the sustainability of NRMS. The strategies for achieving these objectives include: (a) developing training and reference documents on sustainability; (b) applying the MESMIS methodology to a series of case studies within Mexico; (c) implementing training workshops on the MESMIS methodology; and (d) organizing international seminars on evaluating sustainability.

The present report is the core of a more comprehensive *evaluation package*, which includes:

(a) the terms of reference for preparing case studies on evaluating sustainability;
(b) a handbook containing detailed operational information on how to implement an evaluation of sustainability (*i.e.*, recommendations on organizing the work team, tips on encouraging and structuring group participation, information on indicators, etc.);
(c) *SUSTENTA*, a database with over 300 references on sustainability; and
(d) a packet that brings together key papers on sustainability and sustainability indicators. Lastly, a resumen of the experience of applying MESMIS in five case studies will soon be available in book form.

For more information on the MESMIS project, please consult our Web page:

www.mesmis.gira.org.mx

I

INTRODUCTION

Why Evaluate the Sustainability of Natural Resource Management Systems?

THE CONTEXT

On of the greatest challenges that faces the discourse on sustainable development – and particularly sustainable agriculture – is how to design and implement an operative framework that, in a tangible and precise manner, effectively evaluates, or assesses, the sustainability of different projects, technologies or agro-ecosystems.

This is indeed a considerable challenge; transforming the concept of sustainability into an operational application requires integrating a substantial amount theoretical study with a good dose of pragmatism. In effect, the conceptual complexity of sustainable development and the diversity of its interpretations (which often remain merely discursive elements) create the risk that sustainability will become little more than an unmanageable *cliché*, suited to serve the context of any given moment. Furthermore, attempting to create an operational framework for sustainability without an adequate discussion of its underlying theoretical foundations has produced a seemingly endless list of indicators which, paradoxically, obstruct a clear and coherent view of the tenets of sustainability (for an example, see the United Nations' World Commission on Environment and Development's proposal to adopt a general definition of terms [WCED, 1987]).

Moreover, another difficulty in making the concept of sustainability an operational application surfaces when questioning the conventional methods of evaluating projects, technologies and natural resource management systems (NRMS). Evaluating sustainability requires a well-integrated interdisciplinary effort, one that is capable of synthesizing the analyses of both environmental and socio-economic processes (Toledo, 1998). It also involves working within multi-criteria frameworks based on qualitative and quantitative indicators.

Lastly, a true evaluation of sustainability requires integrating wider perspectives within a longer time frame than those common to conventional evaluations.

Beyond conducting a purely academic discourse lies a critical need to assess the relative degree of sustainability in differing production systems, especially those throughout the rural sector of the developing world. Development projects proposing alternative systems for farming, forestry and livestock management call for new evaluation schemes that enable assessment and encompass efforts towards greater ecological, social, and economic sustainability.

EFFORTS TO EVALUATE SUSTAINABILITY

The wealth of recent articles and writings on the subject of evaluating sustainability illustrates how this topic has become the focus of intense research and debate worldwide. Of particular interest has been the subject of sustainability indicators; a significant number of publications attempt to define a set of sustainability indicators for environmental, economic, and to a lesser extent, social systems, at varying scales and levels of detail. (Taylor *et al.*, 1993; Azar *et al.*, 1996; Shaw, 1996; Syers *et al.*, 1994; Bakkes *et al.*, 1994; Winograd, 1995; Hammond *et al.*, 1995). Outlined below are some of the prevalent theories concerning indicators, indices and other methodological approaches that have emerged from the literature.

Some indicator-related studies have been specifically designed for implementation on a national or macro-regional level (Winograd, 1995; Hammond *et al.*, 1995; Bakkes *et al.*, 1994), making their application in the local context difficult. Conversely, other methodologies designed for specific projects are so narrowly focused that their widespread application is inappropriate (Nair, 1993; Taylor *et al.*, 1993; Stockle *et al.*, 1994).

Another group of assessment methodologies is based on determining *sustainability indices*, where information relevant to sustainable systems is aggregated or synthesized into a numerical value. For example, Harrington (1992; see also Harrington *et al.*, 1994) suggests using a *Total Factor Productivity* index, obtained by quantifying all system outputs or benefits, as well as all inputs (short and long term economic and environmental costs). Not only does this strategy fail to take into account critical social and cultural issues, but it also pits itself against the difficult task of transforming environmental externalities into monetary values (and thus converts itself into an extension of a cost-benefit analysis).

Along the same lines, Taylor *et al.* (1993) propose the use of a *Farmer Sustainability Index*, as a function of the activities or strategies adopted by each producer which influence system sustainability (pest control, erosion control, soil fertility conservation, and so on). However, instead of evaluating the sustainability of a management system, this methodology assesses to what degree a series of strategies, which are considered sustainable *a priori*, are adopted by a group of farmers facing similar conditions. Generally speaking, those methodologies whose final aim is to obtain a single numerical value or sustainability index have an inherent pitfall: they must define values for the many different variables under study, in order to reduce them to a single unit of measurement.

Other interesting theoretical approaches characterize sustainability from the perspective of the ecosystem by using the natural ecosystem as the *system of reference* against which management systems are compared (Maass and Jaramillo, 1996). However, in practice such natural ecosystems may not exist in the study zone (for example, in agricultural or cattle-raising areas that have been extensively industrialized). Furthermore, simply comparing natural and exploited systems may in itself be an inadequate approach, given the social nature of management systems. In other studies, general theoretical frameworks are proposed, but contain few guidelines for their actual implementation (Hansen, 1996).

A final group of publications explicitly seeks to develop frameworks whose analytical structure surpasses merely determining indicators and stresses practical applicability. One such example is the framework developed by the International Union for the Conservation of Nature (IUCN) and the International Development Research Centre (IDRC), which has been applied in a number of case studies, and includes a set of four methods for analyzing progress towards sustainability in both management systems and stakeholder organizations or institutions (IUCN and IDRC, 1995; IUCN, 1997). The proposed methods are not fully integrated, but nevertheless contain elements of different evaluation strategies, from sustainability index measurement to participatory and iterative management systems analysis.

The framework developed by the Inter-American Institute for Agricultural Co-operation (IICA) (de Camino and Muller, 1993; Muller, 1995) suggests a systemic methodology for deriving indicators that relies on an extensive bibliographical review of the concept of sustainability and its different variants, defining four categories of analysis: (a) the resource base of the system; (b) the operation of the system; (c) exogenous resources to the system (inputs or outputs); and (d) the operation of other exogenous systems (in terms of input or output). The IICA methodology for obtaining indicators is consistent and has been quite useful in developing the present framework; however, it fails to put forward a strategy for analyzing and integrating results obtained from those indicators.

The most elaborate attempt to create a methodology for evaluating sustainability is undoubtedly the Framework for Evaluating Sustainable Land Management (FESLM), prepared by the FAO (1994). FESLM constitutes one of the most significant attempts to assess sustainability at an international level; together with the application of its different case studies (Gameda and Dumanski, 1994; Latham, 1994), FESLM has served as a key document to the development of the MESMIS methodology. Despite its environmental bias, FESLM proposes a strategy for a comprehensive analysis of management systems, including the economic and social aspects that determine their behavior. Operationally, it suggests a strategy of five steps. The first two steps aim to define and characterize the system under analysis in terms of existing management practices, and determine the scope of the evaluation (in terms of its duration and spatial scale). The next steps identify factors affecting system sustainability, as well as the criteria for their analysis. The last step defines the indicators to be monitored, with their respective thresholds or critical values (FAO, 1994).

To conclude, despite the vast literature available on sustainability assessments and indicators, progress has been slow in developing evaluation frameworks that are both theoretically sound and practically applicable. In particular, scant work has been carried out on agricultural and forestry systems in the Third World. Moreover, the methodology for assessing sustainability that is most often employed falls under the traditional rubric of outside intervention conducted by an “objective” expert or team of experts. In these cases, when the assessment is completed, a global qualification is assigned, which offers little opportunity for feedback to the project stakeholders as much as to the evaluation team. In general, these genre of assessments do little to encourage dialogue between the natural resource management proposals and the evaluation procedures. Any attempt to create a more sustainable model for development must seek to improve upon its two basic elements: the production methods used in the NRMS (including technologies, management practices, organization activities, etc.) and the evaluation framework itself.

THE MESMIS FRAMEWORK

The Indicator-based Framework for Evaluating the Sustainability of Natural Resource Management Systems (MESMIS) emerged to address some of the above-named issues and tackle problems insufficiently addressed by other methodologies. MESMIS incorporates the following general elements:

a) a discussion about the basic attributes of sustainable natural resource management, *e.g.*, productivity, resilience, reliability, stability, adaptability, equity and self-reliance (self-empowerment);
b) a clear delineation of the objects under study (*e.g.*, the objectives and characteristics of the management system, the duration, and the geographic scope of the evaluation);
c) a derivation of diagnostic criteria and concrete indicators related to the attributes of sustainability;
d) the measurement and monitoring of the selected indicators;
e) analysis and integration of results; and
f) proposals and recommendations in the form of feedback to improve both the management system being evaluated and the evaluation process itself.

This procedure addresses the three basic questions that underlie any assessment of sustainability: (i) which elements constitute the evaluation? (ii) how is the evaluation performed?, and (iii) how are the results reported, integrated and applied in order to enhance the profile of the natural management systems under evaluation?

The MESMIS framework is directed towards farming, forestry and cattle-raising projects carried out either collectively or individually, which are oriented towards development and/or research. The evaluation procedure must be more than just an instrument for *qualifying* given alternatives; it must serve as a supporting construct that makes sustainability operational, towards a more equitable and environmentally-conscious development strategy in rural communities.

To reach this goal, MESMIS proposes a cyclic structure, specially adapted to different levels of information and technical capability. Its practical focus is based on participation, to encourage discussion and feedback between the evaluators and the evaluated. Additionally, MESMIS provides an interdisciplinary approach to promote a comprehensive understanding of the opportunities and constraints of NRMS, which emerge through the intersection of environmental and socio-economic processes.

Lastly, the MESMIS framework is comparative in nature, in one of two ways: either a proposed management system is compared to a system of reference, or the changes in one management system are compared over time. This procedure provides two things: first, an examination of the actual sustainability of an alternative management system relative to its reference; and second, the identification of a series of critical points for sustainability (which will ultimately guide implementing changes). The comparative nature of the framework along with its cyclic structure make it a valuable planning tool that enables flexible and dynamic design, implementation, and evaluation strategies – strategies that are critical to improving the social and environmental features of the assessed systems, and to fine-tuning the evaluation framework itself.

This book is divided into two chapters. The first chapter delineates the theoretical foundations of sustainability, and discusses its application to NRMS. Beginning with a synopsis of the concepts of sustainable development, sustainability and sustainable agriculture, the chapter progresses to discuss the operative principles or attributes in the context of natural resource management. The remaining section presents an operational definition of sustainable management systems.

Chapter two presents the operational strategy of the MESMIS framework. It begins by outlining the analytical structure of MESMIS. The ensuing sections provide detailed descriptions of each stage of the evaluation, including the demarcation of the evaluated systems, the selection of indicators, their measurement and monitoring, the integration and presentation of results, and the conclusions and recommendations.

The final section of the book recapitulates the MESMIS framework, and outlines some issues requiring future attention and development. The two appendices respectively illustrate examples on how to integrate the results of the analysis, and provide a directory of individuals and institutions working in various issues concerning sustainability and its evaluation.

II

SUSTAINABLE NRMS: DEFINITION AND ATTRIBUTES

THE CONCEPTS OF SUSTAINABILITY AND SUSTAINABLE DEVELOPMENT

An essential first step in designing a framework for evaluating sustainability is to discuss and articulate the main attributes of what is meant by "sustainability". One of the main weaknesses of existing evaluation frameworks is that they have developed criteria and indicators without engaging in an adequate discussion of the underlying concept of sustainability. Rather than rehash the plethora of existing arguments on the subject, we intend simply to clarify the theoretical bases from which the MESMIS operational framework is derived.

The discussion about sustainability and sustainable development is both broad and complex. One of the main difficulties faced by those attempting to clarify the concept is that the words used to describe it have become mere *clichés*, inconsistently defined and used without the proper context. For a revision of the terms (including their creation, main characteristics, attributes and practical derivations) refer to Lélé (1991 and 1993), Dixon and Fallon (1989), and Tolba (1984).

The above-named revisions arrive at one particularly critical conclusion: it is impossible to arrive at a universal definition of sustainability and sustainable development. The expansive diversity of interests, problems, perspectives and scales involved in the current discourse hinder reaching any strict consensus of terms. Therefore, rather than look for a general, or universal, theoretical definition, finding a 'common ground' constitutes a more practical approach, where central elements are shared commonly. Definitions that can be applied to actually existing case studies must be found and used consistently.

Following this logic, the concept of sustainable development may be defined as the process by which all material and spiritual needs of individuals and communities may be permanently met, while improving, rather than harming, the socio-environmental resources on which sustenance is based. When seen this way, sustainable development may be considered as a process of directed change, in which *the ends are as important as the means*. The notions

Table 1. General Objectives of Sustainable Development

- Ensure the satisfaction of essential human needs, beginning with those of the poorest.
- Promote cultural diversity and plurality.
- Reduce inequality among individuals/regions/nations.
- Preserve and enhance the existing natural resource base.
- Improve the possibility of adapting to natural and anthropogenic disturbances.
- Develop efficient and low resource use technologies adapted to local social and ecological conditions, without implying any risk for present or future generations.
- Generate structures of production, distribution and consumption that provide the necessary goods and services and promote full employment and meaningful labour, in order to improve the development capabilities of humankind.

of *permanence* (related to the adequate care of socio-environmental factors), and *equity* (related to the equitable inter- and intra-generational distribution of costs and benefits) compose two indispensable elements for the definition of sustainable development. Moreover, ends are not static, but are continuously redefined, according to the evolution of social processes and their interaction with the environment.

From a socio-cultural perspective, particular goals include promoting cultural diversity and plurality, and reducing inequality between and within nations, regions and communities. Environmental objectives encompass the conservation and restoration of natural resources, and the promotion of technologies that enable an efficient and synergistic use of those resources. Finally, economic objectives include the generation of productive structures that provide the necessary goods and services for society, by ensuring full employment and meaningful labor (Lélé, 1991; Lawrence, 1997) (see Table 1).

The strategies needed to achieve these comprehensive objectives (and in some cases the definition of the objectives themselves) require an integration of social, political, economic, and environmental interests. It is obvious that the concept of *needs*, as well as the means to satisfy them, are radically different depending on the human group considered. However, generally speaking, two broad schools of thought may be defined. First, are those who emphasize *corrective* strategies, which assume that sustainable development will result from a simple modification of the existing institutional and socio-political structures, without significantly altering the *status quo* (Repetto, 1986; CLADE, 1990; World Bank, 1987). The second group advocates *transformative* strategies, based on a comprehensive change of prevalent institutions, natural resource use patterns, and policies (Gallopín *et al.*, 1989; Escobar and Thrupp, 1990). Within this latter group, transformative strategies generally include effective democratization, increased participation and control by local people, and the redistribution of wealth and means of production. Furthermore, these strategies imply reorienting and redirecting scientific and technological innovations towards peaceful applications whose goal is to solve existing problems and create a more just international economic order.

A discussion of sustainable development should incorporate three central aspects: (a) development is a dynamic concept and process in which human needs need to be continually re-defined as time progresses. (b) priorities must be established; it is not possible to optimize all desired objectives simultaneously, and (c) *sustainable development* is a generic concept whose definition and attributes must be determined at the local or regional level.

Definitions of the concept of sustainability range from general and vague to highly field specific. Pezzey (1989) provides a list of more than 27 different definitions of sustainability, while Hansen (1996) includes nearly 20 definitions in the field of sustainable agriculture alone!

Dixon and Fallon (1989) identify three distinct conceptions of sustainability: (a) a purely biophysical concept applied to a particular natural resource; (b) a biophysical concept applied to a set of natural resources or an ecosystem; and (c) a biophysical, social and economic concept.

The first of Dixon and Fallon's definitions was created to define the *physical* limits for the exploitation of a single class of biological renewable resources, such as forests or fisheries. In this context, the definition is conceptually restricted to consider a given renewable resource in isolation. Sustainability in this context - more correctly termed as *sustainable yield* - is thus conceived as the use of resources without physically reducing the available stock. This is analogous to spending the interest generated by a savings account and leaving the capital intact so that it continues to yield interest in the future (Dixon and Fallon, 1989).

The concept of sustainability may be expanded to a larger system comprising a number of natural resources. In this broader context, sustainability is measured in physical quantities but, instead of considering a single component, it takes into account the different inputs and outputs of the ecosystem. As a result of interactions within the system, a single resource considered to be managed sustainably within a subsystem could be considered unsustainable within the context of the entire system. For example, it is possible to sustainably extract timber from a forest. However, this extraction may have negative impacts in other subsystems of the forest, such as soil erosion and silting, degrading aquifers and reducing local biodiversity, therefore rendering the extraction activity unsustainable at the system level (Dixon and Fallon, 1989). Many questions arise due to the nature and complexity of ecosystem components and their interconnections: for example, what would be the trade-offs resulting from an alternative system of development? Clearly, such an analysis requires well-defined system boundaries.

The definition of sustainability is further complicated when taking into account social and economic factors influencing the environmental sustainability of a given system - or in other words, when the sustainability of a *socio-environmental* system is investigated. In this broader sense, sustainability may be defined as the continued maintenance of a variety of desired objectives or attributes over time, making sustainability a dynamic concept that must be founded on a system of human values. Due to the difficulty of formulating a universal set of human values, it has been impossible to arrive at a global definition of sustainability. To provide such a definition, three main questions must be answered:[1]

[1] Dixon and Fallon (1989) list a series of key questions to be considered when attempting a rigorous approach to the notion of sustainability: (a) How should the concept of inter- and intra-generational equity be applied vis-à-vis resource management decisions? Who benefits from what? Who pays for using more or less resources today or in the future? How can the needs of the present generation be fulfilled without compromising those of future

- What will be sustained?
- For how long?
- At what scale?

When considering these questions, sustainability becomes a multidimensional attribute of a socio-environmental system. As such, sustainability must be analyzed within the social context in which alternatives are developed, analyzed and implemented. In order to answer the fundamental questions, reference must be made to the following complementary questions*:* *Sustainability for whom? Who will carry it out?* and *How?* (*i.e.* who makes decisions? by means of which socio-political procedures? who enforces the concept in practice, and how?) Making the concept of sustainability operational implies understanding and incorporating the variety of preferences, priorities and perceptions implicit in the objectives of the sustainable system. As in the case of sustainable development, determining a specific concept for sustainability must occur at the local scale, using processes that adequately articulate relevant issues between the different levels of analysis (micro-regional, national and global).

DEFINING SUSTAINABLE NRMS

The literature on sustainable natural resource management systems (NRMS) is equally broad and diverse, with varying conceptual definitions depending on the author's discipline or the scale of the system under study. While in many cases, discussions in the literature are focused on *sustainable agriculture*, this study investigates comprehensively the concept of sustainable NRMS, to include forestry, livestock raising, etc. Nevertheless, understanding the terms 'sustainable agriculture' as they are used in the literature is relevant to the theoretical structure of MESMIS.

Hansen (1996) characterizes four diverse definitions for sustainable agriculture: an ideological framework; a series of strategies; the possibility of satisfying certain goals; or the ability to maintain certain attributes over time.

Definitions on sustainable agriculture range from specific interpretations to very general definitions. For example, Conway (1994) promotes a completely agro-systemic perspective: "Sustainability measures the behavior of an agroecosystem in response to the normal fluctuations in the surrounding environment; [it] is the ability of an agroecosystem to withstand such disturbing forces". Conversely, the American Society of Agronomy (1989) adopts a more general view, in which a sustainable agriculture is that which, in the long term, qualitatively enhances the environment and the resource base on which agriculture depends; provides the fibers and the food supply required by mankind; is economically viable, and improves the quality of life of farmers and society as a whole.

generations?; (b) How far into the future should our concern reach? Do we care about next week, next year or next century? In any form of sustainable development, each of these time-horizons implies different resource utilisation patterns. As the time-horizon becomes narrower, it is more difficult to expect that a given resource use pattern will be sustained for prolonged time periods; (c) Should some resource use patterns be acceptable, whether the resource is preserved or lost? For example, are extinction of species and genetic losses always necessarily harmful? Which habitats, resources or environments should be protected, which lost, and which left hanging in wait for an adequate policy?

Basically, all definitions involve the following elements:

- improvement and conservation of soil fertility and productivity;
- management strategies (low-cost inputs, etc.);
- satisfaction of human needs;
- economic viability;
- social adaptability (equity and improved welfare of farmers and society);
- ecologically sound (impact minimization, environmental protection and improvement); and
- *long-term* system durability (as opposed to short-term profitability).

Other general elements are also often included, such as the satisfaction of spiritual and material needs and the long-term balance between social development and environmental protection (Conway, 1994; USAID, 1988; Edwards *et al.*, 1990; Randhawa and Abrol, 1990; Francis and King, 1994; Altieri, 1994).

Altieri (1994) defines sustainable agriculture as a mode of agriculture aimed at achieving yields sustained over the long-term, by means of technologies and management practices which improve the system's biological efficiency. In this rendering, efforts are directed towards optimizing the agroecosystem as a whole, and not on maximizing short-term profit.

Overall, sustainable agriculture aims to achieve a number of main tenets: ensure the fair and equitable distribution of costs and benefits within a community; recover more traditional management practices used by various ethnic groups and cultures; diminish the existing inequalities in the access to productive resources; develop technologies and management systems that suit the diversity of local ecological, social and economic conditions; and finally, promote economic profit - one that avoids being dominated by short-term thinking.

Most authors emphasize the need to adopt a systemic approach that encompasses a multiplicity of goals. For example, Levins and Vandermeer (1990) propose that production in sustainable agro-ecosystems must incorporate a holistic understanding of the system, which focuses on the multiple goals of yield, profitability, decrease of uncertainty and vulnerability, equity, health care of farmer laborers and consumers, environmental protection, and long-term system flexibility.

Achieving these goals, and promoting long-term sustainability of NRMS can come through diverse means. Altieri (1987) suggests the following:

- Use energy and resources efficiently.
- Apply production methods which aim to re-establish the homeostatic mechanisms leading to community stability, optimize recycling rates of nutrients and organic matter, maximize the use of the system's multiple capabilities, and develop an efficient energy flow.
- Produce local food in accordance with existing socio-economic and natural conditions.
- Reduce costs and increase economic efficiency and viability of small and mid-size farmers, encouraging a potentially vigorous and diverse agricultural system.

From an environmental perspective, the degree to which an agroecosystem increases its sustainability will depend fundamentally on management practices which include optimizing the following processes (Altieri, 1987; Reijntjes et al., 1992):

- **Availability and balance of nutrients:** The productivity of an agroecosystem is directly related to the magnitude of the flow, immobilization and conservation of nutrients. These, in turn, depend on a sustained input of organic matter, and on the promotion of biological activity in the soil.
- **Protection and conservation of soil:** The management of surface soils and vegetation through cover crops, mulching, zero-tillage, or other erosion-reduction techniques effectively preserves soil and water resources. Additionally, these techniques reduce the deterioration of the soil's physical, chemical and biological properties.
- **Conservation and integration of biodiversity:** The efficiency of nutrient recycling and resistance to pests or diseases depends on both the quantity and the type of biodiversity present in the system; that is, in terms of organization in space and time (structural diversity), as well as interactions and synergy (functional diversity). Both functional and structural diversity may be increased by means of multiple-cropping, agroforestry, mixed agro-pastoral systems, etc.
- **Enhance adaptability and complementarity in the use of genetic resources from plants and animals:** Using local breeds and varieties which are adapted to existing environmental heterogeneity and which respond well to a low levels of external input management.

From the socio-economic perspective, the following are a few basic mechanisms to promote sustainable agriculture:

- **Improve the efficiency of production processes**, by taking advantage of synergies between diverse economic activities.
- **Strengthen mechanisms for local co-operation and solidarity**, as well as the effective participation of all stakeholders involved in the design, implementation and evaluation of natural resource management alternatives.
- **Expand local capabilities and skills**, by means of participatory training and education processes promoting self-reliance.
- **Maintain respect for diverse cultural traditions**, and promote cultural and ethnic plurality.

To sum up, sustainable agriculture requires setting in motion a process of *social motivation* to create the conditions that empower local participants.[2]

[2] Based on an ample revision of experiences in several parts of the world, and on the specific context of common resource management systems, Becker and Ostrom (1995) suggest a series of important principles for promoting sustainability from a social perspective: (a) **Clear demarcation of the system's limits.** The limits of the management system, as well as the individuals who are entitled to benefit from its products, must be precisely established. (b) **Proportionality of costs and benefits.** The profits derived from the system must be proportional to the labour and money invested in their generation (*e.g.*, more profit should correspond to those who work more).

Key to this discussion is equity, a concept that, at its core, is an ethical premise, but also functions as an operational requirement (and here, inequity should be understood in the broadest sense, *i.e.*, not merely in economic terms). Societies where inequity exists require the creation of coercive structural institutions, which often generate explicit and implicit aggression and violence. These in turn often lead to outbreaks of violence between individuals or social groups. In other words, the absence of equity will sooner or later present obstacles towards sustainability by destabilizing social institutions.

Finally, it should be pointed out that achieving true sustainability goes beyond addressing social and technical issues solely at local levels. Creating effective entry-points to integrate the management of agro-ecosystems within regional, national and global contexts is critical to the process of achieving sustainability. (One clear example would be to make farming policies compatible with a macroeconomic environment that promotes fair prices, generates employment at the local level, and incorporates environmental externalities to conventional practices.) Another critical area of investigation is understanding the politics behind developing and disseminating technologies applicable to a multiplicity of local conditions. Promoting local self-empowerment as well as effective self-representation among different social groups in decision-making processes constitutes a democratic process that is critical to any sustainable management system.

SYSTEMIC ATTRIBUTES OF SUSTAINABLE NRMS

Fundamental to deriving an operational definition for the concept of sustainability is identifying a series of general properties, or attributes, of sustainable agro-ecosystems. These attributes will structure the system analysis around the more relevant issues, and will eventually be used to derive sustainability indicators in the evaluation process. Various efforts have been made to identify and define pertinent attributes, some of which are outlined below.

Some studies have defined these attributes in a rather *ad hoc* fashion, such as in FAO's (1994) proposal, in which a consensus of the FESLM team identified **productivity**, **security**, **protection**, **viability** and **acceptability** as the pillars for supporting the evaluation of sustainability. This set of attributes attempts to take into account all the basic tenets that a NRMS should satisfy in order to be considered a sustainable system. In practice however, some of these attributes, such as viability and acceptability, are extremely difficult properties to define.

(c) **Collective decision-making rules.** This means that participants themselves determine the rules for resource use and protection. (d) **Existence of supervision or monitoring.** There must be people in charge of physically monitoring the physical status of the resources and of supervising user activities. (e) **Graded sanctions.** The penalties received by those which fail to comply with the rules - imposed by other users or by representatives accountable to the whole group - must be determined in relation to the severity of the violation and the particular context. (f) **Conflict-resolution mechanisms.** In cases of conflict among group members, or between groups and either authorities or the technical staff involved, users and group representatives must have access to prompt, low-cost, local conflict-resolution mechanisms. (g) **Sufficient recognition of the right to self-organisation.** The users' right to develop their own institutions must not contradict external authorities; likewise, users must have the right to long-term tenure over resources.

Other frameworks define their attributes more systematically. For example, according to the Inter-American Council for Sustainable Agriculture (Spanish acronym GIDSA), the most important attributes of a sustainable management system include:

(a) The maintenance of resource **availability** over time;
(b) **adaptability** and flexibility;
(c) **vigor**, **resilience** and **stability**;
(d) **responsiveness to changes** (both internal and external);
(e) **self-reliance**; and
(f) **empowerment** (GIDSA, 1996).

Conway identifies four basic attributes for sustainable systems: **productivity**, **stability**, **sustainability**, and **equity** (Conway, 1994; Conway and Barbier, 1990). Productivity is defined as the relation between production and the amount of resources required to achieve a given level of production. Stability is the system's capacity to maintain a constant level of productivity. Sustainability, in this case, is the system's capacity to respond to a stress or shock to the system while maintaining an acceptable level of productivity. Equity is defined as the degree to which benefits in the system are distributed among stakeholders. This systemic vision for identifying the attributes of sustainability provides a more consistent theoretical framework that has been applied by several authors in case studies (Muller, 1995; González, 1998).

For an evaluation framework to remain theoretically consistent, its attributes must be based on fundamental systemic properties. Taking into account the attributes that have been identified by other authors, MESMIS proposes seven basic attributes for sustainability (see Figure 1):

Productivity: The capability of an agroecosystem to yield the required amount of goods and services. It represents the value of the production (yield, profits, etc.) at a given point of time. For example, it may be measured as the value of production in the year of study, or the average over a given period.

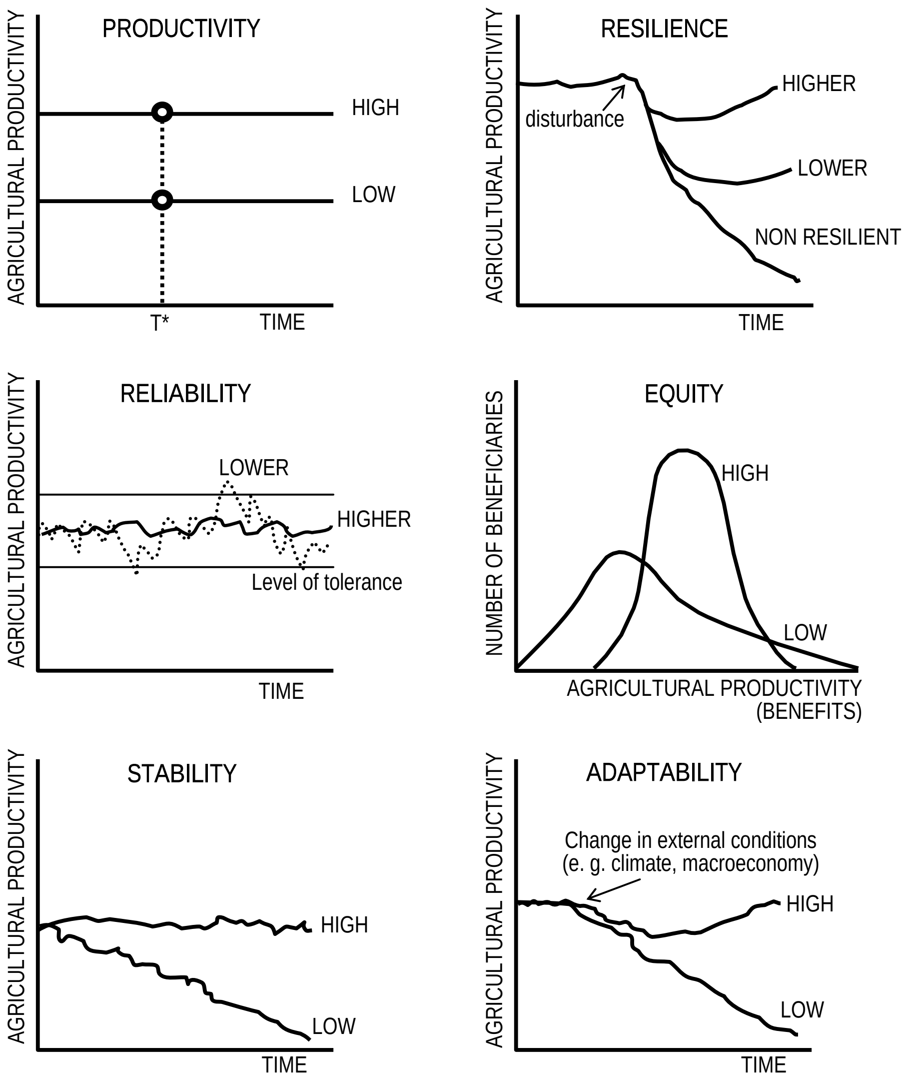
Stability. The ability of the system to maintain a stable dynamic equilibrium. This system's benefits remain at a constant level over time, in normal or average conditions. It is usually associated with the notion of *constant* production, yet, strictly speaking, constant production is only one particular example of a system in a state of dynamic equilibrium.

Resilience. The capability of the system to return to a state of equilibrium, or to sustain its productive potential, after undergoing a severe shock (for example, following a catastrophic event such as a hurricane, a fire, or the sudden fall in price of a key market product).

Reliability. The system's capability to maintain its productivity or desired benefits at levels near its equilibrium, when facing normal disturbances in the general environment.

Adaptability. The capability to find new equilibrium levels (to remain productive, or provide benefits) when faced with long-term changes in the environment (*e.g.*, new economic or biophysical conditions). Also, adaptability includes the capability of the system to actively seek out new levels or strategies of production (*i.e.*, the capability to generate new technological or institutional alternatives in order to improve upon existing conditions). In other words, the concept of adaptability applies to all aspects of the system, from diversifying

Figure 1. General Attributes of Sustainable Agroecosystems



production activities and technologies, to modifying the processes of social organization, to building human capacity.

Equity. The system's capability to distribute fairly all benefits and costs related to the management of natural resources, both intra- and inter-generationally.

Self-reliance. The system's capability to regulate and control its interactions with outlying systems. It includes the socio-cultural processes and mechanisms that regulate internal decision-making capabilities that define objectives, priorities, identity and values.[3]

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[3] These seven attributes are essentially compatible with the aforementioned studies. For example, vis-à-vis GIDSA's (1996) proposal, *productivity*, as used in MESMIS, incorporates resource availability, whereas *adaptability* includes the system's response capacity. Insofar as Conway's (1994) proposal is concerned, his definition of *sustainability* is equivalent to *resilience* in our scheme (namely, the system's capacity to return to its original state of equilibrium after undergoing severe shocks or stresses), whereas his *stability* matches our definition of *reliability*. Finally, the first three attributes of FESLM (FAO, 1994) are included in our proposal. However, both *economic viability* and *social acceptability* have been excluded, since they are not basic systemic properties. In fact, one could argue that,

Three important aspects of these attributes are worth some additional attention:

1. The sustainability of a system depends as much on its internal properties as on its links (flows) with external forces and with other systems. In other words, it is necessary to consider both the system's *intrinsic* properties as well as its *structural* properties and interactions (in ecological terms this would be translated as auto-ecology and synecology). The sustainability of a given component in a system may depend on its interactions with other elements in the system. As an example, a cultivated field on a slope is inherently unsustainable when considered in isolation, but may become sustainable after incorporating the human activities associated with agricultural management. Or, in another scenario, a management system may be sustainable even when some of its components are not; for example, slash-and-burn agriculture may be sustainable under certain conditions, despite involving a chain of unsustainable practices (GIDSA, 1996).
2. Attributes of systemic sustainability serve to characterize management systems as a whole; that is, they address a system's social, economic, environmental and technological elements. Focusing on these attributes allows sustainability indicators to reflect the fundamental systemic properties of natural resource management, thus avoiding the lengthy compilations of purely descriptive factors and variables that do not have a clear impact on management systems.
3. The above attributes organize the discourse on sustainability and provide a consistent foundation on which to make the concept operational. However, they are not meant to be taken as the last word in the debate about sustainable development. Particularly from a social standpoint, any discussion on sustainability should include an in-depth analysis on how proposed alternatives actually contribute to ensuring the satisfaction of the basic human needs: the livelihood, protection, esteem, understanding, participation, leisure, creation, identity and freedom of individuals and social groups (Max-Neef, 1991).

OPERATIONAL DEFINITION OF A SUSTAINABLE NRMS (OR AGROECOSYSTEM)

The discussion in the two previous sections leads us to define sustainable management as those systems which:

- Achieve a high level of **productivity** through the efficient and synergistic use of natural and economic resources.
- Maintain **reliable**, **stable** and **resilient** production over time, ensuring the access and availability of the resources of production; promote the renewable use, restoration and conservation of local resources; integrate adequate temporal and geographic diversity of the natural environment with economic activities; and, incorporate risk distribution mechanisms.

for a system to be economically viable in the long run, it must satisfy the *productivity*, *reliability* and *adaptability* criteria. Likewise, the *acceptability* of a system will depend on factors such as its *productivity*, *reliability* and *adaptability* to the natural and cultural milieu.

Table 2. Connection between Sustainable Agriculture Attributes and Diagnostic Criteria

ATTRIBUTE	USUAL DIAGNOSTIC CRITERIA
Productivity	Efficiency Average revenue (*e.g.*, yields) Resource Availability
Stability; reliability; resilience	Trends and fluctuations of average revenue Resource quality, conservation and protection Renewability of resource use Biological and economic diversity of the system Ratio of system income to opportunity costs Risk sharing mechanisms (insurance, moral economy)
Adaptability	Range of technically and economically feasible choices Capability for change and innovation Strengthening the learning and training processes
Equity	Distribution of costs and benefits among participants / target group Democratisation of decision-making process Generating employment
Self-reliance (self-empowerment)	Participation Dependence on external inputs and factors Organisation Economic and political control over the system and the decision-making process

- Provide flexibility (**adaptability**) to suit new economic and biophysical circumstances, by accommodating innovation and evolving learning processes, as well as through the use of multiple option strategies.
- Distribute, in an **equitable** manner, the costs and benefits of the system among the various stakeholders, ensuring both economic accessibility and cultural acceptance of proposed alternatives.
- Promote an acceptable level of **self-reliance (self-empowerment)**, such that the system can control and respond to changes exerted from beyond its borders, while keeping intact its identity and values.

According to this definition, the degree of sustainability of NRMS - and therefore the starting point for deriving indicators - will depend on the satisfaction of *five general attributes*: (a) productivity; (b) stability, reliability and resilience;[4] (c) adaptability; (d) equity; and (e) self-reliance (self-empowerment). Table 2 summarizes the central attributes of sustainable agroecosystems and illustrates some commonly used diagnostic criteria that are associated with each one of these attributes.

[4] We decided to include stability, reliability and resilience in one single sustainability attribute, because, in practice, several of the criteria that could *measure* any one of these properties overlap substantially. For example, *diversity* in bio-physical terms (*i.e.*, the number of species managed or present in a system) or in economic terms (*i.e.*, having a diversified customer portfolio), will be as much related to stability as to reliability, and even to resilience.

III

OPERATIONAL STRUCTURE OF MESMIS

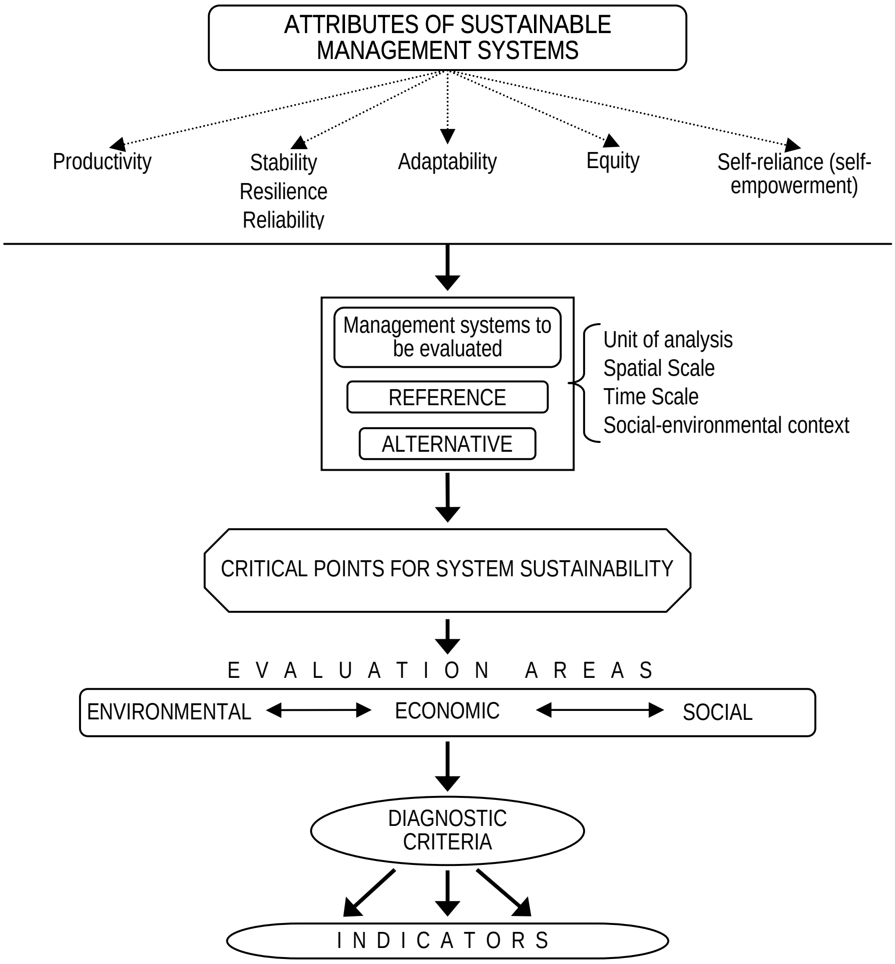
GENERAL OVERVIEW OF MESMIS STRUCTURE

The main objective of MESMIS is to provide a methodological framework to evaluate the sustainability of NRMS at a local level (plot, household, community). MESMIS proposes the following premises:

1. The concept of sustainability is defined on the basis of five general attributes of agroecosystems or NRMS: (a) productivity; (b) stability, reliability and resilience; (c) adaptability; (d) equity; and (e) self-reliance (self-empowerment).
2. Evaluating sustainability is valid only in the context of: (a) specific management systems in a given geographical location and in a given social and political context; (b) a specifically defined spatial scale (plot, household, community or watershed); and (c) a determined time scale.
3. Sustainability cannot be evaluated *per se* – it must be measured as a *comparison* or *relation* of systems. There are two ways to achieve this: (a) by simultaneously comparing one or more alternative or innovative management systems with a reference system (cross-sectional comparison); or (b) by comparing the evolution of a single system over time (longitudinal comparison). This premise constitutes a substantial distinction vis-à-vis other evaluation frameworks such as FESLM (FAO, 1993).
4. The evaluation of sustainability is a cyclic process aimed at strengthening the effectiveness of both the NRMS and the evaluation methodology itself.
5. Evaluating sustainability is an interdisciplinary and participatory process. The evaluation team must include both external evaluators and direct stakeholders (farmers, technicians, community representatives, and others).

Operationally, the general attributes of sustainability are "grounded" in defining a series of critical points for system sustainability, which are related to three evaluation areas (environmental, social and economic). For each evaluation area, diagnostic criteria and

Figure 2. Overview of MESMIS: Connection between Attributes and Indicators



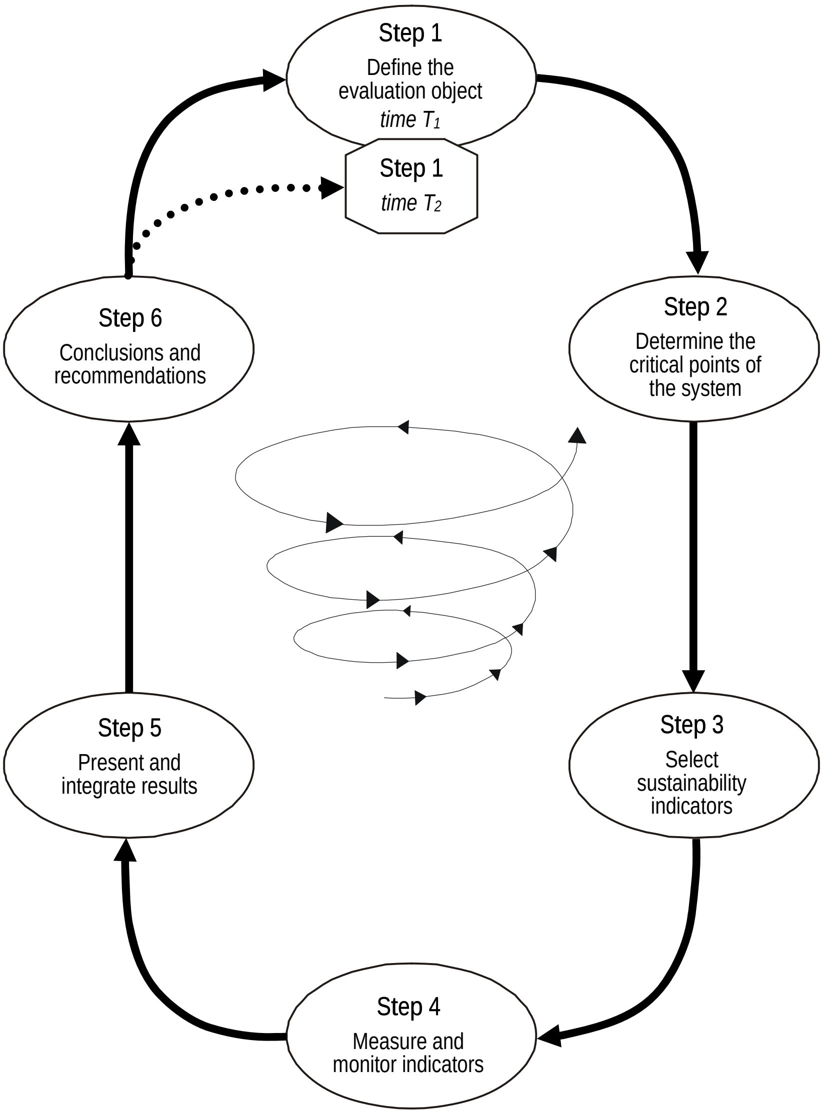
indicators are defined. This procedure guarantees a consistent relationship between sustainability indicators and the general attributes (see Figure 2).

Finally, the information obtained through the indicators is *integrated* using multicriteria analysis techniques, so as to obtain a value judgement for the NRMS and suggest ways to improve the socio-environmental profile.

An *evaluation cycle* is proposed, including the following steps:

1. Define the **object** of evaluation, *i.e.*, the NRMS to be evaluated, its characteristics and the socio-environmental context of the evaluation.
2. Determine the **critical points** affecting system sustainability.
3. **Select indicators** by first defining diagnostic criteria and then deriving strategic indicators.
4. **Measure and monitor** indicators, which includes designing appropriate analytic tools and methods for collecting data.

Figure 3. The MESMIS Evaluation Cycle



5. Present and integrate **results**. After comparing the management systems being evaluated in terms of sustainability, the main positive and negative aspects of each system are discussed and analyzed.
6. Propose **conclusions and recommendations**. Synthesize the analysis and propose specific strategies to fortify system sustainability as well as to improve the evaluation process itself.

After going through the six steps, the evaluation team should reach a better understanding of the systems under study; in particular they should have a clear idea as to those specific elements within the system that impact sustainability. Then, as the next step in a natural progression, a new evaluation cycle begins (step 1, time T_2 in Figure 3).

1 STEP ONE: DEFINING THE OBJECT OF EVALUATION

This first step of MESMIS includes: (a) identifying the management systems under study, as well as the socio-environmental context and scope (in terms of space and time) of the evaluation; (b) defining the management system of reference in the region (i.e. the prevailing system, whether traditional or conventional); and (c) characterizing an alternative system or systems. (In the case of longitudinal studies, the system should be characterized both before and after the modifications are introduced.)

However, before going further, it is useful to define the concept of NRMS.

What is a Natural Resource Management System (NRMS)?

To begin, a system may be defined as “an array of components, a set or collection of things, linked or related in such a way that they appear and act as a unit, an entity or a whole” (Hart, 1985). The elements of a system are its components, the interactions between components, the inputs, the outputs, and the boundaries. The components may be physical (geologic substrate, soil, parcel of land), biological (plants, animals, microorganisms), or socio-economic (family, household unit of production). The interactions between components -- the mesh that weaves the system together -- may be quite complex indeed. In García’s (1992) terms, this is known as the structure of interactions of the system. The inputs and outputs of the system are any and all matter, energy and information flows entering or leaving the system (*e.g.*, chemicals, money, maize, etc.). The system’s boundaries determine the object of study and are established according to the objectives sought. For example, the *system* may be a farm, a community, or a region. However, a system’s boundaries differ from its physical limits. The term *boundaries* and the derived notions of *inside* and *outside* reflect the nature of the problem to be analyzed, the conceptual framework adopted, and the time and spatial scales (of time and space) of the phenomenon under study (García, 1992). Finally, a system may contain a variable number of *subsystems*.[5]

To analyze sustainability in ecosystems, it is particularly important to relate living systems (biotic elements) with their physical environment (abiotic elements). Ecosystems should be considered functional units that include biotic and abiotic elements, as well as their processes of interaction, regulation, reproduction and evolution.[6]

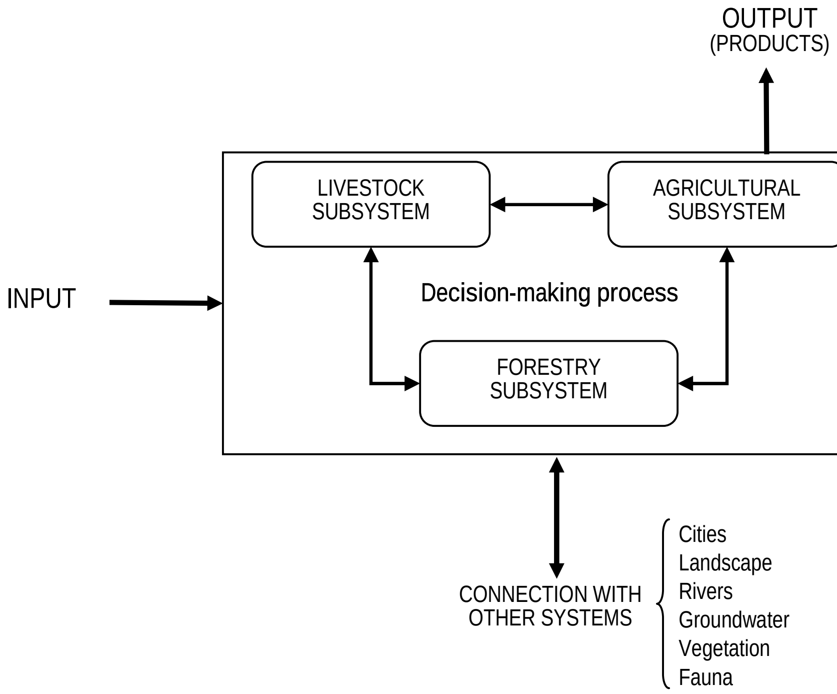
In a sense, natural ecosystems have been domesticated, transformed by human beings into processes geared towards obtaining animal, agricultural and forestry products. Within the context of this study, such transformed ecosystems are termed *natural resource management systems (NRMS)*[7] or *agroecosystems*. While it is difficult to define the exact limits of an agroecosystem, abstract limits may be assigned, which demarcate the object of study in terms

5 See Hart (1985) for a more comprehensive discussion on this subject.

6 More explicitly, an ecosystem may be defined as an open system comprising plants, animals, organic waste, atmospheric gases, water and minerals, which interact by means of energy and material flows, species interaction patterns and evolutionary processes (Morris, 1973).

7 Management implies human intervention. The sustainability of *natural* biological systems is not discussed here.

Figure 4. General Structure of a Management System



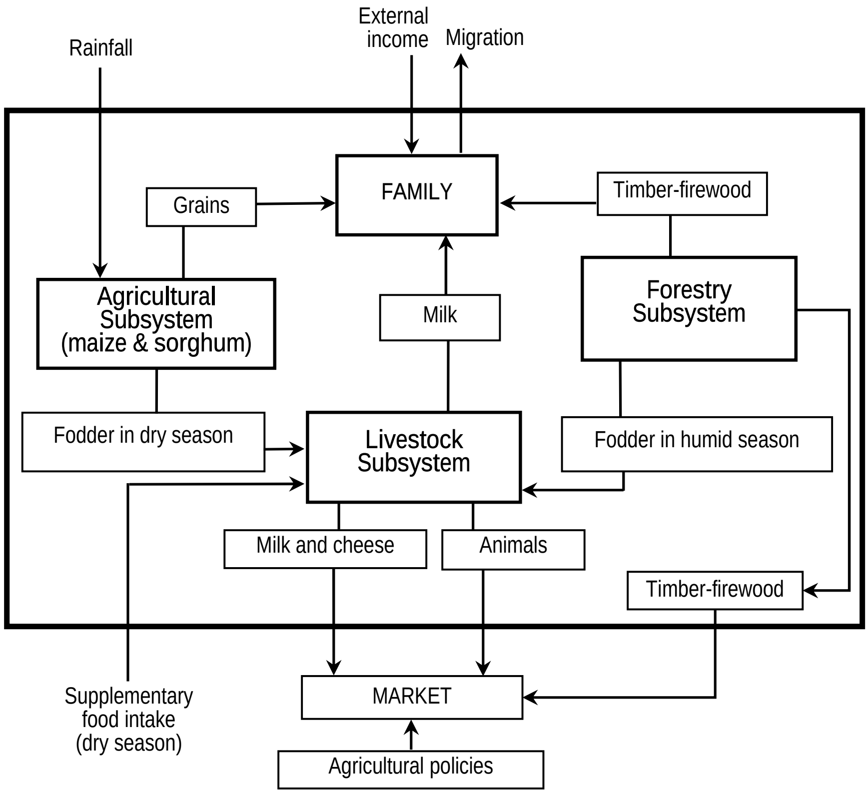
of its components and their interactions, its inputs, and its outputs. It is important to remember that agroecosystems are open systems that receive *inputs* from the outside, and render outputs, or *products* which enter other external systems (see Figure 4).

Another fundamental aspect of agroecosystems is their *dynamic* nature, mediated through their constant response to internal and external changes. Understanding both the system's behavior internally as well as its responses to changes or disturbances in the external environment (for example, the degree of stability, flexibility and resilience vis-à-vis drastic changes in inputs and outputs, such as an increase in their price) is integral to obtaining a holistic view of systems and systems change.

Even though each household or farm operates differently, they often share similarities that enable them to be grouped together, according to type of agriculture, system of land management or agroecosystem. Similarities can be established on the basis of a number of common characteristics - biophysical, economic, social, cultural and technical – which can then be combined and integrated within one household (*e.g.*, animal husbandry, agriculture, and forestry).

Diagrams capture quite effectively the complexity of management systems. Figure 5 shows the traditional management system of small farmers in the southern region of the state of Sinaloa. This system is characterized by three subsystems: agriculture (the cultivation of maize and sorghum); animal husbandry; and communal forests (also called *agostadero*, or feeding grounds). Interconnections between the subsystems can be seen in the feeding patterns of bovines, whose fodder consists of byproducts from cultivated maize fields and underbrush and grasses of communal forests.

Figure 5. Traditional Mixed (agriculture-cattle-forestry) System, South of Sinaloa, Mexico



Source: Martínez *et al.* 1999

Defining the Systems to Be Evaluated: The Reference System and the Alternative System

As has been previously stated, the MESMIS project proposes an evaluation of *comparative* sustainability, *i.e.*, an evaluation that leads to statements like "this system is more (or less) sustainable than that one." It avoids making blanket statements such as "the system under analysis is (or is not) sustainable", precisely because measuring sustainability in absolute terms is not possible.

Given this, MESMIS proposes evaluating sustainability by comparing a *reference* system with one or more *alternative* systems, either cross-sectionally or longitudinally. The reference system represents the technical and social arrangements and patterns most commonly practiced in the region. The alternative management system incorporates any technological or social innovations. Technically, the focus of these innovations may be agro-ecological (such as the use of coverage crops, crop rotation, multiple crops, biological pest control, integrated pest management, organic fertilization, etc.), Green Revolution-based (use of fertilizers, pesticides, high mechanization, etc.), or a mixture of both. Socially, innovations may represent

Table 3. Main elements for characterising agroecosystems (management systems)

ELEMENTS	DESCRIPTION
BIOPHYSICAL	Climate Soil, original vegetation and physiographic characteristics
TECHNOLOGY AND MANAGEMENT	Relevant species and varieties managed: crops, forestry and animal husbandry Chronological and spatial organisation: crop schedule, frequency, sequence and layout (mono-crop, multiple crop) Management practices (type and schedule) Technologies employed (manual, mechanised, draft, mixed) Soil management: preparation (type of tilling) and type of fertiliser applied (chemical, organic or mixed fertilisers) Management of pests, weeds and plant diseases: Integrated Pest Management, biological control, cultural practices Agricultural subsystem: *e.g.*, rotation of annual crops, multiple crops, etc. Cattle raising subsystem: extensive or intensive husbandry, confinement, free foraging, mixed foraging Forest subsystem: selective cutting, clear cutting, type of regeneration (natural or planted)
SOCIO-ECONOMIC AND CULTURAL	Characterisation of producers and households: ▪ Income level / socio-economic level ▪ Ethnic group ▪ Objective of production (subsistence, commerce, both) ▪ Scale of production (size of production unit) ▪ Type of production unit (household, enterprise, mixed) ▪ Number of participants in the production unit under analysis Characteristics of the producers' organisation: ▪ Type of organisation (community, ejido, NGO, credit union, co-operative, enterprise, etc.)

changes in producers' organizations, marketing schemes, gender participation, and so on. Ideally, these innovations should be in place long enough to manifest clear results.

The key point here, where MESMIS deviates substantially from other frameworks, is that evaluations of sustainability are based on a process of *comparison* between systems. For example, when making a longitudinal evaluation, MESMIS compares the evolution of the sustainability of a particular system over time. In this case, the *reference system* is the system as it existed in the initial or baseline year of evaluation, and the *alternative system* refers to the same system over the ensuing years. This kind of study may be retrospective (where the reference system refers to a moment in the past, and the alternative system refers to the current situation of the management system) or prospective (where the comparison is made using present and future data). When making longitudinal evaluations, establishing the appropriate timing for system monitoring is critical to adequately observe any significant changes precipitated by implementing alternative management strategies.

Regardless of the type of study initiated, participatory techniques that incorporate producers as well as the evaluating team are indispensable for achieving a clear understanding of the important features of management systems and their connections with other systems.

Theoretically, participatory techniques should more adequately define the object and scope of the evaluation, a significant factor to consider when often, the technical, logistic and financial characteristics of the evaluating team may adversely influence the nature of the study. In many cases, it is possible to initially restrict the evaluation to a specific subsystem, while maintaining a clear understanding of the interactions with other subsystems. With time, the analysis may be later expanded beyond this starting level.

Characterizing management systems, or agroecosystems, must include an accurate description of the following:

- Components of the system.
- System inputs and outputs. (It is useful to make a diagram containing a qualitative description of all the system’s inputs and outputs, as well as the interactions between components [*e.g.*, between animal husbandry, agriculture and forestry].)
- Productive activities involved in each system.
- The main social and economic characteristics of producers and the type of organization.

Table 3 contains the generic elements needed to characterize a management system, while Table 4 illustrates an example of two coffee production systems in the Highlands of Chiapas, Mexico.

Table 4. Reference and Alternative Management Systems for the production of organic coffee in the Highlands of Chiapas, Mexico

<table>
<tr><th colspan="3">AGROECOSYSTEM DETERMINANTS</th><th>REFERENCE MANAGEMENT SYSTEM</th><th>ALTERNATIVE MANAGEMENT SYSTEM</th></tr>
<tr><td colspan="3">ORIGINAL BIOPHYSICAL CONDITIONS</td><td colspan="2">Climate: (A)C(m??) lukewarm-humid. Elevation: 900-1800 masl. Average annual rainfall: 2000-2500 mm. Original vegetation: Mountain cloud forest. Slope: 10-45%. Soil: erosion-prone litosols and luvisols.</td></tr>
<tr><td rowspan="8">TECHNOLOGY AND MANAGEMENT</td><td colspan="2">Main managed species and varieties</td><td>Coffee</td><td>Coffee</td></tr>
<tr><td colspan="2">Cropping system</td><td>Coffee with mono-specific shade, without annual pruning</td><td>Coffee with multi-specific shade with annual forming and production pruning</td></tr>
<tr><td colspan="2">Technology utilised</td><td>Manual</td><td>Manual</td></tr>
<tr><td colspan="2">Labour employed</td><td>Low (40 days/ha/year)</td><td>High (84 days/ha/year)</td></tr>
<tr><td rowspan="4">Soil management</td><td>Fertilisation</td><td>None</td><td>Composting of crop and domestic waste and manure</td></tr>
<tr><td>Conservation practices</td><td>None</td><td>Terracing, cover crops and live barriers</td></tr>
<tr><td>Pest and disease management</td><td>None</td><td>Biological control of the coffee berry borer</td></tr>
<tr><td>Weed management</td><td>Machete-weeding</td><td>Machete-weeding and mulching</td></tr>
<tr><td rowspan="3">SOCIO-ECONOMIC AND CULTURAL</td><td colspan="2">Producers characteristics</td><td>Tzotzil and Tzeltal small households</td><td>Tzotzil and Tzeltal small households</td></tr>
<tr><td colspan="2">Objective of production</td><td>Monetary income</td><td>Monetary income. Producing certified organic coffee</td></tr>
<tr><td colspan="2">Characteristics of production organisation</td><td>Unión de Ejidos Majomut (technical support, storage, processing and marketing centre)</td><td>Unión de Ejidos Majomut (technical support, storage, processingand marketing centre)</td></tr>
</table>

Source: Pérez-Grovas, 1999

2 STEP TWO:
IDENTIFYING THE SYSTEM'S CRITICAL POINTS

After having defined the management systems to be evaluated, the next step is to analyze the critical points of the system; namely, the main features or processes that enhance or constrain system productivity, stability, resilience, reliability, equity, adaptability, and self-reliance.

Some key questions involved in identifying critical points include: What makes the NRMS vulnerable? What presents particular problems? What constitutes the strongest, most prominent features of the NRMS? These features, or critical points, exist as the environmental, technical, social or economic factors or processes that, isolated or in combination, have a critical impact on the survival of the management system. Table 5 lists the critical points, grouped by sustainability attribute, that frequently appear in the analysis of NRMS.

Table 5. Possible Critical Points for the Sustainability of Management Systems

ATTRIBUTE	CRITICAL POINT
Productivity	Low yield Low quality of outputs High opportunity cost of labour
Stability; resilience; reliability	Soil loss or degradation Deforestation Soil and water pollution Damage due to pests or weeds Price instability of system inputs and outputs
Adaptability	High input prices High reliance on external sources of funding
Equity	Migration Social differentiation within the community
Self-reliance	Deterioration of communal organisation Lack of producers' organisations Farmers' indebtedness

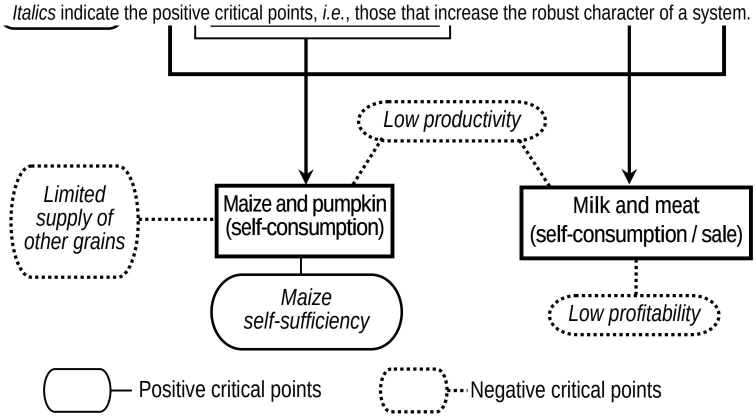
Note: The critical points shown here are only illustrative. The analysis of concrete management systems will indicate which are the critical points that are relevant for the appraisal.

As with characterizing management systems, pinpointing critical points requires substantial co-ordination between the interdisciplinary evaluation team and stakeholders. The main objective here is to implement effective participatory strategies that rank the critical points according to their relative importance. Group discussions involving both evaluators and producers are among the most useful ways to locate critical points, which can be easily depicted by using flowcharts (see Figure 6).

Table 6. Critical Points for the *año y vez* Agricultural Management System, Purepecha Region, Mexico

ATTRIBUTES	CRITICAL POINTS
Productivity, equity, stability, resilience, reliability, adaptability, self-reliance	*Satisfactory source of maize for grain and fodder (self-consumption)*
	Low profitability
	Low agricultural and cattle productivity
	High adoption rate of system
	Limited supply of other basic grains to household
	High diversity of the agricultural subsystem
	Soil degradation
	Limited organisation of producers

Source: Modified after Astier *et al.*, 1999.
Note: *Italics* indicate the positive critical points, *i.e.*, those that increase the robust character of a system.



Source: Modified from Astier *et al.*, 1999

It is useful to identify as many critical points as possible when characterizing the system. However, because the evaluation is an interactive process, some specific points not recognized initially may show up later during the evaluation phases (for example, while undertaking socio-economic surveys), prompting the team to reconsider or add some critical points to the list.

Once the critical points of the NRMS are identified, they should be linked to the different sustainability attributes, so as to ascertain that all attributes have been addressed in the evaluation. Critical points may be related either to a single attribute, or to a set of attributes. For example, a serious problem in a number of management systems in Mexico is the scarcity of labor due to migration, which has direct repercussions in system productivity, stability and self-reliance. Table 6 presents the connection between attributes and critical points for the *año y vez* agricultural system (a system with fallow periods every other year) in the Purepecha village of Casas Blancas, Michoacán (Mexico) whose flowchart is shown in Figure 6.

The process of identifying the system's critical points focuses on the nature of the problem under study, giving it more manageable dimensions. There is a multiplicity of factors that in theory affects the sustainability of management system; without some attempt at synthesis, obtaining truly useful results from the evaluation would become very difficult.

Likewise, determining the critical points for sustainability can strengthen alternative systems promoted by various organizations. In effect, only through knowing and influencing the critical points of the reference system can alternative systems be tested. In this respect, proposals for alternative NRMS are frequently made without a thorough understanding of the intrinsic problems present in already existing systems. In order to avoid this error, when evaluating the sustainability of an *alternative* management system, one must clearly distinguish between problems related to recent innovations and problems inherited from the reference system.

3

STEP THREE:
SELECTING DIAGNOSTIC CRITERIA AND INDICATORS

Once the systems under study (*i.e.*, the reference and the alternative management systems, together with their objectives and characteristics) and critical points have been identified, the next step is to define a series of diagnostic criteria and indicators. However, before describing the various types of indicators that can be used, it is important to first define what diagnostic criterion and indicator mean.

What is a Diagnostic Criterion?

Diagnostic criteria elaborate on the general attributes of sustainability. They represent a level of analysis more detailed than attributes, but more general than indicators. Diagnostic criteria serve as a necessary intermediary link between attributes, critical points and indicators, that enables a more effective and coherent evaluation of sustainability.

For example, let us assume that the system under evaluation is a seasonal maize farming plot where frequent presence of frosts and droughts is considered a critical point. This critical point is directly related to the attributes of *resilience* and *stability*, whose diagnostic criterion is *risk sharing mechanisms in the face of adversity* and whose corresponding indicators could be, in the economic arena, *access to credit*, and in the environmental arena, *product diversity index*.

According to area of evaluation and in relation to their respective attributes, some diagnostic criteria that usually appear in sustainability analyses are:

Environmentally: productivity: efficiency; stability: resource conservation (soil, water, and vegetation) and diversity; and self-reliance: self-sufficiency.

Economically: productivity: economic efficiency; stability: income diversification and risk sharing mechanisms; and self-reliance: financial self-sufficiency.

Socially: equity: cost and benefit distribution; stability: quality of life; adaptability: encouraging the apprenticeship process; and self-reliance: participation, control and organization (see Table 7).

It is important to keep in mind that, in order to ensure an adequate coverage of a diagnostic criterion, the information provided by a single indicator is usually not sufficient; several indicators are required. Likewise, in very particular circumstances - for example, when only relatively vague data on certain areas of a management system are available - diagnostic criteria may be used as indicators. This typically occurs when considering the diagnostic criterion *organization*, which is often qualitatively measured and assigned values such as *high*, *medium*, or *low*, turning it into an indicator.

Table 7. Diagnostic Criteria and Sustainability Indicators for the Evaluation of Natural Resource Management Systems

ATTRIBUTE	DIAGNOSTIC CRITERIA	INDICATORS	Evaluation areas
Productivity	Efficiency	Yield; energy efficiency	A
		Cost-benefit ratio; investment (in money and labour); labour productivity; income	E
Stability; resilience; reliability	Diversity	Number of species managed and present; multiple crop; crop rotation	A
		Number of crops; degree of integration in production and marketing	E
		Number of ethnic groups involved in resource management	S
	Resource conservation	Soil and water quality	A
		Critical nutrient input/output relationship	A
		Number of native varieties utilised	A
		Saving capacity	E
	System fragility	Pest and disease incidence	A
		Yield trends and variations	E
	Risk sharing	Access to credits, insurance, or other mechanisms	E
	Quality of life	Quality of life indices	S
Adaptability	Strengthening of learning process	Training of farmers	S
		Local adaptations to proposed systems	S
	Capacity for change and innovation	Evolution of the number of producers per system	S
		Generation of knowledge and practices	S
Equity	Distribution of costs and benefits	Number of beneficiaries, according to ethnic group, gender, or social group	S
	Evolution of employment	Labour demand and job displacement	E
Self-reliance (self-empowerment)	Participation	Beneficiaries' involvement in all project phases	S
	Self-sufficiency	Degree of reliance on critical external inputs	A
		Level of self-financing	E
	Control	Acknowledgement of property rights (individual or collective)	S
		Use of local knowledge and skills	S
		Decision-making power over critical aspects of system operation	S
	Organisation	Type, structure, decision-making process	S

Note: This table contains a general description of indicators for illustrative purposes. Not all indicators shown are necessarily relevant to all management systems; likewise, there may be important indicators for specific projects that are not shown here. As discussed in the text, there are three evaluation areas that need to be explored: environmental (A), economic (E), and social (S).

What is an Indicator?

Distinct from exclusively numeric information, an indicator describes a specific process. That is, indicators are specific to the processes to which they belong such that indicators suitable for some systems may be inappropriate for others. For this reason, it is not possible to define a list of universal indicators (Bakkes *et al.*, 1994). In fact, the indicators used in the evaluation will depend on three things: the characteristics of the specific problem being studied; the scope of the project; and the type of access to, and availability of, data.

The environmental indicators will vary widely depending on the spatial scale involved in the study. For example, at the village level the indicator *deforestation rate* could indirectly describe the process of soil degradation; however, at the plot level, this indicator would be nearly meaningless for estimating soil degradation. In this case, it is more useful to measure directly the level of soil erosion or the amount of organic matter present in the soil.

The set of indicators to be used in the evaluation process should be robust but not necessarily exhaustive; robust in the sense that the indicators meet the conditions described above, that they are sensitive, and that they are based on sufficient measurements or statistics (De Camino and Muller, 1993). The list must include solely those indicators that have a critical influence on the problem under study.

In order for the evaluation scheme to be truly operational, the proposed indicators must be (Torquebiau, 1989; Bakkes *et al.*, 1994; Dumanski, 1994):

- Integratable (*i.e.*, provide condensed information about a number of key system's attributes). Preferably, they must describe the more than just immediate processes.
- Easily measurable, susceptible to monitoring, and derived from readily available information.
- Adequate for the level of analysis (e.g. plot, farm, watershed) of the system (see Figure 7).
- Preferably applicable for a range of ecosystems and socio-economic and cultural conditions.
- Highly robust and truly reflect the target attribute of sustainability.
- Based on reliable basic information (direct or indirect).
- Simple to understand (not just by experts).

Furthermore, they should:

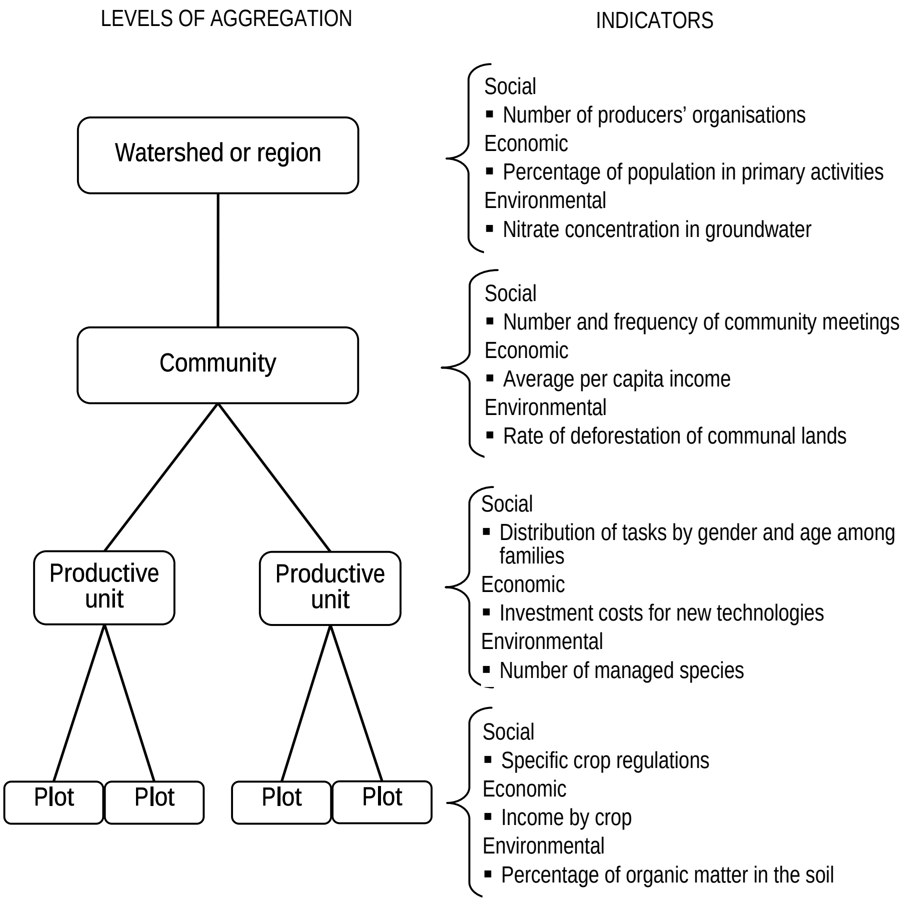
- Allow for the measurement of changes in the system's characteristics during the evaluation time period. For example, parameters that show virtually no changes over time, such as the percentage of clay in the soil or the density of wood, may not be used as indicators. On the other hand, variables such as the percentage of vegetation cover or the contents of organic matter do change through time, and reflect other processes such as soil erosion or water retention capability, making them appropriate indicators.
- Focus clearly on practicalities, in a way that facilitates the participation of local people in the measurement process.

How are Indicators Chosen in MESMIS?

In order to select the sustainability indicators for a given management system, five methodological stages are considered:

1. Determine the **general attributes of sustainability**: productivity; stability, reliability and resilience; adaptability; equity; and self-reliance (self-empowerment).
2. Define the **critical points** for the specific management systems under study, ensuring that they cover all attributes of sustainability.

Figure 7. Levels of Analysis for Deriving Indicators



3. Define a series of specific **diagnostic criteria** that evaluate the system's critical points. Due to the interactions between environmental and socio-economic factors, the set of diagnostic criteria and indicators must cover three dimensions or **evaluation areas**: (a) **social**, including cultural and political aspects; (b) **economic**; and (c) **environmental**.[8] Just as in the case of the critical points, it is important for diagnostic criteria to cover as much area as possible in all attributes of sustainability.
4. Once all diagnostic criteria are clearly established, compile a **list of indicators** for each criterion. This procedure ensures that a link exists between indicators, diagnostic criteria, critical points and attributes of sustainability (see Figure 2, p. 18, and Table 7, p. 29). This avoids compiling endless lists or selecting useless indicators.
5. Finally, once the list of possible environmental, economic, and social indicators has been compiled, make a final selection in order to generate a set of **strategic indicators**. For

[8] In many cases, these diagnostic criteria may be applied to more than one area. For example, the *efficiency* criterion is important both in the environmental sphere (*i.e.*, energy and productive efficiency) and in the economic sphere (economic efficiency).

this, a shortlist needs to be made, selecting those indicators which are truly integrative, easy to measure, reliable, etc. A set of indicators that are commonly present in sustainability analyses is presented hereafter, arranged according to their evaluation areas.

Economic Indicators

Within this area there are several conventional indicators which are often geared toward evaluating the economic *cost effectiveness* of a given investment project or management system. Cost-benefit analysis is the primary measurement tool; it measures all costs and returns of the project, including future interest rates, as an estimated monetary value. The cost-benefit analysis may be made from economic or financial perspectives as much as from social or individual standpoints. From this analysis three main indicators are derived:

Cost/Benefit Ratio (C/B). The ratio of total costs to revenues of the project, considering future discount rates, *i.e.*, accounting for the assets earned and spent in future years, *adjusted* in accordance with effective interest rates (or, more correctly, discount rates) for the considered stakeholders. In order for a project to be attractive, this ratio must have a value greater than one.

Net Present Value (NPV). The difference between a project's total revenues and costs in accordance with future discount rates. For a project to be viable, NPV must be greater than zero.

Internal Rate of Return (IRR). The value of the discount rate for which the net present value is equal to zero and the cost/benefit ratio is equal to one.[9]

Traditionally, these indicators have been used most frequently when evaluating the relative advantages of projects or technologies. One of their greatest attractions is that they seem to provide an *objective* and *quantifiable* analysis of a set of alternatives. However, their use faces numerous practical, methodological and conceptual handicaps, especially when promoted as the *only* valid indicators and, even more specifically, within the context of evaluating sustainability.

The exclusive use of economic indicators draws much criticism, for a number of reasons. First, the tendency to *collapse* or *aggregate* all revenues and costs into a single monetary unit is misleading (for example, as in assigning a monetary value to a peasant's family-operated farm, despite the fact that there is generally no market for such a labor force, and peasants do not typically include this cost in their assessment of the economic return of their production options.) Other criticisms justifiably arise over the operational assumption that markets are

[9] In mathematical terms, these three indicators may be defined according to the following equations:

$C/B = [\Sigma\, Bt/(1 + r)^t\,] / [\Sigma\, Ct/(1 + r)^t\,]$

$NPV = \Sigma\, (Bt - Ct)/(1 + r)^t$, where Bt are the benefits or revenues during year t, Ct the costs during year t, and r the discount rate.

The internal rate of return (IRR) is the discount rate r^* that complies with:

$\Sigma\, (Bt - Ct)/(1 + r^*)^t = 0$.

The reader may find a more detailed discussion of these indicators in Pearce and Turner (1990).

perfect; the determination of the individual and social discount rates to be used in the analysis; and the difficulty of assigning monetary value to environment externalities. For these reasons, these indicators may not be used on their own to represent system sustainability. The reader may find a more detailed description of the conventional indicators, their scope and their problems in Pearce and Turner (1990), Manning (1987) and De Graaff (1993).

Attempts have been made to address these issues through sensitivity analyses (using different discount rates), option-value analyses (Fischer and Haneman, 1985) and through the internalization of environmental costs. The latter can be achieved by means of functions that relate the environmental damage caused by a given project or technology (*e.g.*, soil losses) with the reduction of crop yield, and thus revenues (Faeth *et al.*, 1993). A recently proposed alternative is the use of the concept of *Total Factor Productivity* as the basic sustainability indicator (Harrington *et al.*, 1994). As mentioned in the introduction (see p. 2), this indicator is defined as "the sum of the value of all outputs divided by the sum of the value of all inputs, including all economic and environmental costs" (Harrington *et al.*, 1994:6). However the authors themselves recognize that calculating this concept empirically requires immense amounts of information. Besides, this calculation does not solve the fundamental problem of aggregating all criteria into a single monetary variable.

In sustainability analyses, conventional economic indicators should be seen as an auxiliary tool: relevant, but only indicative of partial aspects of the whole problem. Whenever possible, these indicators should incorporate a sensitivity analysis and attempt to include the most direct environmental costs of the proposals under consideration.

Other useful economic indicators include (see Table 8):

Investment costs. An estimate of the initial costs of implementing the management system (or of recovering the present system). It may be measured both as a monetary value (*$/ha*), or as invested labor force (*working days/ha*). Its calculation should include all crops or subsystems included in the management system.

Economic returns (or net income). The difference between gross income and total costs. It may be estimated in monetary units (*$/ha* or *$/producer*) or by means of a productivity index *($/kg of product* or *working hours/kg of product*). Ideally, the value obtained should be compared to the opportunity cost for peasants (*i.e.*, to the economic return that may be obtained through alternative activities) so as to achieve a better estimate of the viability of the proposed system.

Employment. The number and kind of working days required by the management system, or the number of jobs gained or lost within the community or organization.

Access to insurance. The capability of economic recovery (resilience) after severe disturbances to the system. This can include commercial insurance policies when their use does not imply the subordination of producers to financial institutions. Even more interesting are household-based strategies, such as emergency savings pools, to be used in the case of such disturbances.

Table 8. Generic Economic Indicators

ATTRIBUTE	DIAGNOSTIC CRITERION	INDICATOR
Productivity	Efficiency (profitability)	Cost-Benefit Ratio (C/B)* Net Present Value (NPV)* Internal Rate of Return (IRR)* Net income
Stability; resilience; reliability	Diversification of productive activities	Equivalent Value Index (EVI) Input Substitution Index (ISI)* Percentage of income from different products or buyers
	Risk sharing mechanisms	Access to credit and insurance
	System fragility	Price evolution of critical inputs and main system products
Adaptability	Income and technology options	Number and type of available management options
Equity	Technology Adaptability	Investment costs Investment/income ratio for producers
	Evolution of employment	Labour demand; job displacement
Self-reliance	Self-sufficiency	Level of financial self-sufficiency Index of Reliance on External Inputs Level of indebtedness, internal savings Percentage of food supply costs covered by own production

* These indicators are mathematically defined in the text.

Liability level Capability to endure credits or debts. This measures the system's financial vulnerability or self-reliance, measured as the percentage of debt to producers' income, or to the assets of an enterprise or organization.

Diversification of productive activities. An estimate of risk reduction strategies. These refer, for example, to the prevalence of strategies towards diversifying activities (*e.g.*, whether or not the system includes only primary activities or also secondary activities), to market diversity for a given product, or to the percentage of the total income from various products of the system. When measuring the efficiency of biodiversity in the case of multiple crops, indicators such as the Equivalent Value Index (EVI), or the Input Substitution Index (ISI) are used.[10]

Evolution of the prices of critical inputs and main products. An estimate of the variability of the economic environment in which the production unit exists, together with the system's capability for reacting to or controlling changes (*e.g.*, by finding access to alternative markets, such as that for organic coffee, which secures a minimal price for the product). Variability may be estimated by looking at the change in a series of regional prices for the main inputs and products over time.

[10] **EVI** = $(aP_1 + bP_2) / aM_1$; **ISI** = $(aP_1 + bP_2) / (aM_1 - C)$, where a = price of first crop; b = price of second crop; P = multiple crop, M = mono-crop; C = cost of the input which should be replaced by the multiple crop.

In all the cases described above, evaluating the indicator values as they exist and change produces the most useful result.

Environmental Indicators

Environmental indicators should provide information on proposed management systems and strategies in particular regards to their capability to be environmentally *productive* and sustainable. The level of detail required when gathering data will depend on the problem being studied and on the available resources for the project in question. For example, the greatest level of detail executed in research will occur in those projects that have a sound scientific infrastructure, and that furthermore include in their goals the measurement of environmental indicators. In certain cases, it may be desirable to include some indicators that describe the status of the environment or the processes that prevent environmental degradation or foster its protection. Tables 9 and 10 (a and b) respectively show some examples of generic and specific environmental indicators that are often employed in the evaluation process. Some important indicators are detailed below:

Yields. Total crop yield, or total biomass per hectare in the cases of agroforestry or multiple crop systems. For forest systems, yields may be estimated as current annual increase (CAI) or as mean annual increase (MAI) of main managed species or genera. In this case, the evolution of the total volume and volume per hectare of managed forest should be monitored, since this represents an important share of the system's *natural assets*.

Table 9. Generic Environmental Indicators

<table>
<tr><th>ATTRI-BUTE</th><th>DIAGNOSTIC CRITERION</th><th>INDICATOR</th><th>MEASUREMENT METHOD</th></tr>
<tr><td rowspan="2">Productivity</td><td rowspan="2">Efficiency</td><td>Yield</td><td>Total biomass distribution, according to number of systems, layouts and managed species
Yield by product and sub-product</td></tr>
<tr><td>Energy efficiency</td><td>Unit of product per unit of critical input
Energy outputs / energy inputs</td></tr>
<tr><td rowspan="7">Stability; resilience; reliability</td><td rowspan="4">Diversity in time and space</td><td>Yield evolution and variation</td><td>Yield variation trend and coefficient</td></tr>
<tr><td>Land-use pattern</td><td>Rate of change in land use</td></tr>
<tr><td>Diversity index</td><td>Number of managed species, Shannon Index</td></tr>
<tr><td>Complementarity index</td><td>Input/output ratios between production unit systems</td></tr>
<tr><td rowspan="2">Resource conservation</td><td>Soil and water quality</td><td>Percentage of organic matter; stability of aggregates; chemicals in water and soil</td></tr>
<tr><td>Soil degradation</td><td>Water infiltration rate in soil, compactness, erosion (kinds, level, percentage)</td></tr>
<tr><td>System fragility</td><td>Incidence of pests, diseases and calamities</td><td>Evolution of damages due to pest, hail, frost, etc.
Frequency of natural disasters</td></tr>
<tr><td rowspan="2">Self-empowerment</td><td rowspan="2">Self-sufficiency</td><td>Energy subsidies</td><td>Fossil energy inputs / Energy-in-product outputs</td></tr>
<tr><td>Degree of external reliance</td><td>External inputs / Unit of product
Proportion of basic needs covered by own production</td></tr>
</table>

Table 10a. Specific Environmental Indicators and Possible Measurement or Estimation Procedures

INDICATOR	MEASUREMENT METHOD
Yields	Total or useful part (*e.g.*, grain, fodder, etc.) biomass (kg/ha)
Energy efficiency	Products or outputs (Mcal) / Inputs or consumption (Mcal)
Diversity indices for species or varieties	Shannon Diversity Index* Percentage of total surface covered by each species or crop (ha)
Land equivalent ratio	Σ (multiple crop yield / mono-crop yield)**
Soil coverage	Percent of cover in different seasons
Level of soil erosion	Percentage of eroded surface Mean erosion (ton/ha/year) Universal Soil Laminar Erosion Equation (USLE) (ton/ha)
Organic matter	Percentage of total C and N Dry Combustion (0-10 cm)
Chemical soil properties	Nutrient availability (Levels of N (%) and P (ppm) and amount of N and P in plants); CEC (molc/kg or meq/100g); pH; [Al]; Salinity (CE (mmmho/cm or S/m) or change in colour)
Physical soil properties	Infiltration rate (cm/hr); apparent density (g/cm^3); porosity (%); root density (g/cm^3)
Biological soil properties	Monitoring of sensitive micro-organism species, such as nitrifying, *Rhizobium*, and actinomycets (biomass/g soil) or organic matter decomposition and nitrification rate Macro fauna species: earthworms (temperate zones), termites (tropical/subtropical zones), coleopterans
Yield variation due to environmental calamities	Damaged surface (% of total surface) Impact on yields (% of harvested produce damaged) Population of pest or beneficial insects (colonies/m^2 or no. of individuals/plant) in certain critical dates

* Shannon index = Σ (ni/N) log(ni/N), ni = number of individuals of species i, and N = total number of individuals.

** Land Equivalent Ratio (LER) = $\Sigma\ Ap_i / Am_i$, Ap_i = Yield of crop i in multiple crop system (kg/ha); Am_i = Yield of crop i in mono-crop system (kg/ha); if LER > 1, multiple crop is more efficient, and if LER < 1 mono-crop is more efficient (*e.g.*, if LER = 1.17 it means that using multiple crop represents saving 17% of land surface)

Yield evolution and variability. The stability and reliability of the systems under consideration, which should include preliminary estimates of yield variations in response to pests, diseases, and physical factors (climate, fires, etc.).

Energy efficiency. The ratio of the energy contained in the system's products to the energy contained in the inputs required for their production.

Biological diversity indices (related to the conservation of germoplasma). The number of crops within multiple crop or crop rotation systems, or the number of managed species and varieties. Additionally there are indices such as the Land Equivalent Ratio (LER), EVI, and ISI (mentioned above), which reflect the degree of diversification efficiency: *i.e.*, if interactions between species are positive (synergism) or negative (competition). Additionally, the presence or absence of key species (bio-indicators) may provide valuable information about the status of the functional biodiversity (for example, counting the number of beneficial insects in 100 plants, the number of leguminous species per hectare or subsystem, or estimating the level of damage on harvested crops).

Degree of dependence on external inputs. The relationship between system products and the use of external inputs, calculated by means of an index.

Soil quality indicators. Used to evaluate *ecological restoration* projects and projects that propose new management systems. These may include estimates of erosion level, contents of organic matter, compaction, chemical degradation, acidity, salinity, alkalinity, and other biological properties (levels of organic matter, macro- and meso-fauna).

Pollution or degradation of natural resources. The modification of water and soil quality caused by certain cattle raising, agriculture, and forestry management practices (such as the excessive use of agrochemicals). Examples of specific indicators include: the quality of irrigated water; the quality of well water; level of contaminants in the soil; and level of toxic substances in harvested products.

For forestry projects in particular, some important indicators include:

Changes in forest cover. Measured as deforestation or reforestation rates, *i.e.*, the rates of reduction or growth in forest cover over time. It estimates the *stability* of the forested area included in the management system.

Biological diversity indices. In the case of forestry systems, usually estimated as a diversity index (such as the Shannon index), and a species composition index. Both should be monitored over the course of several logging cycles.

Changes in the quality of forest mass. The annual increase of forest volume, divided by the annual volume of wood harvested. When this ratio is less than one, the system may not be sustainable. This indicator must be estimated separately for each forest species or genera. Likewise, when logging is particularly concentrated in a given area, any measured increases in

Table 10b. Environmental Indicators for Forestry Projects and Possible Measurement or Estimating Procedures

ATTRIBUTE	DIAGNOSTIC CRITERION	INDICATOR	MEASURING METHOD
Productivity	Efficiency	Yields	Current Annual Increase (CAI) for main managed species
Stability; resilience; reliability	Species and genera diversity	Diversity indices	Shannon diversity index, or others
		Species composition	Species composition index
	Resource conservation	Changes in forested area	Deforested area - reforested area
		Changes in forest mass quality	Net Annual Increment = CAI / Annual harvested volume
		Forest fires	Area affected by forest fires per year
		Level of soil erosion	Percentage of eroded area
			Mean erosion (ton/ha/year)
			Universal Soil Laminar Erosion (USLE) equation (ton/ha)
		Carbon sequestration	Carbon density (total metric tons captured / forest area)
			Net carbon volume captured by the forest
		Regeneration	Number of seedlings per hectare
			Seedling survival (year 1 to year 5)

extracted volume must also be restricted to such sites.

Regeneration. An estimate of the capacity for forest recovery in a given management system; it may be estimated as the number of seedlings per hectare, and as the number of survivors after the most critical initial growth period (usually between one and five years).

Carbon sequestration. Assessment of the management system's contribution to the problem of global change, whether through emitting or capturing carbon. This indicator is gaining increasing relevance for forestry and agroforestry management systems; it is estimated as the net total and annual metric tons of carbon captured or emitted by the system. For general guidelines for estimating carbon sequestration in various forest management systems, see Masera (1995 and 1996).

Social Indicators

In conventional evaluations, social indicators often receive somewhat fleeting, if not fragmented, attention. Because social indicators tend to be qualitative and difficult to define accurately, they do not lend themselves easily to numeric transfigurations. Moreover, social indicators are far less developed in agricultural literature than are economic or environmental indicators. Despite these constraints, social indicators are valuable contributors to any holistic analysis on sustainability, and should be given thorough attention.

The following are some of the most relevant social indicators (see also Table 11):

System beneficiaries. An estimate of the social access of the proposed systems; it may be calculated as the proportion of beneficiaries (men, women, ethnic groups, etc.) to the total target group. The management system's benefits may be public or private, monetary, rendered in services, or exist as infrastructure. Another important indicator in this area is the proportion of expenditures to benefits resulting from participation in the management system.

Conflict resolution mechanisms. The types of mechanisms available to system users for solving internal conflicts, between users, authorities or project staff. The simpler and cheaper these mechanisms are, the more effectively they function. In its simplest form, this indicator may be recorded as a binary indicator (yes/no).

Quality of life indices. Assessment of the impacts of the management system on the physical living conditions of producers and their families. An important indicator in this direction is the nutrition index (or inversely, the malnutrition index) of stakeholders. In some management systems, adequate health risk indicators may be derived which measure, for example, exposure to pesticides (in the case of intensive commercial agriculture), or accidents in the workplace (in the case of management systems involving the use of machines or other risks).

Table 11. Generic Social Indicators

ATTRIBUTE	DIAGNOSTIC CRITERION	INDICATORS	MEASURING METHOD
Equity	Allocation of costs, benefits and decision-making	System beneficiaries	Number and type of beneficiaries by gender, social sector, age, ethnic group Proportionality of costs and benefits
		Degree of democratisation	Mechanisms for distribution of decision-making power
Stability; resilience; reliability	System fragility	Capability for sorting severe eventualities	Survival of project after conflicts, severe problems, or lack of funds
		Mechanisms for conflict resolution	Type, complexity, and effective enforcement of penalties for not complying with obligations
	Living standards	Standard of living indices	Nutrition indices, health indices, education level, life expectation
Adaptability	Capability for change and innovation	Generation of knowledge and training sessions	Type and frequency of training, mechanisms for diseminating knowledge among members
		Assimilation of innovation	Adoption or adaptation of changes in the various aspects of community life; appropiation of changes by the community
Self-reliance (self-empowerment)	Participation	Producers' involvement in system design, implementation and monitoring	Number and frequency of participants' involvement in each phase
	Control	Recognised property rights (individual or collective)	Kind of land tenure regime, rules for the use and availability of resources
		Decision-making power vis-à-vis critical aspects of the management system	Local control over prices and supply of inputs and products; access to machinery
	Organisation	Type, structure, and permanence of local organisations	Existence of associations for input acquisition or product sale, co-operative, credit unions Rules and sanctions for collective decision-making

Note: The most important level of evaluation for social indicators is the production unit (*i.e.*, household, group) and the organisation. Several of the most complex indicators may be measured as binary indicators (*e.g.*, presence-absence of training) or as qualitative ratings (*i.e.*, high, medium, low). The reader may find a more detailed discussion of key diagnostic criteria for sustainable common-resource management in Wade (1987), and in Becker and Ostrom (1995).

In rural Mexico, as well as in many poor countries of the world, the rate of alcoholism in the population constitutes another indicator of increasing importance.[11]

Generation of knowledge and training sessions. Those factors relating to training producers or organization members, as well as other mechanisms that increase the possibilities for innovation and adaptation to change. This may be measured as the number, kind, and frequency of training courses, or as the presence of mechanisms for the generation and transfer of knowledge among peasants communities themselves.

Control indicators. The capability of local groups to appropriate and effectively command the proposed systems. For example, the existence of clearly defined (private or collective)

[11] As mentioned in the previous chapter, the ideal situation in a more detailed analysis is to include indicators that measure the degree of satisfaction of the psychological needs which characterise the quality of life, such as affection, protection, creation and identity.

property rights; the degree of dependence on external information, inputs, or skills for critical aspects of the proposed system's ability to function; and the capability of social actors to negotiate with outside agents (government agencies, municipalities, universities, NGOs, banks, businesses, etc.).

Participation. Participation is key for the self-reliance of management systems. However, because the concept is relatively complex, there are a number of differing ways to define and measure participation. Here, participation is understood as the degree of involvement of the target group in the processes of decision making, diagnosis, design, and implementation. Cohen and Uphoff (1980) present a detailed and comprehensive framework that facilitates the analysis of participatory processes.

Organization. These are complex indicators intended to reflect the ways in which proposed projects are effectively strengthening the process of *local self-empowerment*. These indicators may be assessed by gathering information about the degree of development of local organizations, their permanence and their capacity for change. Other important indicators are the existence of clear regulations in collective decision-making, and the enforcement of penalties imposed on members who do not comply with their assigned obligations. An in-depth discussion about these factors, and particularly about the management of common resources, can be found in Wade (1987), as well as in Becker and Ostrom (1995).

Integrating Indicators

Once the specific indicators for each area have been determined, it is useful to summarize in a table the final list of environmental, economic and social indicators selected. This serves multiple purposes: it provides a panoramic view of the evaluation that addresses all system critical points and general attributes of sustainability; it allows for a review of the possible connections between indicators in different areas; and it enables possible modifications (additions or deletions) to the list of indicators.

Table 12 summarizes the indicators obtained during an evaluation of sustainability of two coffee production systems in the Highlands of Chiapas, Mexico (Pérez-Grovas, 1999). The table includes the general sustainability attributes, diagnostic criteria, and specific indicators used for environmental, social, and economic areas of evaluation.

Table 12. Indicators Used for Evaluating the Sustainability of Two Coffee Production Systems in the Highlands of Chiapas, Mexico (*Union De Ejidos Majomut*)

ATTRIBUTE	DIAGNOSTIC CRITERION	STRATEGIC INDICATORS	MEASUREMENT METHOD
Productivity	Efficiency	Yields	Sampling to determine fresh and dry weight
		Product quality	Random sampling to determine percent of aborted berries and defective berries
	Profitability	Marginal cost / benefit	Cost-benefit analysis
		Labour demand	Socio-economic survey
		Net income / total income	Socio-economic survey
Stability; resilience; reliability	Biological diversity	Number of managed species	Surveys of flora
	Economic diversity	Income from non-coffee crops	Census of non-coffee plants and products in plots
		Market diversification	Coffee marketing process
	Biological vulnerability	Pest incidence	Random sampling in plots
		Erosion	Measuring in runoff plots
		Nutrient balance	Soil, compost and berry analyses
	Economic vulnerability	Input availability	Technical monitoring dossier per plot
		Fluctuations in coffee price	History of coffee prices
	Social vulnerability	Permanence of producers in the system	Majomut producers' registry
Adaptability	Capacity for change	Producers per system	Majomut producers' registry
		Surface per system	Majomut producers' registry
Equity	Distribution of benefits, and decision-making power	Decision-making mechanisms	Interviews with Majomut Directive Board
		Distribution of returns and benefits	Institutional survey
Self-reliance	Participation	Attendance to assemblies and other events	Institutional survey
	Training	Number of trained producers	Quantification of training courses for practitioners
	Self-sufficiency	Reliance on external resources	Financial statistics of Majomut
	Control	Planning, implementation and surveillance mechanisms	Majomut regulations

Source: Modified from Pérez-Grovas, 1999.

4 STEP FOUR:
MEASURING AND MONITORING INDICATORS

Once the summary table containing the final list of environmental, economic and social indicators has been compiled, a detailed discussion on measuring and monitoring procedures may ensue.

A multiplicity of ways exists to measure indicators. Because sustainability reflects a system's behavior over time, emphasis should be placed on those data-gathering procedures that enable the monitoring of processes during a given time period, or the analysis of historical data series and models of variables.

In general, the methods available include:

(a) a review of the literature, including information useful for establishing *trends* in indicator behavior;
(b) direct measurements (*e.g.*, the measurement of total biomass and crop yields, or the analysis of organic matter contents in the soil);
(c) setting experimental plots or runoff lots to measure erosion rates;
(d) simulation models (*e.g.*, the use of the EPIC model to determine the erosion-productivity relationship);
(e) surveys (*e.g.*, to determine the opportunity cost of family labor);
(f) formal and informal interviews; and
(g) participatory group techniques.

The object or scale of measurement will often determine the most suitable type of indicator; in terms of MESMIS, the measurement scales usually applied are on the level of plot, household, community, and watershed or region (see Figure 7, p. 31). Logically, the most suitable indicators that correspond with the environmental, economic and social areas will depend on the scale of the evaluation chosen. In terms of social measures, efforts usually focus on determining appropriate indicators at the household, community or regional level. Regardless however, achieving an acceptable statistical representation of the unit of analysis is of paramount importance; the type of monitoring needed to obtain valid information for each indicator will depend on the management system and on the problem under scrutiny. For certain environmental indicators, such as soil humidity fluctuations, continuous monitoring will be required throughout the cropping cycle. In other cases, obtaining information on a yearly basis may prove sufficient.

The final selection of intensity and type of measurement for the indicator will depend on the availability of human and economic resources to carry out the evaluation. One should try to avoid over-simplified schemes based solely on gathering indirect information; in this case, it is wise to simply postpone the evaluation.

To apply the MESMIS framework correctly, a combination of direct and indirect measurement techniques is advised. Establishing a detailed program for measuring the indicators related to the most critical processes is particularly important to obtain the best results. The following indicator measurement techniques have been applied to MESMIS to case studies:

Methods for Obtaining Environmental Indicators

1. Comprehensive review of the literature regarding regional environmental characteristics. Access to meteorological databases (rainfall, natural disasters, etc.). Compilation of historical data on crop yields.
2. Direct measurement through sampling methods of crop yields, soil properties, diversity of managed species, pest and weed incidence, etc.
3. Installation of monitoring devices in farms (runoff plots to measure erosion, insect traps, etc.)
4. Construction of a *Matrix of Technical Coefficients* to obtain *desired* technical characteristics for each system (labor demand, inputs, costs and productivity), through the analysis of cultivation practices.
5. Application of simulation models - for example, the EPIC model aimed at estimating the erosion-productivity relationship - in order to determine the expected long-term behavior of a system's yields. In forestry systems, modeling is absolutely necessary, because the results of management practices usually require significant amounts of time to appear.

Methods for Obtaining Social and Economic Indicators

1. Comprehensive review of the literature of regional socio-economic characteristics. Historical review of the changes in the price of inputs and harvested products of the management system.
2. Surveys with institutions and households, by organization or community.
3. Open-ended and semi-structured interviews with farmers, key community members and project staff. Participatory methods - *e.g.*, rapid rural appraisals, (WRI-GEA, 1993) - may prove advantageous.

The reader may find a detailed discussion of applied methods for measuring indicators in the MESMIS case study reports. Table 12 (p. 41) exemplifies a measuring program for two coffee-producing systems in the Highlands of Chiapas.

5

STEP FIVE:
INTEGRATING RESULTS

In this stage of the evaluation cycle, the results obtained by monitoring the indicators will be summarized and integrated. The *differentiation* phase, which focuses on gathering data for each indicator, leads to the data *synthesis* phase. This in turn precipitates a value judgement regarding the management systems under study, to reflect how compared systems fare in terms of sustainability.

At this stage, the evaluating team is grappling with a number of highly diverse and complex indicators that describe a range of environmental, economic and social factors, many of which express qualitative data only.

Developing procedures to effectively integrate results is not an easy task. According to Clayton and Radcliffe (1996), determining sustainability does not typically involve choosing between alternatives that are simply "good" and "bad"; rather the choice involves a range of consequences (in economic jargon, costs and benefits) that impact the environment and society. In fact, it may be said that integrating the results from an analysis of sustainability requires active research in and of itself, and neither a general agreement nor a preferred praxis on the matter exist.

The results of the analysis must, in some way, promote the possibility for improvements in the management system via decision-making channels. Clearly presenting the results is integral to explicitly revealing the advantages and limitations of the analyzed systems.

The principal challenge here is finding a way to effectively handle a series of indicators which function as condensed units of information from widely varied sources, and which typically are quite difficult to aggregate. More precisely, six general problems challenge integrating the results: (a) imprecise decision-making criteria; (b) mixed data; (c) non-commensurable data; (d) inter-relations between attributes and indicators of sustainability; (e) difficulty in discriminating between closely related indicators; and, (f) difficult ranking the different alternatives (Dunn *et al.*, 1995). As a result, using multicriteria methods becomes an essential component of integrating the results of an analysis.

In order to achieve an adequate integration and synthesis of the results, five stages should be followed:

1. Condense all results (for every indicator and every system) into a single table or matrix, using original units of each indicator.
2. Determine *thresholds* or baseline values for each indicator.
3. Build indices for each indicator, according to baseline values or thresholds. These indices may be built on both qualitative (*e.g.*, *high*, *medium* and *low*) and quantitative data.
4. Present all results together, using graphs, tables, and multicriteria analysis techniques.
5. Examine the connections - including the positive and negative feedback - between indicators.

Stage **1** above offers a holistic view of the findings and provides an idea as to the type of data contained therein (*i.e.,* mainly qualitative, mainly quantitative or mixed).

Stage **2** identifies the maximum or optimum values in terms of sustainability, as well as the minimum required or acceptable values for the strategic indicators used in the evaluation (critical values).

The literature provides several studies that deal with establishing sustainability indicator thresholds, especially in the area of biophysics (Syers *et al.*, 1994; FAO, 1994). The most commonly utilized baseline values are those found in the literature: for example, the highest tolerable erosion rate under given soil and slope conditions, the minimum amount of organic matter in the soil, or the presence of a given population of beneficial insects. However, especially within the socio-economic sphere, using these general baseline values as indicators is simply ineffective or irrelevant. In these cases, using specific regional values based on reliable statistics, or on participatory planning and evaluation activities (*e.g.*, short, medium or long term goals proposed by development projects or stakeholders) presents much more adequate representation of conditions.[12] In this area, thresholds constitute an important tool for identifying and ranking those aspects of the system that will eventually require greater or lesser attention.

Creating indices (stage **3**) facilitates comparing indicators of dis-similar units, and presents all indicators in a common format without losing the original information. Indices can be built according to sustainability thresholds or baseline values for each indicator. The techniques and relevant case studies for creating indices are described below.

Multicriteria analysis techniques encompass a wide range of possibilities for presenting and integrating the results (stage **4**). One primary method obtains an aggregate index for each management system analyzed. Other methods compare systems and illustrate them graphically, in terms of the strategic indicators chosen.

Generally speaking, there are three techniques for presenting and integrating the results: (a) quantitative; (b) qualitative, and, (c) graphical or mixed techniques. Each has its relative advantages and disadvantages. For example, quantitative or formal techniques are well developed and allow the detailed analysis of complex situations, but usually require advanced training in statistics and mathematics. Qualitative techniques are, many times, easier to use; often however, their graphic presentations are attractive but of dubious quality. It should be understood that switching from quantitative to qualitative techniques does not imply a loss of analytical objectivity. When properly designed, qualitative techniques may provide more effective methods for identifying problems than complicated numerical analysis, where in many cases it is not clear how the final coefficients resulted. Likewise, switching from qualitative to quantitative techniques does not necessarily imply an increased objectivity or accuracy in the analysis, though this change provides a numerical value.

The last important stage in this **5**th step of the evaluation is to explore and identify connections between indicators. This exercise, though difficult, is critical; a common mistake

[12] For a more in-depth discussion concerning the establishing of thresholds, and for a few examples of variables, see Syers *et al.* (1994), as well as the FESLM (FAO, 1994)

made in sustainability analyses is assuming that the different indicators (which describe system sustainability attributes) may be simultaneously maximized in an independent manner. In other words, by implicit assumption, it is theoretically possible to design systems that are simultaneously the most productive, the most stable and resilient, the most adaptable and so on with the other attributes.

In practice this is almost always impossible, since the different indicators - or attributes - are related to each other, and not necessarily in a positive way. The case that is most frequently mentioned in the literature is the connection between the attributes *productivity* and *stability* (or yield and soil conservation, in terms of indicators). In effect, one of the strongest criticisms of the Green Revolution model of agriculture has been its emphasis in designing systems that maximize yields at the expense of other system properties (*e.g.*, soil losses or pollution). In other words, maximum productivity does not necessarily lead to the most stable system.

Generally, indicators may be linked to each other through complex relationships: synergy (when improving one indicator involves improving another indicator), competition (or trade-off, when improving one indicator implies worsening another one), or mixed relationships (when for certain indicator levels the attributes reinforce each other, while in others they compete against each other). In the last few years there has been an increasing interest in the analysis of these connections. Most published studies focus their analysis at the levels of sustainability attributes (Yiridoe and Weersink, 1997; Viglizzo and Roberto, 1998; González, 1998; FAO, 1994); for example, they tackle the connection between a system's productivity and its stability or resilience. However, due to the complexity of this subject, no methodological agreement has been reached to quantify the connection between sustainability attributes.

We acknowledge that, due to the extensive monitoring of all indicators, developing this issue in-depth is, in practice, quite complex. However, within MESMIS we suggest exploring possible trends, by seeking to answer the following questions: Are there trade-offs between indicators? To what extent does improving one indicator have a positive effect on others? Monitoring indicators periodically will be a key element to identifying and quantifying their connections with each other.

The following paragraphs contain a deeper description of the techniques described above for presenting and integrating results. The discussion will show the different aspects involved in this evaluation step, from first bringing all indicators together in a single format to finally presenting them graphically.

Quantitative Techniques

Quantitative techniques are usually based on so-called multivariate statistical analysis, which may be relatively simple or quite sophisticated. The methods most commonly used include factorial, principal component, cluster, and discriminate function analyses (Manly, 1994).[13]

[13] A detailed discussion of multivariate statistical analysis lies out of the scope of this document. The reader may find a review of the various methods in Manly (1994), at both comprehensive and introductory levels.

A somewhat simpler method, used by several authors in analyzing sustainability, is to obtain an aggregate index, also called a *sustainability index* (Taylor *et al.*, 1993). Some interesting examples of this method are found in Subbakrishna and Dilip (1991) for comparing energy systems, and in Taylor *et al.* (1993) for analyzing agricultural management systems. In general, the procedure involves assigning an index to each indicator (or indicator group, when more than one indicator has been chosen for a given diagnostic criterion). Such indices are obtained by normalizing data within a scale - 1 to 5, or 1 to 10 - which indicates the degree to which the desired objectives (thresholds) are achieved. In some cases, indicators may have negative values, signifying that the evaluated effect is contrary to what is desired (Taylor *et al.*, 1993).

Measured indicators are subsequently aggregated, assigning a unique value to each management system. Indices may be aggregated by means of simple or weighted numerical averages (the latter option involves assigning a weight to each indicator). As a result of this process, each management system has a numerical sustainability index, which enables its comparison with other systems analyzed.[14] If the indicators for each system have been derived from a relatively large sample of producers or farms (greater than 10), the analysis may be refined by making a correlation matrix to exclude those indicators which are closely correlated. In any case, it is also advisable to conduct a sensitivity analysis (*i.e.*, varying the value of individual indices within a given range), so as to evaluate the importance of each system's indicators when weighing factors are modified. Appendix 1 presents an example of this kind of analysis for a large group of cabbage producing farmers in Malaysia (Taylor *et al.*, 1993).

The main drawbacks of qualitative analysis are the difficulties of assigning a numerical value to certain qualitative indicators, and estimating the relative import of each indicator. As stated by Clayton and Radcliffe (1996), relying on a single aggregated indicator involves three general problems:

- By simplifying the final decision-making, it involves the greatest data loss.
- In general, it does not provide adequate information about dynamic interactions between the various elements or dimensions of the evaluation.
- Any decision-making procedure based on a single index - money, for example - relies on assigning *values* and weights to the different factors. The method used to arrive to this aggregate index is normally the most critical part of the evaluation; however, because estimates focus on the final value of the indicator, in many instances the methodology remains hidden within the analysis, particularly when using more sophisticated techniques.

Finally, it must be considered that both the measurement unit of the global index (in this case, a *sustainability unit*) and its specific numerical value will clearly depend on the local context, and on the specific procedure followed to arrive at the aggregation. In consequence,

[14] It must be stressed that such a *sustainability index* may **only** be used to compare management systems for which exactly the same method of aggregation has been used (*i.e.*, using the same indicators, range of values, and weighing factors).

comparing systems whose indices were calculated by means of different procedures produces invalid results.

Other more elaborate techniques to deal with these sorts of problems are multicriteria analyses for decision-making and multiple-objective programming (De Graaff, 1993), which are used extensively in environmental impact assessments. In these models, indicators may have numerical values or be ranked in an ordinal scale (*e.g.*, *high*, *medium*, *low*). The various alternatives may be subsequently analyzed by means of decision-making matrices - which illustrate the viewpoints of the various stakeholders or sectors, or the impacts of a system on several environmental and socio-economic aspects - by using concordance and dissonance indices, or through other techniques (Bodini and Giavelli, 1992). When searching for the optimal alternative, weights have to be applied to each indicator (De Graaff, 1993). A procedure which enables working with vague or ambiguously defined variables is the use of techniques based on *fuzzy logic* (Dunn *et al.*, 1995; Bellehumeur *et al.*, 1997). Despite their attractiveness, the efficient use of multicriteria analyses normally requires specialized computer software and adequate training. Appendix 1 presents an example of the kind of matrices used in these methodologies.

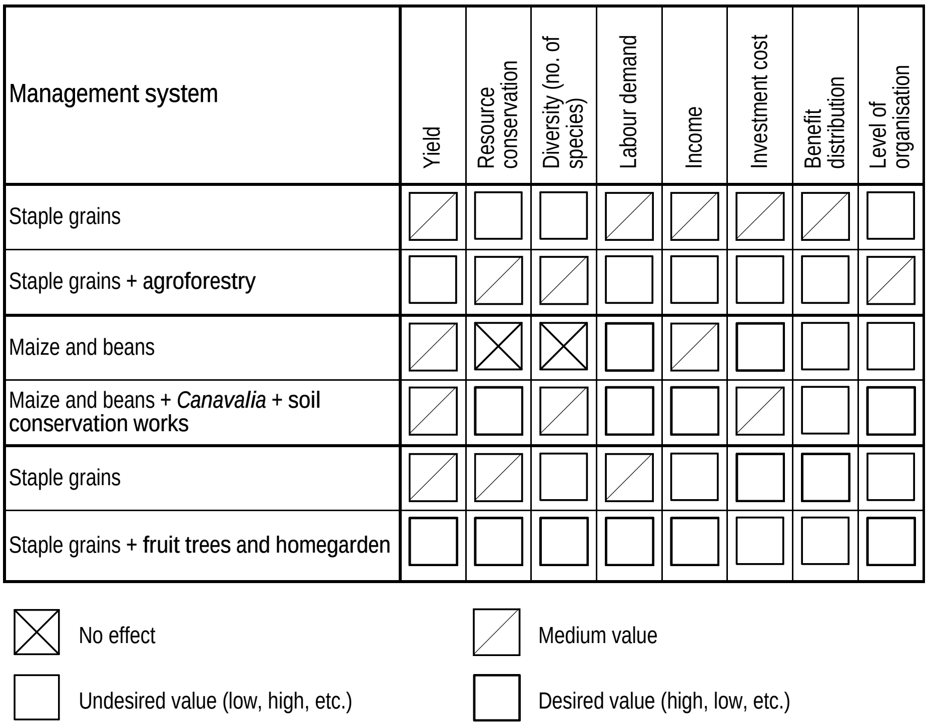
Qualitative Techniques

Qualitative techniques aim to integrate the results of an evaluation in a format that is both simple and clear. In the case of sustainability analyses, where a large number of indicators are measured, qualitative techniques are particularly useful, since they offer a global view of a set of selected indicators.

Participatory rural appraisals (WRI-GEA, 1993) have made extensive use of qualitative techniques. One of the most useful forms of presenting results is through using diagrams, which provide a graphic illustration of the values of a number of indicators. To achieve this, indicators are given lax values - such as *high*, *medium*, and *low* - (Altieri and Masera, 1993). Usually these diagrams are filled out together with farmers or other evaluation stakeholders.

Figure 8 shows an example of this kind of diagrams for the evaluation of three maize production systems in El Salvador. Plotted along the horizontal axis are the eight indicators used in the analysis (yield, resource conservation, number of cultivated species, labor demand, income, investment cost, benefit distribution, and level of organization). The vertical axis represents the three alternative management systems studied (two staple grain production systems, and a maize-bean system), as compared to the three corresponding reference systems (in this case the traditional systems). Each indicator is represented by a small box, either shaded or empty, according to the particular value for the indicators in each system. With shaded boxes representing desired properties and empty boxes representing undesired properties, one can appreciate immediately the relative strengths of each system in terms of the various facets that were considered in the evaluation.

Figure 8. Diagram for Presenting and Integrating Sustainability Evaluation Results

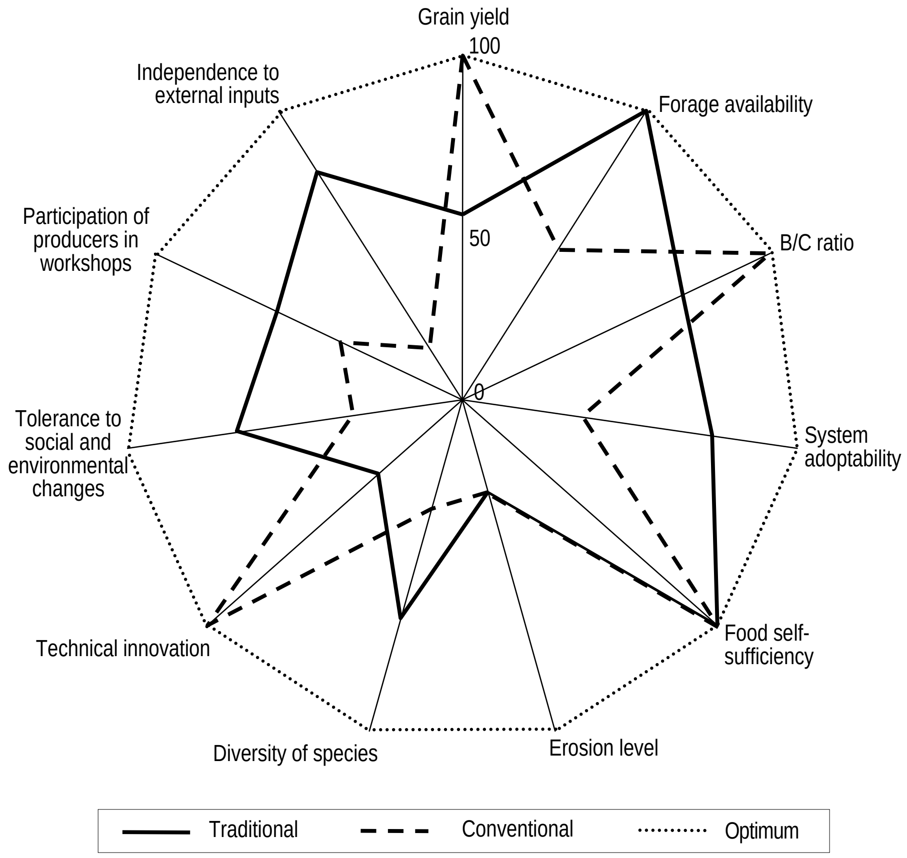


Mixed Techniques

In mixed techniques, graphic representations are combined with numerical information, for suitable indicators only. Among these techniques, the AMOEBA procedure has recently become popular (Brink *et al.*, 1991). In AMOEBA, a radial diagram is made in which each axis represents one of the selected indicators with its adequate units. Alternatively, to facilitate diagram interpretation, indices are calculated for each indicator, representing the percentage of the analyzed situation as compared to the ideal value or threshold (reference value).

After this, each management system is plotted in the diagram, by joining the different points (corresponding to each indicator) attained by the system in each axis, as well as the points attained in the ideal situation (see Figure 9). By this procedure, a specific geometric figure is obtained (similar in its outline to an amoeba, hence the name), which varies for each system. These diagrams show, in qualitative terms, to what extent the objective has been met for each indicator, and enable a simple yet comprehensive graphical comparison of the advantages and limitations of the evaluated management systems. A similar method is based on *sustainability maps*, also used in *position analyses* (Clayton and Radcliffe, 1996).

Figure 9. Evaluation of two maize producing systems, by means of an AMOEBA-type diagram (Michoacan, Mexico)



Source: Modified from Astier *et al.*, 1999.

Figure 9 illustrates the use of AMOEBA diagrams for two maize production systems in Michoacán, Mexico. For the sake of clarity, a few details from the original diagram (which included more indicators) were omitted.

The dashed line represents the conventional system, the continuous line the traditional (reference) system, and the dotted line the desired goal. All axes have been normalized as percentages, so that the goal is always equal to 100%.[15] Table 13 shows the values of the indicators that were used in the AMOEBA in their original units, as well as the optimal values and the resulting ratios (percentages).

In the illustrated example one sees rapidly that, from social and biophysical standpoints, the traditional system is far better than the conventional system. However, in productive and economic terms that are closely linked to the capacity for technological innovation, the conventional system displays better conditions. Plotting both systems in subsequent years

[15] Please note that some indicators show undesirable features of management systems (*e.g., erosion level*); therefore, in order to avoid confusions, they should be worded in a positive form (*e.g., erosion control*).

Table 13. Indicator weighing for building the AMOEBA of Figure 9

INDICATOR	Optimum	%	Traditional	%	Conventional	%
Grain yield (ton/ha)	2.2	100	1.2	54	2.2	100
Forage availability (kg/AU/month)*	370	100	370	100	194	52
B/C ratio	1.81	100	1.32	72	1.81	100
System adoptability (%)	100	100	74	74	36	36
Food self-sufficiency (%)	100	100	100	100	100	100
Erosion level (ton/ha)	1.8	100	2.5	28	2.5	28
Number of managed species	3	100	2	67	1	33
Technical innovation (%)**	100	100	30	30	100	100
Tolerance to social and environmental changes (%)***	100	100	60	60	30	30
Participation of producers in workshops (%)	100	100	60	60	40	40
Independence to external inputs (%)	100	100	21	79	92	18

Source: Modified from Astier *et al.*, 1999. A full description of every indicator and of the procedure that was used for obtaining the optimum values can be found in the original source.

* *AU* means Animal Units.

** This indicator refers to the percentage of producers that have implemented significant innovations in their management systems.

*** This indicators represents system robustness, when facing possible changes in maize baseline prices, fertiliser prices and delays in seasonal rainfall.

provides a simple evaluation of the advances made towards reaching the desired goals in terms of sustainability, or simply shows how one system improves in relation to another.

As mentioned above (see p. 45), it is difficult at present to recommend one particular technique for integrating the results of a sustainability evaluation. Each working team must examine which technique is more appropriate given its objectives, taking into consideration the capabilities of the participants, their knowledge of statistical techniques, the level of detail with which the evaluation is made, and the time constraints.

Due to their technical complexity, quantitative multicriteria analyses may be inappropriate for many projects. However, AMOEBA diagrams constitute a useful and applicable alternative for integrating results; they provide a good starting point for graphically *monitoring* the evolution over time of chosen indicators in each system. For this reason, the AMOEBA diagram may become a useful tool for planning and integrating strategies aimed at strengthening the social, environmental and economic profiles of the systems under study.

6 STEP SIX: CONCLUSIONS AND RECOMMENDATIONS REGARDING MANAGEMENT SYSTEMS

With this step, the first cycle of the evaluation comes to an end. Step six recapitulates the results of the analysis to judge how the different systems compare in terms of sustainability. Step six is also the phase in which to reflect upon the examination process itself, and put forward strategies and recommendations to initiate a new evaluation cycle in qualitatively different conditions (time T_2 in step 1, Figure 3, p. 19). In order to achieve these goals, the evaluation team must make use of participatory techniques with farmers, practitioners, researchers and other individuals involved in the evaluation process.

Presenting Conclusions

The first objective of step six is to present a series of clear conclusions about the management systems analyzed. For this purpose, the evaluating team should conduct the following:

1. **An appraisal** on how the reference and the alternative systems compare in terms of relative sustainability. This appraisal must be specific, *i.e.*, along the lines of: "the system is shown to be more sustainable according certain indicators and attributes, but problematic or unsustainable according to others". Additionally, a general judgement may be included about the comparison of both systems at aggregate level. This appraisal may be based on quantitative analysis (*e.g.*, through calculating indices), but should include an AMOEBA-like analysis, so as to enable a completely transparent comparison of sustainability indicators.[16]
2. **A discussion** about the main elements that enhance or inhibit the alternative system in improving its sustainability as compared to the reference system. Included here, there must be at least a brief discussion about the constraints and opportunities created by the political, socio-economic or environmental *boundary conditions* of the system.

Likewise, within the conclusions, it is important to analyze the evaluation process itself, so as to pinpoint its weaknesses and strengths in the following:

1. **Logistical aspects**. For example, was the work of the interdisciplinary evaluation team effective? Was the communication with all stakeholders of the NRMS adequate?
2. **Technical or methodological aspects**. For example, how reliable were the indicators and measurement techniques used in the evaluation? Was proper attention given to the different evaluation areas?

Presenting Recommendations

Taking into account the conclusions made, the evaluation team should propose recommendations to improve the system's socio-environmental profile. In order to achieve

[16] In order to assure a grater objectivity, FESLM suggests validating evaluation results through independent experts.

this, an effort is required to *establish priority actions* (weighing needs and alternatives), *i.e.*, carry out a careful analysis of the system characteristics that may require changes, by ranking future development and research needs.

In practice, in order to propose strategies to change management systems, the evaluation team, regardless of the employed technique, should try to take into account the needs and priorities of all stakeholders (producers, development workers, researchers, decision-makers, and so on).

Regarding the methodological procedures, the team should propose strategies that strengthen the evaluation process, considering the conclusions that were obtained for both logistical and technical elements.

EVALUATING SUSTAINABILITY AS A PERMANENT PROCESS: THE SUCCESSIVE EVALUATION CYCLES

The conclusions and recommendations that were obtained in the sixth step of the evaluation are the starting point to begin a new sustainability evaluation cycle, as shown in step one, time T_2 in Figure 3 (p. 19).

When this point is reached, the work that was undertaken during the first evaluation cycle, together with the process of incorporating recommendations, will lead to a re-characterization of the management systems. For example, the team may recommend overlooking the reference system and focusing on evaluating the alternative system over a given period of time. Or they may decide to change certain components of the management systems. Whatever strategy is followed, the re-characterization of the management systems will involve re-defining the system's critical points, which *triggers* naturally the new evaluation cycle.

When initiating a new cycle, it is logistically important to restructure or incorporate additional human resources within the interdisciplinary evaluation team, so as to strengthen the comprehensive analysis of management systems. Likewise, strategies should be proposed that enrich the participation of all stakeholders (*i.e.*, people involved in both the system management and the evaluation process).

Technically, a re-structuring of the utilized indicators is required, eliminating or modifying those indicators which are proven to be inappropriate for describing the desired processes, difficult to monitor, or simply unnecessary. Regardless of the modifications made to the indicators and the measurement techniques, the evaluation team should keep in mind the desired characteristics of the set of strategic indicators, maintaining the links between them and the critical points via the diagnostic criteria. The team should also seek to ensure that all seven sustainability attributes are adequately covered.

The endeavor can be considered a success if it precipitates an iterative action-evaluation process, in which an analysis of sustainability constitutes as an intrinsic component in the development of alternative NRMS. Every new evaluation cycle will then redefine and improve the social and environmental profile of management systems so as to realize a relatively higher level of sustainability. In order to achieve this objective, it is essential that all identified actions and changes be translated into tangible benefits for those who implement the NRMS.

CONCLUSIONS

The Challenges of Evaluating Sustainability

To date, research and development conducted in alternative management systems in agriculture and forestry have been overwhelmingly dominated by what we call ‘the productivist paradigm’. This paradigm focuses on maximizing short-term yields, and is based on a reductionist conception of nature and society, one that simplifies the complex agroecological processes to “industrial” operations in which the results are above the means.

When considering the rapid degradation of global resources, conventional evaluation strategies that are disproportionately based on the idea of productivity prove increasingly inappropriate for addressing the complex, interdisciplinary nature of current development problems. Promoting the sustainable management of natural resources compels a re-examination of the terrain, one that significantly departs from a productivist orientation to adopt a more holistic approach that addresses the dynamic nature of natural resource management systems.

In essence, sustainability articulates an alternative vision for managing natural resources. In order for the concept of sustainability to function as the central driving force for systems management, it must encompass strategies that are rooted in systemic, interdisciplinary and participatory approaches. This key distinction from the conventional productivist paradigm prompts us to seriously contemplate the links that exist between the environment, the economy and society. This is not to say that more information on systems is necessarily required; rather, what is needed is a re-orientation in conceptual approach. To quote Rolando García (1992), "It is not about learning more things, but about thinking differently."

However, moving beyond the simple rhetoric of sustainability into a process that actually assesses the relative sustainability of a system is no easy task. Perhaps one of the most critical components here is developing evaluation frameworks that explicitly determine the relative advantages and disadvantages of alternative NRMS *in terms of environmental, economic and socio-cultural factors*. Such frameworks will still evaluate system productivity and profitability; however, they will also incorporate into their analysis other factors such as system stability, resilience, and reliability, as well as adaptability, equity and self-reliance. This deviance is especially relevant in the context of peasant production systems: despite exhibiting a high level of diversity, resilience and renewable use of local natural resources, peasant production systems have been generally undervalued when analyzed by productivist criteria, which overlooks these qualities and focus on short-term economic benefits.

It has been widely acknowledged that conventional procedures for evaluating the sustainability of systems have proven insufficient in addressing the complexity of systems analysis (one example is the insufficiency of cost-benefit analyses for determining the sustainability of NRMS). Currently however, most efforts are still focused on what might be called *cumulative* approaches. According to this perspective, evaluating sustainability is, at the end of the day, a conventional assessment exercise to which environmental and social criteria have been added, by means of a list of *sustainability indicators*. Since the concept of sustainability has become somewhat fashionable, and its analysis a precondition for fund-raising, any treatment of the subject has become simplistic and often demagogic.

In our opinion, evaluating sustainability effectively requires two things: a) an evaluation approach that is systemic, interdisciplinary and participatory; and, b) the development of a *qualitatively distinct* methodological framework for deriving and measuring sustainability indicators. For this methodological framework to be effective, it cannot be based on the simple juxtaposition of the results obtained independently for each indicator or evaluation area. Rather, it must seek to integrate the social, economic and environmental dimensions of the system during the evaluation process.

Moreover, we consider the very nature of indicators - which are difficult to aggregate, quantify or extrapolate, which are usually vaguely or inaccurately determined, and which involve a range of stakeholders and perspectives - as a *challenge* rather than an *obstacle* to the evaluation. This is to say that the particular problems under study should dictate the development of appropriate evaluation techniques. A multi-dimensional and interdisciplinary problem requires evaluation frameworks that take advantage of these complex characteristics, rather than consider complexity itself a limitation. We have endeavored here to create such a framework, where the particular problems under study dictate the development of appropriate evaluation techniques.

MESMIS was designed so that sustainability indicators would constitute a consistent set that is closely linked to both the system's critical points and its general sustainability attributes. For this reason, the set of indicators responds not only to the environmental and socio-economic constraints within a specific local context, but also to the key systemic attributes that characterize and enable the operational definition of sustainability in all systems. In this way, we attempt to satisfy two otherwise opposing problems to sustainability evaluations: local specificity and universality. Sustainability can not be defined abstractly or universally, but must resolve itself on the level of specific socio-environmental and temporal context. However, sustainability must also correspond to those attributes that are generally common to all systems.

Furthermore, MESMIS was conceived to evaluate sustainability as a cyclic process, one that is iterative and continuous, considered successful only when it improves the social *and* environmental profile of a management system. In other words, the evaluation aims not only to *qualify* management options by grade of relative sustainability, but also to start a process that identifies the problem, and formulates an action plan geared towards improving the management system. Evaluating sustainability must be, ultimately, a *tool for planning and design*; success will lie in the tool's capacity to be appropriated and applied within the day-to-day activities of farmers in projects aimed at improving the sustainability of NRMS.

As with any theoretical exercise - particularly one involving such a broad, controversial and complex concept as sustainability - the MESMIS framework should be considered an open work-in-progress undergoing constant evolution. Any framework attempting to close the discussion on sustainability would essentially prove its incompatibility *vis-a-vis* the dynamic nature of the subject, and would greatly reduce its capacity for widespread adoption.

This said, there are still a number of areas within the MESMIS methodology that need further attention. The following paragraphs will outline what some of those areas are.

<u>Building a set of indicators consistent with sustainability attributes</u>. Continuing the discussion about fundamental systemic properties, especially within the realm of determining attributes and deriving indicators, is critical to understanding the meaning of the term 'sustainability'. Within this domain, particular attention should be placed on exploring social and particularly political aspects of the issue. An in-depth discussion on the critical points for the sustainability of management systems is required, to more firmly establish a broad set of generic critical points that focus on developing diagnostic criteria and sustainability indicators.

<u>Integrating indicators</u>. By integrating indicators we are referring to essentially two processes: (i) improving the integration of environmental and socio-economic factors in the system; and (ii) developing methods to integrate the results.

Insofar as the first process is concerned, one should keep in mind that indicators do not respond to specific areas linked to a specific discipline, but rather to *fundamental system properties*. For this reason, we have maintained the idea of *areas of evaluation* as a sort of artificial category, which seeks to ensure that these fundamental system properties will be understood in their totality (i.e. not just in terms of economics, for example, but also in terms of environmental and social forces). When seeking to determine appropriate indicators, the focus should be the attributes, and not the areas of evaluation.

As for integrating evaluation results, the most basic problem is the lack of satisfactory methodological precedents in the literature. Generally speaking, due to their complexity, current techniques for integrating results (especially those relying on sophisticated mathematical or statistical calculations) have become the private domain of specialists. This process at times generates speculation as to the validity and comprehensibility of presented results.

Ideally, the most effective strategy would be to design multicriteria analysis techniques which enable a simple and clear presentation of the various dimensions of analysis by showing the complementarity or conflict (trade-offs) between different indicators. Moreover, further development is required for techniques to integrate those indicators that have been vaguely or imprecisely determined.

Interconnection of indicators. In the near future, analyzing interconnections among sustainability attributes and among indicators should take top priority. In effect, a majority of efforts so far have been directed towards determining which indicators should be individually measured or optimized, without carefully examining more holistic strategies to increase the sustainability of the entire system. Particularly, more research is needed in analyzing how interconnections between indicators may potentially lead to trade-offs (e.g. when an increase in productivity leads to a decrease in stability or resilience) or conversely to situations of greater synergy, so as to define a minimum set of truly robust indicators.

Articulation between scales of evaluations. In this document, we have focused our efforts to address systems on a local scale, at the level of the community. Future endeavors should begin to conceptualize evaluation frameworks and indicator sets that suit case studies on the regional and even national level. An important question here is how to maintain consistency between indicator sets and evaluations conducted on local and regional (and even national and global) levels.

Along these lines, from an operational viewpoint, evaluation frameworks must be able to adapt to the wide array of technical profiles and local capabilities for gathering and processing information. The central issue is determining the minimal level of detail needed for a rigorous and practical evaluation for the sustainability of a NRMS.

Participatory techniques. Developing inclusive participatory techniques for more effectively incorporating the priorities and perspectives of farmers (or, in general, natural resource managers) constitutes one of the most important directions for future analysis. Opening up the decision-making processes to key players, so as to incorporate the perspectives of all management stakeholders, takes on a primary role in devising participation strategies that work. This type of analysis is usually carried out in environmental impact assessment, but is virtually absent in sustainability evaluations. Likewise, the process that determines threshold or baseline values for each indicator needs serious improvement; ideally, indicators should become activity planning guides and ranking axes for the people in charge of natural resource management.

We reiterate that, germane to the dynamic nature of sustainability, MESMIS is a work-in-progress; MESMIS is an evolving process that promotes an operational, locally applicable framework for evaluating sustainability.

Equally important to developing a comprehensive strategy is creating an information network to liase with others working in this field. The MESMIS project seeks to address these challenges through a comprehensive strategy that involves developing and disseminating research and training resources on sustainability evaluations, undertaking detailed case studies for representative management systems in Mexico, training individuals and organizations in the use of the methodology, developing a sustainability database, and exchanging experiences with other groups. Through this process, perhaps a minimal methodological *standardization* will be reached, maintaining a healthy diversity of approaches but also facilitating a general comparison of sustainability evaluation results.

It is our hope that the continued implementation and evolution of the MESMIS framework will contribute to future theoretical and practical innovations in the field of sustainability, where alternative practices may be proposed, assessed and implemented with a greater degree of effectiveness. In a world of diminishing resource domains, creating a more sustainable future is dependent on embracing a deeper, more integrated understanding of the complexity of natural resource management systems; such an understanding is critical not only to the sustainability of natural resources, but also to the well-being of all humankind.

APPENDIX 1

Quantitative Techniques for Integrating the Results of Sustainability Analyses

As mentioned in the text, there are two main quantitative techniques for integrating analysis results, through a sustainability index, or a multicriteria analysis .

SUSTAINABILITY INDICES

This approach to analyzing and integrating the results of the evaluation process is geared towards aggregating all indicators in a single value or sustainability index. Taylor *et al.* (1993) illustrate a procedure that uses quantitative techniques to measure the sustainability of cabbage production among a group of farmers in Malaysia. An index of environmental sustainability was computed for each producer in the sample, by using 33 indicators distributed in four areas: (a) insect control; (b) disease and control; (c) soil fertility maintenance and enhancement; and, (d) soil erosion control (see Table A-1). Each indicator was assigned a numerical score, usually between 0 and 4, according to the degree in which it had a positive effect on the system (*e.g.*, crop rotation as weed control practice). Indicators may also exhibit negative values in cases in which the farmer's activities have a detrimental effect on the environment (*e.g.*, intensive use of pesticides or chemical fertilizers). The sum of the scores for all indicators is the farmer's *sustainability index*. In this case, the maximum possible value of the index - or goal - was 82, assigning different weights depending on the area of evaluation. By comparing the maximum value of the sustainability index with the actual value of the producer, farmers may be rated in a *sustainability scale* (see Table A-2).

Table A-1. Production Practices Included in the Farmer Sustainability Index. Case Study, Malaysia

TYPE OF PRODUCTION PRACTICE				SCORE	
Weed control (maximum score = 6)	Number of sprayings to control the most significant weeds			0-1	+1
				2	0
				3-6	-1
	Use of non-chemical weed control	Use of crop rotation		Yes	+1
				No	0
		Adjustment of sowing season		Yes	+1
				No	0
Maintenance and improvement of soil fertility (maximum score = 18)	Percentage of total nitrogen (N) applied from organic sources			0%	-1
				1-20%	0
				21-40%	+1
				41-60%	+2
				61-80%	+3
				81-99%	+4
				100%	+3
	Number of applications of inorganic fertilizers			0 or 1	0
				2	+1
				3	+2
	Changes during the last 5 years in the application of:	Inorganic fertilizers		More than before	-2
				No change	0
				Less than before	+2
		Cattle manure		More than before	+1
				No change	0
				Less than before	-1
		Other organic fertilizers		More than before	+1
				No change	0
				Less than before	-1
	Other means to improve soil health and fertility:	Crop rotation including leguminous crops		Yes	+1
				No	0
		Use of lime		Yes	+1
				No	0
		Use of rice husk		Yes	+1
				No	0
Control of soil erosion and multi-purpose practices (maximum score = 6)		Efforts to control soil erosion		Yes	+2
				No	0
		Cabbage production in rotation		Yes	+3
				No	0
		Cabbage production in association		Yes	+1
				No	0
Insect pest control (maximum score = 43.5)	Integrated Pest Management practices	Bases for applying pesticide for *P. xilostella*:	According to the application timetable in the dry season	Yes	0
				No	+1
			Whenever adults are observed	Yes	+1
				No	0
			Whenever damages by *P. xilostella* are observed	Yes	+1
				No	0
		Counting *P. xilostella* larvae		Yes	+2
				No	0
		Use of bactericide insecticides		Yes	+3
				No	0
		Use of mixtures of pesticides		Frequently	-2
				Sometimes	+1
				No	0

	Chemical insect control	Number of sprayings to control the most important insect pests	0	+2
			1-3	+4
			4-6	+2
			7-9	0
			10-12	-2
			13-15	-4
			16-18	-6
			More than 18	-8
		Changes, during the last 5 years, in the application of insecticides	More than before	-4
			No change	-2
			Less than before	+2
	Non-chemical insect control	Crop rotation	Yes	+½
			No	0
		Selection of resistant varieties	Yes	+½
			No	0
		Adjustment of sowing season	Yes	+½
			No	0
		Use of lime	Yes	+½
			No	0
		Avoid the use of sprayers	Yes	+½
			No	0
Disease control (maximum score = 8.5)	Number of sprayings, during the last 5 years, to control the most important diseases		0	+1
			1-3	+2
			4-6	+1
			7-9	0
			More than 9	-1
	Use of non-chemical control measures:	Crop rotation	Yes	+½
			No	0
		Selection of resistant varieties	Yes	+½
			No	0
		Adjustment of sowing season	Yes	+½
			No	0
		Use of lime	Yes	+½
			No	0
		Avoid the use of sprayers	Yes	+½
			No	0

Source: Modified from Taylor *et al.*, 1993.

Table A-2. Result of the Farmer Sustainability Index (FSI) for a group of cabbage producers in Malaysia

FSI	VALUE
Mean	56.9
Median	57.1
Mode	51.5
Range	23 – 81

Source: Modified from Taylor *et al.*, 1993.

Frequency distribution	(%)
0.0 - 40.0	8.2
40.1 - 50.0	11.8
50.1 - 60.0	38.8
60.1 -70.0	29.4
70.0	11.8

MULTICRITERIA ANALYSIS

This type of analysis suits those cases which necessitate meeting a broad set of objectives, which cannot be easily aggregated into a single unit (by converting everything into a monetary value, as in conventional cost-benefit analyses) – which is a typical scenario in sustainability evaluations. There is a range of methods for carrying out multicriteria analyses, from those that deal with numerical variables to those that use qualitative data. Some methods are able to combine both types of variables, while others work with "fuzzy logic" techniques. While a full review of these methods lies outside the scope of this book, we will briefly discuss the general procedure that is followed for undertaking these analyses using a simple example to illustrate the procedure.

Some of the most widely used methods for multicriteria analysis are multi-objective programming, (lexicographic or weighed) goal programming and multicriteria decision-making (MCDM). On the basis of these methods, several techniques or models have been developed for specific cases (ELECTRE, MAUT, STEM) (Rehman and Romero, 1993). Even though these methods have different degrees of complexity, objectives, and fields of application, they all share a few essential elements.

In general, the first step for starting a multicriteria analysis is to produce a matrix (known as an impact matrix) where the values of indicators or criteria for each alternative system are summarized in their respective units. The second step, each criteria is assigned relative weights, either through the judgement of a team of experts or through the incorporation of different perspectives or social sectors in the analysis. In the latter case, a sequence of weights by criterion can be obtained for every perspective. Both the original indicators and the weights can be determined in a quantitative or qualitative fashion.

The third step consists of combining the different weights (by both criterion and perspective) with the original values for each criterion, so as to determine which of the considered alternatives function best - or which fulfil the tenets of sustainability - in this case. For this purpose, it is possible to build concordance or discordance matrixes, fuzzy-logic dominance matrixes, and so on (Graaff, 1993; Bellehumeur *et al.*, 1997; Rehman and Romero, 1993). With this information as starting point, it is possible to rank the alternatives according to viability so as to facilitate their implementation.

Multicriteria analyses are increasingly used in evaluating sustainability. Bodini and Giavelly (1992) present an interesting example that illustrates the above discussion. In this case, their aim is to decide which one of four alternative development plans is the most suitable for an island in the Mediterranean. In order to compare the alternatives, 14 indicators or criteria were used, covering environmental, economic and social factors. They begin by building an impact matrix, using the values for each criterion and for each one of the four alternatives plans being studied (see Table A-3). Simultaneously, they conduct a survey among different social sectors of the island, so as to determine the value assigned by each sector to the 14 selected criteria. This process permits building a matrix of weights by criterion and social sector (see Table A-4). The authors then combine both impact and weight matrixes

Table A-3. Impact matrix for the multicriteria analysis of development plans in Isla Salina, Italy

Criterion	Development plan			
	A	B	C	D
Flora (ha)	677	418	358	358
Fauna (%)	100	51	40	20
Oasis (ha)	1,600	800	677	677
Coasts (%)	36	27	18	20
Water (m^3)	100,000	200,000	350,000	450,000
Labour market (%)	86	95	100	100
Cultural patrimony (no. of areas)	8	16	8	8
Immigration (no. of migrants)	0	60	104	160
Health (M lit*)	0	16	400	416
Productive sector (%)	50	32	20	10
Real state (%)	90	60	45	40
Roads (km)	51	57	33	51
Tourism index	36	72	72	480
Energy (MW)	2,800	3,600	4,000	5,500

* Million Italian Lire.

Source: Modified from Bodini and Giavelli, 1992.

by means of first a concordance analysis and then a discordance analysis, in order to facilitate the decision-making process. The concordance analysis permits determining how often one plan is preferred over another one, whereas the discordance analysis permits observing how often one alternative is rejected in favor of another. They present all the results in the form of an index matrix (see Table A-5) in which the preferred alternatives are those showing the highest positive value in the concordance analysis (the bold characters in Table A-5) or the highest (in absolute value) negative value in the discordance analysis. A detailed discussion of the evaluation method can be found in the original paper.

Table A-4. Weights assigned by different social sectors

Criterion	Viewpoints			
	Primary sector	Unemployed	Students	Neutral*
Flora	2.8	0	8.8	5.2
Fauna	0	0	0	5.2
Oasis	0	0	2.9	5.2
Coasts	0	0	0	5.2
Water	2.8	0	5.9	5.2
Labor market	34.5	44	23.5	5.2
Cultural patrimony	2.8	0	2.9	5.2
Immigration	2.8	0	5.9	5.2
Health	23	20	5.9	5.2
Productive sector	5.7	12	11.8	5.2
Real state	2.8	0	2.9	5.2
Roads	0	0	0	5.2
Tourism	0	8	11.8	5.2
Energy	5.5	5.6	5.6	5.2

* This viewpoint is maintained here as a reference, and includes equal values for all criteria. For the sake of simplicity, this table shows only four perspectives or viewpoints about development plans. The original paper includes 7 perspectives.

Source: Modified from Bodini and Giavelli 1992

Table A-5. Results of multicriteria analysis, by using the impact matrix of Table A-3 and the weights of Table A-4.

		Viewpoints			
		Primary sector	Unemployed	Students	Neutral
Weighed concordance analysis	A	- 1.60	- 2.14	- 1.00	- 0.07
	B	- 0.44	- 0.61	- 0.07	0.50
	C	0.76	1.14	0.28	- 0.57
	D	1.38	1.61	0.78	0.14
Weighed discordance analysis	A	0.35	0.39	0.21	- 0.06
	B	0.20	0.25	0.21	0.08
	C	- 0.25	- 0.17	0.09	0.24
	D	- 0.31	- 0.48	- 0.52	- 0.26

Source: Modified from Bodini and Giavelli, 1992.

APPENDIX 2

Sources of Information regarding Evaluating Sustainability and Determining Indicators

Institution	Centro Internacional de Agricultura Tropical (CIAT), Colombia
Contact	Gilberto C. Gallopín, Manuel Winograd and Peter Jones
Fields of interest	Experts in sustainability indicators for production systems
Address	CIAT, A.A. 6713, Cali, Colombia
Telephone	(57-2) 445-0000 Colombia; (1) (415) 833-6625 Direct from USA
Fax	(57-2) 445-0273 Colombia; (1) (415) 833-6626 Direct from USA
Web page	www.ciat.cgiar.org

Institution	Centre for Land and Biological Resources Research (CEF), Canada
Contact	Julian Dumaski
Fields of interest	Framework for Evaluating Sustainable Land Management (FESLM)
Address	Research Branch, Room 108, Bldg. # 74. Central Experiment Farm. Ottawa, Ontario K1AOC6
Telephone	(613) 995-5011
Fax	(613) 996-0646
Web page	http://res.agr.ca/ecorc/program3/pub/indicat/overview.htm select FESLM

Institution	Programa de Agroecología, Facultad de Ciencias Agrarias y Forestales, Universidad de la Plata (UNLP), Argentina
Contact	Santiago J. Sarandón
Fields of interest	Indicators for sustainability evaluation in agricultural systems
Address	CC31, 1900, La Plata Argentina
Telephone	(57) 21 251896 / 44500 / 33658
Fax	(57) 21 252346

Institution	Department of Environmental Science, Policy and Management, University of California, Berkeley (UCB), United States
Contact	Miguel A. Altieri
Fields of interest	Sustainable Agriculture Networking and Extension (SANE)
Address	Department of Environmental Science, Policy and Management University of California 201 Wellman Hall # 3112 Berkeley, California 94720-3112, USA
Telephone	510-642-9402
Fax	510-642-7428
Web page	http://nature.berkeley.edu/~agroeco3

Institution	Centro Agronómico Tropical de Investigación y Enseñanza (CATIE), Costa Rica
Contact	Ronnie De Camino and Sabine Muller
Fields of interest	Agriculture and natural resource sustainability
Address	Código Postal 7170, Turrialba, Costa Rica
Telephone	(506) 556-1016 / 556–6431
Fax	(506) 556-0914 / 556–1533
Web page	www.catie.ac.cr/catie/

Institution	Grupo de Recursos Naturales, Centro Internacional de Mejoramiento de Maíz y Trigo (CIMMYT), Mexico
Contact	Larry Harrington
Fields of interest	Applications of sustainable agriculture
Address	Lisboa 27, Apartado Postal 6-641, 06600, Mexico City
Telephone	(595) 544 10
Fax	(5) 726 7558 / 7559

Institution	International Center for Living Aquatic Resources Managment (ICLARM), Philippines
Contact	Jens Peter Tang Dalsgaard and C. Lightfoot
Fields of interest	Model for determining the sustainability of productive systems
Address	MCPO Box 2631, 0718 Makati, Metro Manila, Philippines

Institution	World Resources Institute (WRI), United States
Contact	Lori Ann Thrupp
Fields of interest	New partnerships for sustainable agriculture
Address	1709 New York Avenue, N.W., Washington, D.C. 20006
Telephone	202 - 662–3499
Web page	www.wri.org

Institution	International Union for the Conservation of Nature (IUCN) / International Development and Research Centre (IDRC), Switzerland - Canada
Contact	International Assessment Team
Fields of interest	Tools and training: An approach for the evaluation of progress towards sustainability
Address	Rue Mauverney 28 CH – 1196 Gland, Switzerland
Web page	www.idrc.ca/nayudamma/progress_e.html

Institution	Hart Environmental Data
Contact	Maureen Hart
Fields of interest	Sustainability indicators
Web page	www.subjectmatters.com/indicators/

Institution	Instituto para la Cooperación en Agricultura y Medio Ambiente (ICOAMA) - Centro InterEclesial de Estudios Tecnológicos y Sociales (CIEETES), Nicaragua
Contact	Víctor Gonzálvez
Fields of interest	Methodology for the analysis and the comparison (conventional vs. organic) of agricultural and cattle-raising systems in Latin America
Address	Apartado Postal RP-082. Managua, Nicaragua
Telephone	(505) 267 30 33 / 267 30 34
Fax	(505) 267 10 10

Institution	International Federation of Movements of Organic Agriculture (IFOAM), Netherlands
Contact	Rob Witte
Fields of interest	Methodology for the analysis and the comparison (conventional vs. organic) of agricultural and cattle-raising systems in Latin America
Address	Van Kellstraat 19,6721,VT Bennekom, AGROECO P.O.Box 176, 3970.AD Driebergen, Netherlands
Telephone	(31) 318 418 236 / 343 536 100
Fax	(31) 343 531 700

Institution	University of Guelph, Canada
Contact	Farming Systems Research Team
Fields of interest	Obtaining and use of sustainability indicators
Web page	http://tdg.uoguelph.ca/www/FSR/collection/indicator/program.txt

Institution	Agriculture Man Ecology (AME), India
Contact	Dilip Chinnakonda
Fields of interest	FARMS data processor, that enables a rapid analysis of a farm’s management
Address	PO Box 7836, J.P. Nagar, Bangalore 560 078, India
Telephone	(80) 6642835 / 642303
Fax	(80) 6653471
E-mail address	Farms-1@etcnl.nl

Institution	Centre for Information on Low External Input and Sustainable Agriculture, Netherlands
Fields of interest	Low input sustainable agriculture
Address	PO Box 64, NL-3830 AB Leudsen, Netherlands
Telephone	(31) 33 4943086
Fax	(31) 33 4951779
E-mail address	Ileia@ileia.nl
Web page	http://www.bib.wau.nl/ILEIA

Institution	Grupo Interdisciplinario de Tecnología Rural Apropiada (GIRA A.C.), Mexico
Contact	Marta Astier, Santiago López and Omar Masera
Fields of interest	Indicator-based Framework for Evaluating the Sustainability of Natural Resource Management Systems (MESMIS)
Address	A.P.158, 61609, Pátzcuaro, Michoacán, Mexico
Telephone / Fax	(434) 232 16
Web page	http://www.laneta.apc.org/rock/mexico/proyecs/proycola.htm select MESMIS
	http://www.laneta.apc.org/rock/ select “Gestión de Recursos Naturales”
	http://www.oikos.unam.mx/gira

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