Environment, Development and Sustainability (2005) 7:51–69
DOI 10.1007/s10668-003-6976-x

MULTISCALE METHODOLOGICAL FRAMEWORK TO DERIVE CRITERIA AND INDICATORS FOR SUSTAINABILITY EVALUATION OF PEASANT NATURAL RESOURCE MANAGEMENT SYSTEMS*

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(Received 10 April 2003; accepted 17 November 2003)

Abstract. Design and implementation of more sustainable natural resource management systems is the current objective of many research institutions, development agencies, NGOs and other stakeholders. But, how to assess whether a system is sustainable? How do we know whether the alternatives designed will increase the sustainability of the system? How to evaluate or assess the sustainability of natural resource management systems?

In this paper we present a multiscale methodological framework for sustainability evaluation. The framework is based on a systems approach from which five general attributes of sustainable natural resource management systems are defined based on scale- and discipline-independent properties (productivity, stability, resilience, reliability and adaptability).

A general operational strategy to derive 'site-specific' criteria and indicators for the attributes at different scales is also presented. This strategy is based on the definition of 'impact scales', at which the different stakeholders can or want to design alternatives, as well as the main stakeholders' objectives and constraints. The application of the multiscale framework is illustrated with a case study in the Purhepecha Region of Michoacán, a peasant mountainous region in the west of Mexico. We used stakeholder consultation to identify the main objectives and constraints as well as to select criteria and indicators. The sets of criteria and indicators suggested for the different scales of analysis of the Purhepecha Region are comprehensive, yet not exhaustive, and represent the main issues related to natural resource management in the region. Further work will be directed towards the quantification of indicators at different scales and their relationships and trade-offs.

Key words: adaptability, attributes, Mexico, peasant agriculture, productivity, resilience, stability.

1. Two decades of sustainability evaluation

Since the publication of the Brundtland report (WCED, 1987), almost all disciplines and sectors have adopted and adapted the concepts of sustainability and sustainable development. In that process, sustainability, has become one of

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the vaguest paradigms of contemporary society and adoption of an unequivocal, generally accepted conceptual definition seems impossible (Bosshard, 2000). In practice, development agencies, research institutions and NGOs have included sustainability in their missions and agendas, and the design of alternatives aimed at improving sustainability is a common priority goal. Therefore, parallel to the ongoing conceptual debate, there is a need for new methodological approaches or frameworks to transform the concept of sustainability into operational definitions and strategies that these designers can use in evaluating the impact of their actions on the system's sustainability.

Since the 1980s, we have witnessed a rapid increase in the number of economic, environmental and social criteria and indicators that have been identified to operationalise the concepts of sustainability and sustainable development. In relation to natural resource management, many efforts have been directed towards the definition of criteria and indicators for different scales of analysis and their characteristics (Torquebiau, 1989; Kuik and Verbrugen, 1991; Bakkes et al., 1994; Dumanski, 1994; Bockstaller et al., 1997; Masera et al., 1999; Morse et al., 2000). An indicator is considered within this project, as a qualitative or quantitative measure that reflects a criterion. A criterion is defined here, literally from the dictionary, as a standard on which a judgement or decision may be based.

Some attempts to operationalise the concept of sustainability have resulted in core sets (templates or checklists) of multidisciplinary criteria and indicators to assess the sustainability of Natural Resource Management Systems (NRMS) (CIFOR, 1999; van Mansvelt and van der Lubbe, 1999). However, one fixed set of indicators for each and every NRMS is inappropriate, as every system is unique, and specific criteria and indicators may or may not be relevant for all cases (e.g. the indicators used to evaluate a farming system or a region in the humid tropics will necessarily be different from those used in the dryland areas of the sub-tropics). Moreover, presentation of a set of indicators without clear strategies to integrate their information produces a fragmented and, as a consequence, sometimes erroneous, understanding of the systems under analysis.

Composite indices have been developed to aggregate the information from a fixed set of indicators into a single value (e.g. Farmer Sustainability Index (Taylor et al., 1993), Indicator of Sustainable Agricultural Practice (Rigby et al., 2001), Agricultural Sustainability Index (Nambiar et al., 2001)). Such composite indices, however, may add to the problem rather than solving it, as the risk exists that in defining composite indices, controversies will come to the fore with respect to the weight to be attached to each indicator. Moreover, the single numerical value, resulting from their application in the evaluation of systems, generally offers little or no explicit insights in their functioning, as a basis for design of alternatives.

It appears that little effort has been directed towards the development of methodological frameworks to support the selection of appropriate (site-specific) criteria and indicators and the integration and transformation of the information, to

set the basis for the design of more sustainable alternatives (Smith and Dumanski, 1994; IUCN-IDRC, 1995). In addition to offering basic guidelines for selection and integration of indicators at one scale, new methodological frameworks have to be designed that allow the articulation of different scales of analysis in the evaluation. In relation to NRMS, there is a need to make explicit the effects of specific *management practices* implemented at scale level and *policies* imposed on a region or nation on the sustainability of the NRMS at multiple scales. Only by understanding the relationships among different scales will it be possible to formulate, on the one hand, management alternatives and, on the other, development policies that enhance the overall sustainability of the NRMS.

At low hierarchical levels, such as the field, the farm or the household, the main objective of evaluations has been to assess the feasibility and impact of alternative management practices, with the aim to identify specific strategies enhancing the sustainability of the NRMS (e.g. Rossing et al., 1997; Masera et al., 1999; Andreoli and Tellarini, 2000). At this scale, markets and policies have been always considered exogenous to the systems (Hengsdijk and Kruseman, 1993; Kruseman et al., 1993). At higher hierarchical levels of analysis, such as the regional or supraregional levels, evaluations commonly aim at assessing the impact of policies or development programmes. This is commonly done by exploring their technical and socio-economic possibilities and feasibilities, with the aim to identify technological innovations and/or policy measures that would enhance sustainability (e.g. Gérard et al., 1995; van Ittersum et al., 1998; Schipper et al., 2000; Barbier, 2001; Deybe, 2001).

In this paper we present a novel multiscale methodological framework for sustainability evaluation (Section 3). The framework employs a systems approach that results in the identification of five basic attributes of sustainable systems based on scale- and discipline-independent properties of NRMS (Section 2). The framework aims at building a multistakeholder and objective-driven platform, in which the objectives and constraints of the stakeholders are coupled to the attributes in order to arrive at useful sets of criteria and specific indicators, meaningful to the stakeholders at different scales.

The framework was specifically developed for the evaluation of peasant NRMS. Peasantry systems are the primary source of staple food in developing countries, and it is estimated that 1.5 billion people earn a livelihood from such activities (Chambers, 1994; Rosset, 2001). Moreover, peasant NRMS or small holdings are generally conceived as complex systems, because of the close interactions among the different activities related to natural resource management and the impact of those activities on achieving a multitude of economic, environmental and social objectives (Collison, 1983; Reijntjes et al., 1992; Brookfield, 2001). To develop alternatives aiming at more sustainable peasant NRMS, new evaluation strategies have to be developed to increase understanding of the complexity of the systems and to set guidelines for designing alternatives at different scales.

The general operational framework to derive criteria and indicators is illustrated with a case study for the Purhepecha Region of Michoacán, a peasant mountainous region in the west of Mexico. Different sets of criteria and possible indicators were derived for different scales of analysis, i.e. for farm, community, municipality and (sub)regional scale.

2. The conceptual approach to sustainable systems

In deriving criteria and indicators for sustainability evaluation at different scales, a systems approach is followed. A system is considered here as a limited, self-organised, part of reality in which a set of elements interact. The system has well-defined boundaries through which it interacts with its environment and with co-existing systems. Systems theory holds that the behaviour of systems at a specific hierarchical level can only be understood by studying the behaviour of its sub-systems and the relationships among them, and that all systems can be characterised by a set of attributes regardless of their hierarchical level (Conway, 1994; Odum, 1994).

In sustainability evaluation, beyond identifying the disciplines that should be included in the analysis (e.g. economic, social, ecological), several efforts have been made to identify, on theoretical grounds, the basic properties, underlying principles, pillars or attributes of sustainable systems. Identification of such basic attributes of sustainable NRMS that apply across scales and disciplines would be an important starting point in the derivation of criteria and indicators for sustainability evaluation at multiple scales. Table I shows such basic attributes proposed by different authors in the last decade.

Some of the attributes in Table I have a disciplinary bias. For example, Smith and Dumanski (1994) refer to *social* security, *ecological* protection, *economic* viability and *cultural* acceptability. Mitchel et al. (1995) also introduces a disciplinary bias in the set of attributes, i.e. futurity defined as inter-generational equity, social equity as intra-generational equity and ecological integrity as protection of the environment. Other attributes such as empowerment (ICSA, 1996), equit(abilit)y (Conway, 1994; Kessler, 1997; Masera et al., 1999) and acceptability (Smith and Dumanski, 1994; Capillon and Genieve, 2000) have explicitly been included in attempts to integrate the social dimension in the analysis, rather than as basic attributes of sustainable systems which are independent of the disciplinary approach.

Apart from these exceptions, most of the attributes in Table I (such as productivity, effectiveness, reproducibility, existence, stability, flexibility, resilience and adaptability) are truly basic attributes of systems, irrespective of the scale of analysis or the disciplinary approach. The ability of a NRMS to provide the desired combination of goods and services to satisfy the objectives of society will depend on the degree to which each attribute is realised. For example, both, the productivity and the stability of a field, a farm, a region, a country or a continent are definite

TABLE I. Attributes proposed in literature for evaluation of sustainability.

Attributes	Conway (1994)	Smith and Dumanski (1994)	Mitchel et al. (1995)	ICSA (1996)	Kessler (1997)	Masera et al. (1999)	Capillon and Genevieve (2000)	Bossel (2000)
Productivity	X	X			X	X	X	
Stability	X			X	X	X		
Equity	X				X	X		
Adaptability				X		X		X
Resilience				X		X	X	
Security		X						X
Self-reliance				X		X		
Acceptability		X					X	
Sustainability	X							
Protection		X						
Viability		X						
Futurity			X					
Social equity			X					
Ecological integrity			X					
Flexibility				X				
Vigour				X				
Responsiveness to change				X				
Empowerment				X				
Diversity					X			
Autonomy					X			
Health					X			
Security					X			
Optionality					X			
Efficiency					X			
Reliability						X		
Reproducibility							X	
Effectiveness								X
Existence								X
Freedom of action								X
Co-existence								X

characteristics of its sustainability. Similarly, the stability as well as the resilience of a system can be analysed from any disciplinary perspective; in other words, the environmental, economic, social and/or political stability of a NRMS at any scale of analysis is a basic attribute that (co)-determines its sustainability.

The attributes used to characterise sustainability can be grouped into two main categories: (a) those referring to the functioning of the system in a specific environment, independently of the changes in its internal functioning and its interactions with the environment and with other co-existing systems and (b) those referring to the continued functioning of the system when facing changes in its internal functioning, in its environment or in other co-existing systems.

For the framework presented here, we suggest a set of five attributes of sustainable systems, two referring to the functioning of the system itself – *productivity* and *stability* – and three related to the behaviour of the system in the face of changes in its internal functioning and in its environment – *reliability, resilience* and *adaptability*.

2.1. PRODUCTIVITY AND STABILITY

The capability of a system to produce a specific combination of outputs and its capability to reproduce those processes needed to attain such productivity are referred to as *productivity* and *stability*, respectively. For any NRMS, these combined attributes represent its internal capacity to maintain a stable equilibrium or, in other words, to produce as effective and efficient as possible, a specific combination of goods and services without degrading its resource base.

The *productivity* of a system has always been included in sustainability evaluation and it appears explicitly in 5 out of 8 references in Table I. In fact, before the word sustainability was introduced, the productivity of a system (its efficacy or efficiency) was the main characteristic evaluated when designing alternatives for NRMS. In the context of this framework, the productivity of a system can be understood as its capacity to produce the specific combination of goods and services necessary to realise the objectives and goals of the stakeholders involved. The productivity of a system may be defined differently at different scales of analysis or from different disciplinary perspectives. However, for any combination of scale and disciplinary perspective it can be concretely defined and measured.

Since the 1970s the term *stability* has been adopted from ecology (e.g. prey–predator), to NRMSs for instance applied to grazing systems (Noy-Meir, 1975). The stability of a system can be interpreted as the presence and effectiveness of negative feedback processes to control the internal positive loops leading to its self-deterioration at a specific level of productivity.

In the context of this framework, the stability of a system refers directly to the conservation of the resource base, such as natural resources, human resources and economic resources. The system must be able to produce the desired goods and services without degrading the existing resources, implying that the actual functioning of the system should not lead to its deterioration or compromise its own functioning. A concrete example, related to NRMS, is that of an agricultural system that, in order to attain a certain level of productivity, resorts to depletion of the soil nutrient store, leading to a reduction in the capabilities of the soil to maintain such productivity. In forest management, the stability of the system can be expressed in terms of the rates of wood extraction and production. Degradation of the resource base can take the form of depletion, but also the form of accumulation and/or pollution of the resources needed for the production of the required combination of goods and services.

The term stability has also been used as the capability of a system to withstand normal variations in its environment (Conway, 1994; Kessler, 1997). However, that feature of a system will be dealt within the second group of attributes below.

2.2. RESILIENCE, RELIABILITY AND ADAPTABILITY

A second group of attributes of sustainable systems is suggested to represent the capabilities of the system to remain at, to return to or to find new states of equilibrium. Most efforts to evaluate sustainability have included, through different attributes, such issues. In an attempt to organise the discussion and set the basis for derivation of criteria and indicators for sustainability evaluation within this framework, three main attributes of sustainable systems are suggested: *resilience*, *reliability* and *adaptability* (Figure 1). This triad of attributes is intended to represent the capability of the system to deal with perturbations in its own functioning and in its interactions with the environment and co-existing systems.

Currently, the conceptual debate on *resilience* is as controversial as that on sustainability (Perrings, 1998). The concept has always been attached to the capabilities of the system to remain at and/or return to stable states of equilibrium after facing 'disturbances'. However, since its origins in the field of ecology, different definitions have been proposed and discrepancies seem everlasting (Holling, 1973; Pimm, 1984; Lele, 1998). In NRMS, some measures of resilience have always

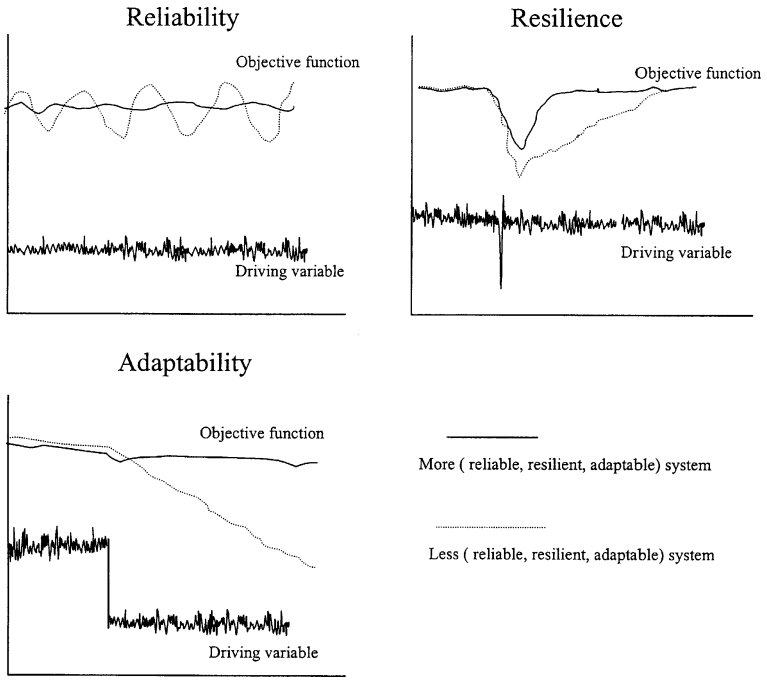

Figure 1. The resilience, reliability and adaptability attributes of sustainable systems.

included, among others, the capability of the system to (a) stand 'shock' or 'stress' and (b) to rapidly return to a stable state of equilibrium. In this framework, in order to derive criteria and indicators, resilience is defined as the degree to and rate at which a system, after 'shock' or 'stress', is able to again produce the necessary goods and services that realise the objectives of the stakeholders.

The capability of the system to remain close to stable states of equilibrium when facing 'normal' perturbations has been acknowledged as a basic attribute of a sustainable system and it has been identified by different names, including stability and resilience. In this framework, this attribute is referred to as *reliability*. The reliability of a system is expressed here as the capacity of the system to maintain its productive and stable state of equilibrium when facing 'normal' variations whether these occur in its own functioning, in its environment or in co-existing systems. In order to derive criteria and indicators for sustainability evaluation, the reliability of a NRMS is defined as its capability to produce, within a confidence range, the specific combination of goods and services necessary to realise the objectives and goals of stakeholders under 'normal' variable conditions.

The *adaptability* of a system is also a common attribute in literature on sustainability evaluation, sometimes called optionality (Kessler, 1997) or flexibility (ICSA, 1996). The capability of a system to adapt its functioning to a new set of conditions, thus finding new states of stable equilibrium, is an indispensable feature of a sustainable system. In the current framework, adaptability is defined as the capability of the system to continue producing goods and services when facing 'long-term' or 'permanent' changes in its internal functioning, its environment and/or its interaction with co-existing systems.

2.3. An operational definition of the concept of sustainable systems

The set of five attributes described in the preceding sections is proposed in this framework as basic attributes of sustainable systems. Operationally, in order to derive indicators for sustainability evaluation, the degree to which a system is sustainable will depend on its capabilities to produce, in a state of stable equilibrium, a specific combination of goods and services that satisfies a set of goals (the system is productive), without degrading its resource base (the system is stable) even when facing 'normal' (the systems is reliable), 'extreme' and 'abrupt' (the system is resilient) or 'permanent' (the system is adaptable) variations in its own functioning, its environment or co-existing systems.

3. Deriving indicators for multiscale sustainability evaluation. The case study of the Purhepecha Region of Michoacán, Mexico

The strategy to derive criteria and indicators from the attributes is part of a general framework for multiscale sustainability evaluation. The general methodological

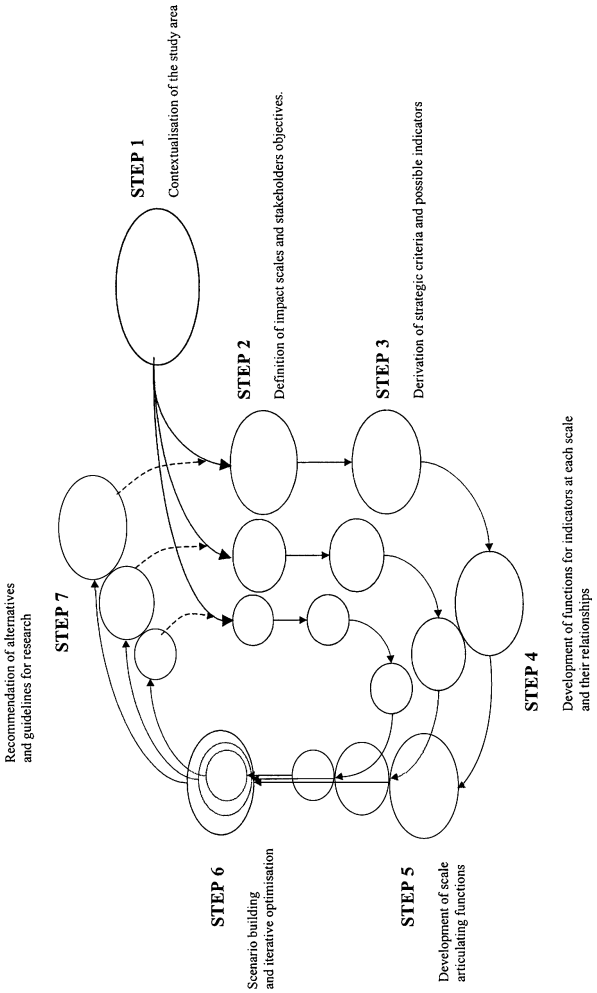

Figure 2. The cyclic structure of the multiscale sustainability evaluation framework.

framework is mainly based on the experiences gained in the MESMIS framework (Masera et al., 1999; Lopez-Ridaura et al., 2002) and on the framework for quantitative land use analysis (van Ittersum et al., 1998, 2004). Operationally, the general framework has a cyclic structure (Figure 2). The result from the evaluation process (Step 7) is intended to serve as the basis for the design and implementation of alternatives aiming at greater sustainability, taking into account the objectives of stakeholders at different scales. The cyclic structure of the framework allows a periodic 'update' of such objectives.

The evaluation cycle can be divided into two phases, a systems analysis phase and a systems synthesis phase. In the systems analysis phase, comprising the first 3 steps of the cycle in Figure 2, sets of criteria and specific indicators for the different scales of analysis are derived. In the systems synthesis phase, the results from assessment of the indicators are analysed, comparing different alternatives through scenario analyses. In this paper, only the system analysis phase is described and applied to a case study in order to focus on the theoretical soundness of the approach to derive criteria and indicators.

In this section, a brief description is given of the main objectives for each of the first 3 steps (systems analysis phase) of the methodology. Moreover, general methodological tools used in the case study to realise those objectives are presented.

3.1. CONTEXTUALISATION OF THE STUDY AREA

The main objective of this first step is to set the context of NRMS in the study area, as a basis for delineation of the boundaries of the largest scale of analysis in the evaluation and identification of common characteristics.

For Purhepecha Region, various documents are available, containing suggestions and plans for development, each comprising different overlapping subregions, whether defined in biophysical or administrative terms (Toledo et al., 1992; Garibay et al., 1998; Herrera et al., 1999). An extensive literature review was carried out to identify and understand the main geographical, historical, biophysical, economic and political issues related to NRMS and, in consultation with stakeholders, a region was delineated that covered most of the development plans related to natural resources management.

Purhepecha Region is situated in the mountains of the western state of Michoacán in Mexico, with an area of ~654 000 ha and a population of c. 670 000, distributed over 935 communities. Purhepecha is the name of the dominant ethnic group in the region, where over 3000 year old maize pollen has been found. Figure 3 shows the location of the region and Table II summarises some of the most important characteristics of Purhepecha Region in relation to natural resource management.

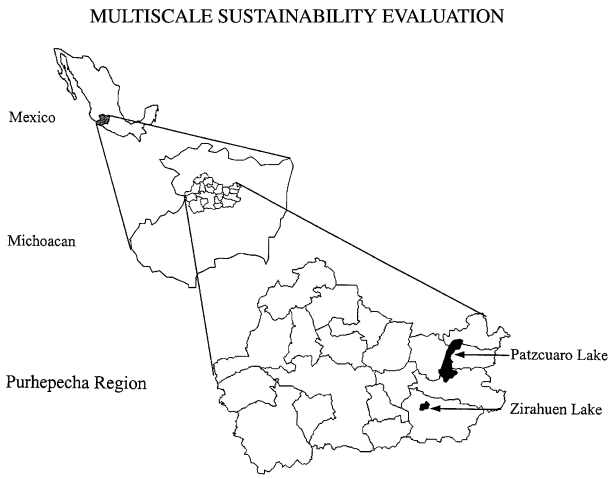

Figure 3. The Purhepecha Region of Michoacán, Mexico.

3.2. DEFINING IMPACT SCALES WITH STAKEHOLDERS

The main objective of this phase of the evaluation is to define, in consultation with the stakeholders, the relevant scales of evaluation and identify their main objectives. Involving stakeholders is a prerequisite to arrive at a meaningful set of criteria and indicators for evaluating sustainability at different scales. The success of a methodological framework aiming at supporting the design and evaluation of alternatives towards sustainability is critically dependent on such involvement.

Different scientific disciplines have created their own integration scale (hierarchy) for systems analysis (Fresco and Kroonenberg, 1992). Biophysical sciences have used physical or biological boundaries to define the scales of analysis, from the organ, to the plant, the crop, the field, the farm, the watershed, to the region or larger. Socio-economic sciences have used other entities to define different hierarchical scales, for example from the individual, to the family, the community, the ethnic group or the province. When dealing with NRMS, where biophysical and socio-economic analyses must be carried out integrally, the management element can offer a starting point for defining the scales of analysis (van Noordwijk et al., 2001).

In the framework presented in this paper, the notion of *impact scale* is introduced. The impact scales of analysis for sustainability evaluation are related to the stakeholders that co-exist in the study area, their perceptions of the system and their objectives. The scale at which a change or an alternative can be designed or is desired varies among stakeholders. For instance, a governmental institution commonly sets the scale of analysis at the administrative entity or a group of entities, depending on the boundaries of their mandate. The individual peasant often sets the boundaries of his/her system so as to coincide with the farm boundaries.

TABLE II. General characteristics of Purhepecha Region in Michoacán, Mexico.

Localisation	Western Mexico. 19.1–20°N, −101.4 to −102.6°W
Total surface	6540 km^2
Population	Total population 2000: 725 000 Average annual population growth (1990–2000): 1.53% Population in primary activities: c. 30%
Geology and soils	Young soils from volcanic ash, and alluvial soils in the lake regions: Andosols 64% Luvisols 9% Litosols 9%
Topography and climate	Rough topography with many volcanoes, average altitude 2100 masl, ranging from 1800 to 3860 Temperate sub-humid climate with annual rainfall between 800 and 1100 mm, and more than 70% concentrated in summer. Mean annual temperature between 11°C and 14°C but variable (21°C in semi-tropical areas and 9°C in semi-cold areas). Between 40 and 60 days of frost from October to February and about 4 days of hail in June or July
Land cover	Most important land covers: Forest (pine, oak, mixtures): c. 276 000 ha Agriculture: c. 274 000 ha Urban: c. 11 000 ha Lakes: c. 10 000 ha
Main activities related to NRM	Principal economic activities are agriculture (crop and animal production), forest management, fisheries, handcrafts (woodwork and pottery) Main crops and proportion of agricultural surface: maize 30%, fallow 30%, avocado 25%, sugarcane, peach, oats, wheat: 5%
Crop and animal production	Maize production important in the region, mainly for home consumption. Common 'año y vez" system, in which half of the arable land is left in fallow and the other half cropped. Most of the peasants keep a small herd for traction and as capital asset. The animals spend about 9 months grazing in the forest and during the 3 driest months of the year are in the agricultural fields feeding on the maize stubble or other forages
Forestry production	Forest exploitation is one of the most important economic activities. Wood is also used for household fuel-wood and handcraft
Political and social organisation	The region comprises 19 municipalities (the smallest political entity in Mexico) and, within each municipality, various communities commonly with social land tenure The region is part of three Districts of Rural Development from the Ministry of Agriculture which are in charge of the design and promotion of activities within the region, the distribution of subsidies and governmental aid Substantial NGO and academic presence in the region also involved in the design and dissemination of alternative NRMS

However, peasant representatives or authorities may also set the system boundaries at the community level. The farm level is a common scale of analysis also for NGOs and research institutions, but boundaries of the systems may also be set at regional, sub-regional or watershed level (independently of the political entities), on the basis of a shared characteristic or problem.

In Purhepecha Region, natural resources are mainly managed by peasants, ∼80% of the agricultural land is under peasant management, while 90% of the forests is in social land tenure of peasant communities. Most peasants live under social ownership (*ejido* or *comunidad indigena*), and the assembly of peasants takes the most important decisions in relation to natural resources. The region is characterised by intensive activities of NGOs related to natural resources and organisational issues. Research institutes from the Ministry of Agriculture (SAGARPA) and the Ministry of Environment and Natural Resources (SEMARNAT) and local Universities (UNAM, UMSNH) are also present in the area. Together with NGOs, many researchers from those institutions are active in the region studying the dynamics of natural resources management at various scales and designing alternatives.

Politically, the region comprises 19 municipalities. Although most of the information and statistics is aggregated to this political unit, the smallest government office for rural development from SAGARPA is the Rural Development District (DDR). Three DDRs are in charge of the Purhepecha Region: Pátzcuaro, Uruapan and Zamora. Pátzcuaro DDR covers the five eastern municipalities of the region (Figure 3), forming a 'mega-watershed' with two important lakes (Lake Pátzcuaro and Lake Zirahuén). This sub-region has captured attention because of the degradation of the lakes, especially Pátzcuaro, through a combination of desiccation, pollution from urban waste, eutrophication and sedimentation. Therefore, this sub-region has been designated a 'Special Region of Attention' by SEMARNAT.

The remaining 14 municipalities in the west of the region comprise the Uruapan and Zamora DDRs. This sub-region is characterised by a high and cold plateau in the north, with small volcanoes, and a transitional zone towards lower and warmer areas at the foot of the Tancitaro peak in the south. In the transitional zone, a wide range of plantations is managed, such as peach, sugarcane and banana. However, avocado has become the most important cash crop in the region, expanding from 3300 ha in 1969 to over 35 000 in 1999 (INI, 1998; SAGARPA, 2001).

In order to define the scales of analysis in Purhepecha Region, we interviewed 21 stakeholders between April and July 2002. All interviewed stakeholders were experts in NRMS in the study area, i.e. peasants, peasant representatives, development officials, NGO workers and researchers. In the interviews the general structure of the methodological framework was presented and discussed. The discussions with the stakeholders focussed on the definition of their *impact scales* and their main objectives and constraints at different scales.

The different stakeholders in Purhepecha Region and their possible impact scales at which they are able to trigger a change, whether through the design, dissemination, adoption or implementation of alternative NRMS are shown in Table III. Table IV shows some of the main objectives identified by the different stakeholders in the region at farm household, community and (sub)regional scales.

TABLE III. Main stakeholders in Purhepecha region of Michoacán and their impact scales.

Stakeholder	Impact scale				
	Farm household	Community	Municipality	Sub-region	Region
Peasant family	•	*			
Peasant assembly	*	•			
SAGARPA[1]	•	*	•	•	*
SEMARNAT[2]		•	*	•	•
NGOs	•	•	*	•	•
Research institutes	•	•	*	•	•

• Major impact.
*Minor impact.
[1]Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación.
[2]Secretaría de Medio Ambiente y Recursos Naturales.

TABLE IV. Main objectives of stakeholders at different scales in relation to NRMS in Purhepecha Region of Michoacán, Mexico.

Farm household scale	Community scale	Regional scale
Increase productivity	Increase productivity	Increase productivity
Reduce labour demand	Secure food self-sufficiency	Increase income generated by NRMS
Increase monetary income	Reduce risk of crop loss	Secure regional food self-sufficiency
Secure food self-sufficiency	Increase communal decision making in NRMS	Reduce soil loss
Reduce soil and nutrient loss	Increase communal control and management of NRMS	Reduce groundwater pollution and lake degradation
Reduce risk of crop loss	Reduce soil loss	Reduce deforestation
Reduce monetary investment costs	Reduce water pollution	Increase communal control and management of NRMS
Increase diversity of activities		Reduce risk of crop loss

3.3. DERIVATION OF CRITERIA AND INDICATORS

The main objective of this last step of the systems analysis phase is to define a set of criteria and specific indicators for each of the scales included in the analysis, that should represent (a) the main objectives of the stakeholders at different scales and (b) the basic attributes of sustainable systems (Section 2). Hence, the objectives identified by the different stakeholders at different scales were combined with the attributes of sustainable systems. When the objective was recognised as related to the efficiency or efficacy of the natural resource management, or conservation of the resource base, it was classified in the first group of attributes (productivity and stability). When it was related to the capability of the systems to deal with perturbations or to reduce risk, it was classified in the second group of attributes (resilience, reliability and adaptability). A list of possible criteria associated with the different attributes was developed. Each objective was translated into several possible criteria, while additional criteria were included for attributes not well represented in the objectives of stakeholders.

TABLE V. Selected criteria and indicators for the evaluation of sustainability at the farm scale in Purhepecha Region of Michoacán, Mexico.

Attribute	Criterion	Possible indicators
Productivity	Farm production	Yield (kg/ha)
Stability		Yield gap (kg/ha)
	Farm profitability	Benefit/cost ratio (−)
		Income ($)
	Food self-sufficiency	Maize production/maize consumption (−)
	Returns to labour	Income generated per unit labour ($/hr)
		Food produced per unit labour (kg/hr)
	Independence from	External inputs/total inputs (−)
	external inputs	Forage self-sufficiency (−)
		Period of forage deficiency (months)
	Soil degradation	Organic matter incorporated into the soil (kg)
		Nutrient balances (kg/ha)
		Nitrogen fixed by leguminous species (kg)
Resilience	Off farm income	On farm income/total family income (−)
Reliability		Added value of production by household
Adaptability		transformation ($)
	Risk of crop loss	Minimum yield in driest years (kg/ha)
		Frost probability after sowing
	Time to recover from	Time to recover from catastrophic events (crop loss,
	production loss	forest fire, animal death or robbery) (years)
	Yield variability due to	Yield variation with temperature variation (kg/°C)
	weather variability	Yield variation with rainfall variation (kg/mm)
	Number of activities in	Yield Std Dev (kg/ha)
	NRMS (#)	
	Diversity of activities	
		Income generation per activity ($)
	Initial investments	Costs of investment ($)

In a second round of interviews (15 stakeholders between December 2002 and January 2003), specific methodological issues related to the attributes of sustainable systems, the use of criteria and indicators, and the possible ways to quantify them were discussed. In this round, discussions were centred around a series of tables containing the main objectives identified, the attributes, the scales of analysis and a long list of suggested criteria and indicators for the different scales of analysis.

The various criteria were discussed with, and scored by the stakeholders in terms of their relevance, in combination with a general discussion on the possible indicators and their relationship with the attributes and criteria. On the basis of the discussions with stakeholders and their scores for the criteria suggested, sets of criteria were defined for the different scales of analysis and indicators were identified for each criterion. Table V and VI present the set of criteria chosen and different indicators proposed to evaluate the sustainability of NRMS at the local farm scales and the regional scale in the Purhepecha Region of Michoacán.

TABLE VI. Selected criteria and indicators for the evaluation of sustainability at regional scale in Purhepecha Region of Michoacán, Mexico.

Attribute	Criterion	Possible indicators
Productivity Stability	Regional productivity	Total production (Mg) Value of the production (M$)
	Food self-sufficiency	Maize production/population in primary activities (−) Maize production/total regional population (−)
	Land degradation	Area of soil eroded (ha) Net deforestation (ha) Animal exceeding carrying capacity (#)
	Water contamination	Nitrogen lost by leaching (kg) Use of fertilisers (Mg) Biocides sprayed (kg a.i.)
Resilience Reliability Adaptability	Communal mechanisms of natural resources management control	Regulations for access to and management of resources Area under communal management (ha, %) Number of communal Societies of Rural Production (SPR) (#)
	Variability of production due to weather variability	Variation in value of production with temperature variation ($/°C) Variation in value of production with rainfall variation ($/mm) Std Dev of value of production (Mg)
	Non-harvested area (ha, %) Production risks	Value of production in driest years (M$) Value of production in coldest years (M$)
	Diversity of activities	Number of activities in NRMS (#) Income generated by different activities ($)

4. Final remarks and prospects

In this paper, we have presented the conceptual approach and the general operational strategy for deriving criteria and indicators to evaluate sustainability of NRMS at different scales.

The five attributes of sustainable systems proposed here are tightly intertwined and, although they can be helpful to derive criteria and indicators for different spatial scales of analysis, the inter-relation of such attributes is stronger at the temporal scales. What is 'normal', 'abrupt', 'extreme' or 'permanent'? It mainly depends in the temporal scale considered. What can be perceived as an abrupt change within a period of analysis of 10 years, could as well be considered as a normal variation in a wider temporal scale of analysis (e.g. 100 years, cf. Fresco and Kroonenberg, 1992). The complexity of peasant NRMS and the complexity of the concept of sustainability would never allow the clear-cut definition of basic properties of sustainable systems. Yet, proposing, discussing and making explicit such attributes and their relationships, as well as developing strategies to operationalise them, is in our view the role of scientist in the public debate on sustainability and sustainable development.

The sets of criteria and indicators suggested for the different scales of analysis for Purhepecha Region are considered comprehensive, though not exhaustive, embracing the main issues related to natural resource management in the region. Specific indicators and the way they are quantified will vary among stakeholders, depending among others on their institutional context and the economic, time and information resources available. However, the framework presented here, allowed identification of criteria for the development of indicators. Evaluating different alternatives to natural resource management in Purhepecha Region will be improved by expressing the impact of such alternatives in terms of the criteria and indicators suggested for the different scales.

Involvement of stakeholders in the evaluation process is a critical aspect for developing the methodological framework and its success. The definition of *impact scales*, the use of objectives for deriving criteria, and their discussion with stakeholders, are central aspects of this multiscale sustainability evaluation framework. Through such interaction with stakeholders, the framework has evolved into its present form.

The framework presented in this paper is part of an ongoing project aiming at the development of a general framework for multiscale sustainability evaluation with emphasis on peasant agriculture. At present, methodological tools to quantify the indicators, integrate their results, analyse trade-offs and evaluate scenarios are being developed. In order to strengthen the theoretical and practical approaches proposed in this framework, it is desirable to apply it to other peasantry regions with different socio-environmental conditions. This will confer major theoretical robustness and operational flexibility of the framework in order to adapt to different conditions.

Acknowledgements

This paper is part of the first author's PhD project fully financed by a scholarship-loan (No. 153928) from the National Council for Science and Technology (Consejo Nacional de Ciencia y Tecnologia) (CONACYT), Mexico.

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