LAND QUALITY INDICATORS (LQI): MONITORING AND EVALUATION

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Summary

Indicators of land quality (LQIs) are being developed as a means to better coordinate actions on land related issues such as land degradation. Economic and social indicators are already in regular use to support decision-making at global, national and sub-national levels and in some cases for air and water quality, but few such indicators are available to assess, monitor and evaluate changes in the quality of land resources. Land refers not just to soil but to the combined resources of terrain, water, soil and biotic

resources that provide the basis for land use. Land quality refers to the condition of land relative to the requirements of land use, including agricultural production, forestry, conservation, and environmental management.

Indicators of land quality address the dual objectives of environmental monitoring as well as sector performance monitoring for managed ecosystems (agriculture, forestry, conservation and environmental management). The primary research issue in the LQI program is the development of indicators that identify and characterize the impact(s) of human interventions on the landscape for the major agro-ecological zones of tropical, sub-tropical and temperate environments. Core LQIs are identified for development, and examples are provided of LQIs already developed.

1. Introduction

The impacts of human interventions on natural systems are increasingly critical issues for the future. Increasing population pressures and increasing demands for services from a fixed land base are threatening the quality and the natural regulating functions of the soil, water and air resources on which sustainability depends. For the first time in history, we are crossing the threshold of new lands available for cultivation. For the first time, the sustainable management of the land resource is more important than land supply for development.

However, land degradation and mismanagement are threatening our opportunities and flexibility for increased services from the land, requiring increased investment in soil conservation and even rehabilitation and reclamation. Oldeman and collaborators have estimated that about 40% of agricultural lands are affected by human induced land degradation. The land quality indicators (LQI) program is being developed to expand our knowledge and understanding on land management and degradation problems in managed ecosystems, and to provide guidance to decision makers on these issues. It is important to know if current land management is leading towards or away from sustainability.

Sustainable land management and the choice of feasible and cost effective management options is hampered by the lack of available indicators for monitoring how land is being managed by farmers, the impacts of policies and programs on land management choices at the farm level, and the impacts of different management scenarios (cause-effect relationships) on land quality. There is clearly a major requirement at national and global levels for increased agricultural production and intensification, but the challenge is to achieve this while maintaining and enhancing the quality of the land resource on which production depends (World Bank, 1997a). This implies the need for standards, such as LQIs, on which to measure and assess progress towards these goals.

Indicators are common instruments for monitoring progress towards some larger objectives. For example, economic indicators, such as GDP, distribution of employment, etc., are used regularly to monitor performance of national and local economies. Similarly, access to social services, literacy rates, etc., are used for comparative assessments of social development. On the environmental side, indicators are available for monitoring and reporting on air and water quality (for which the World

Bank played major catalytic roles). However, indicators which can be used to monitor change in land quality are still not available, and because we cannot monitor land quality, we are not in a position to take appropriate action on land related issues such as land degradation.

Agriculture is traditionally viewed as an environmental problem, but if carefully managed, it can also be a significant part of the environmental solution. However, monitoring the impacts of agriculture on the environment is much more difficult than monitoring other sectors. Hundreds of millions of private farmers, large and small and male and female, are stewards of the globe’s land resources, and monitoring the impacts of their land use decisions is a major undertaking. Although the impact of any one individual is minuscule, the collective impacts of the millions of management decisions can have major regional and even global environmental impacts. For example, lack of soil cover results in erosion and siltation of reservoirs; loss of soil organic matter through land degradation contributes significantly to CO_2 emissions to the atmosphere; mismanagement of irrigated lands results in salinization and water logging. Currently, our procedures for monitoring the extent and impacts of these processes are rudimentary, and greatly hampered by the lack of appropriate indicators, the right kinds of data, and cost-effective monitoring methods.

In the context of LQIs, land quality is the condition of land relative to the requirements of land use, including agricultural production, forestry, conservation, and environmental management. Land is an area of the earth’s surface, including all elements of the physical and biological environment that influence land use. Land refers not only to soil, but also to landforms, climate, hydrology, vegetation and fauna, together with land improvements such as terraces and drainage works.

2. Requirements for Basic (Core) LQIs

Interest in environmental monitoring has spawned a virtual indicator development industry in the recent past. Very often such indicators have been developed by *a priori* identification of candidate indicators by a panel of experts, followed by assembling and analyzing whatever data are available to support this selection. The success of this approach has been mixed, since often the final indicator has to be molded to fit the data available, and to reflect experiences gained in developing the indicator. Consequently, there is a strong possibility of bias in development of the indicator(s), and the final product is often somewhat less than what was intended or desired at the outset.

The LQI program takes an alternative approach. Experience has shown that truly robust indicators are developed first of all through comprehensive analyses of the complex systems to be described and monitored. It is only through such thorough and comprehensive analyses that sufficient understanding of a system is developed to ensure indicators that are simple and useful enough to be used at national and international levels.

The program deals with the important questions of how to integrate socio-economic (land management) data with biophysical information in the definition and development of LQIs, and how to scale and aggregate indicators from local to regional, national and global scales. Equally important, the indicators have to be based on data that are either available or easily assembled, but still sufficiently reliable and robust to stand up under scientific scrutiny.

Land quality should be assessed for specific types of land use and management and for specific agro-ecological conditions (AEZs) in a country. Otherwise, trends and performance cannot be sensibly monitored, interpreted, and reported. This requires the development and application of spatially located and (normally) geo-referenced temporal data bases of the variables to be used to develop the LQIs. Such data bases are developed through spatial integration over time of the socio-economic and biophysical data for the different AEZs of a country. However, census data and other primary data for land management, and AEZ boundaries normally do not coincide, and except for very small countries, most countries are made of several AEZs. Therefore, procedures of spatial integration are necessary, but these must follow recognized protocols such as described for *Hierarchy Theory* (Dumanski et al., 1998). Also, some criteria of correspondence between the different data bases must be applied (e.g, the 70% spatial coverage rule is often used, whereby it is assumed that the local socio-economic and biophysical data are directly related if the spatial coverage of the two sources of data are 70 % or higher).

The steps are first of all to characterize the range of AEZ resources, identify the issues (problems) important in each AEZ, select LQIs relevant to the issues, characterize the land management practices used by farmers in each AEZ, develop the necessary data bases and GIS coverage, then conduct the research to develop, model, test and refine the LQIs (Pieri et al., 1995; World Bank, 1997b). This normally will result in a small, select group of LQIs that relate closely to the (normally limited) AEZs in a given country. When the LQIs are developed and interpreted, they can either be reported by the AEZs, or the results can be aggregated to sub-national and national levels by weighting the LQIs according to their contribution towards some national objectives, such as calculating national wealth, rural poverty reduction, achieving food security, etc.

The World Bank has been leading an international coalition to develop a program on land quality. *A* minimal number of recommended Core LQIs were identified using criteria and guidelines from earlier workshops (Dumanski, et al., 1994; OECD, SCOPE and other indicator initiatives). Emphasis was on making better use of available data and information, and integrating these with new information management technologies such as remote sensing, geographic information systems (GIS), relational data base management systems, the internet, etc.

The Core LQIs may be developed from direct measurement (remote sensing, census, etc), or estimations using well tested, scientifically sound procedures. Emphasis should be on analyses to identify driving force(s) of land use change and the impact(s) of the change. Interpretation of the LQIs should not be done in isolation, but within the context of what is happening with land management/land use in the countries in question. Recommended contextual information to assist in interpretation of the LQIs include social and institutional information (tenure, gender, educational levels, etc), farm household economics, climate, and land use as available from the census.

Characteristics of Core LQIs are:

- measurable in space, i.e. over the landscape and in all countries;
- reflect change over recognizable time periods (5 - 10 years);
- are a function of independent variables;
- are quantifiable and usually dimensionless (ratio estimates).

3. Core LQIs recommended for Short Term Development

3.1 Nutrient Balance and Depletion

This LQI describes nutrient stocks and flows as related to different land management systems in specific AEZs and specific countries. It is based on several years of research and experience in East Africa and Europe by Smaling and collaborators (1996).

The major research issue is nutrient cycling:

- Nutrient mining, nutrient imbalance and decreasing yields caused by removal of harvested products (grains and residue), erosion and leaching, primarily in developing countries with low rates of fertilizer use;
- Nutrient loading and environmental degradation (phosphorus, nitrates, etc.) caused by excess fertilizer and manure application in developed countries, but increasingly also in developing countries with high fertilizer subsidies such as China.

The research process is similar to environmental accounting. It involves establishment of nutrient balance sheets with losses and additions as estimated from nutrient removal through crop harvesting, erosion, etc., compared to nutrient additions due to fertilizers, organic inputs, recharging of the nutrient supply due to legume rotations, deep rooting systems, natural recharging due to atmospheric fixation, etc. Smaling and his team has demonstrated how this LQI can be developed for several hierarchical scales, including the farm level, region (AEZ) level, and national level.

Actual measurements of nutrient cycling are rarely available, but Smaling et al. (1996) have demonstrated that reliable estimates of nutrient balance can be developed using crop yield statistics from national census, nutrient additions from fertilizer trade statistics, and various biophysical models for denitrification, leaching, erosion, etc.

3.2. Yield Gap

Three closely related measures are proposed for this issue:

- Yield trends (direction, rate of change) for the major food crops in specific AEZs;
- Production risk (change in the expected annual variability in yield) for the major food crops in specific AEZs;
- Yield gap (current yields compared to potential farm level, economically feasible yields) for the major food crops in specific AEZs.

These are useful indicators because they are so easily understood, easily converted into economic terms, and they are useful for monitoring both project and program performance. However, they have value as LQIs only if changes in yield are clearly related to land management in specific AEZs and for specific management systems. There are many possible cause-effect relationships with yield, e.g. marketing, climate change, subsidies, land management, etc., and the indicator can be misleading without comprehensive analyses of the driving forces causing yield change. Knowledge of farming systems, marketing, the policy environment and other contextual information, as well as cause-effect relationships of current land management on yield trends and variability are necessary.

The key research issues are:

- To what extent are changes in land quality resulting in corresponding changes in crop yield and production risk?
- How can reliable estimates of yield gaps be developed for developing countries, and what are the management options to improve the yield gap?
- Are there practical biological and economic thresholds (yield and variability) to ensure sustainable production systems?

Yield gap analyses relate to residual yield opportunities that could be realized with improved cultivars, fertilization, and land management. Alternatively, it reflects the extent to which the biological production systems are currently being pushed, realizing that if pushed beyond a biological threshold, the systems will likely fail. Knowledge of this threshold is strategically important for policy, program and management planning in high production environments, since the margin for error decreases as the biological production threshold is approached. Concurrently, the impact of error at these production levels is likely to be significant.

Yield data are available from the FAOSTAT data base, as well as other sources, such as special surveys, safety net and farm subsidy programs, international marketing programs, etc. Alternately, crop growth models can be used to simulate long-term average yields and annual yield variability (to a lesser extent), providing that the models have been thoroughly tested and found to be reliable. Also, remote sensing data can be used to estimate level and variability of crop yields, or to provide agro-meteorological inputs for crop growth models.

A major concern is that national yield statistics are normally a ratio of national production divided by area harvested. Such estimates can be highly biased, since experience has shown that expansion of cultivation on marginal lands, for example, can depress “national average” yields at the same time that yields in more favorable areas are increasing due to increased fertilizer use, improved soil conservation, adoption of improved cultivars, etc. Ideally, yield data for the major food crops should be geographically referenced (disaggregated) on an AEZ basis, and then analyzed in relation to the agricultural production systems and land management practices being used by farmers.

3.3. Agricultural Land Use Intensity and Diversity

These two LQIs are intended to assess the general impacts of current land management at the farm level. Assessing land use intensity and land use diversity provides information on trends towards or away from sustainable land management.

Land use intensity is intended to estimate the impacts of agricultural intensification (and increased frequency of cultivation) on land quality. Normally, intensification involves increased cropping, shift towards more value-added production, and increased amounts and frequency of inputs. Such changes, without concurrent adjustments in land management practices, often result in nutrient mining, soil erosion and other forms of land degradation. However, agricultural intensification, if properly implemented, can also result in improved land quality, as shown in Kenya, Brazil, and other areas by El-Swaify et al. (1999). The difference is the specific management practices adopted by farmers during the transition towards intensification (often based on expected increased profits from the more intensive production systems).

Land use diversity (agro-diversity) is the degree of diversification of production systems over the landscape, including livestock and agro-forestry systems; it is the antithesis of mono-cropping. Agro-diversity is often practiced by farmers as part of their risk management strategy, i.e. to guard against crop failure and financial collapse but, as shown by English and collaborators in Kenya (1994), it is also a useful indicator of flexibility and resilience in regional farming systems, and their capacity to absorb shocks or respond to opportunities. Agro-diversity is assessed on the number, kind and complexity of components in the farming systems, but it can also be approximated from national statistics by the number and kinds of crops per growing season, the extent and frequency of rotations, presence or absence of livestock in the production systems, etc.

The key research issues are:

- Is current land management contributing to increased land degradation or improving land quality?
- Are current agricultural management practices contributing to improved global environmental management?

A major concern with these LQIs is that data on current land management practices are generally not available (except from special surveys), and various surrogates will have to be developed. Some of these are already available in the literature, such as land use intensity based on crops per growing season, extent and frequency of rotations; cultivation intensity, etc.; ratio of cultivated land to cultivable land; area and frequency of soil enhancing to soil depleting crops; ratio of mono-cropping to mixed cropping, etc. These are based on data available from the census and from agricultural and household surveys. Time series information on crop rotations, etc. can be generated from remote sensing.

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Bibliography

Dumanski, J. (Ed.) (2000). Indicators of land quality and sustainable land management. Special Issue. *Agriculture, Ecosystems and Environment*. 81(2). Elsevier. [This special issue is the state of the art publication on LQIs. Several examples are provided of LQIs already developed and in use].

Dumanski, J. (1994). *Proceedings of the International Workshop on Sustainable Land Management for the 21st Century*. Volume 1: Workshop Summary. The Organizing Committee. International Workshop for Sustainable Land Management. Agricultural Institute of Canada. Ottawa. [This report explores issues in sustainable land management, and provide the scientific basis for much of the subsequent work on LQIs].

Dumanski, J., Pettapiece, W.W. and McGregor, R.J. (1998*). Relevance of scale dependent approaches for integrating biophysical and socio-economic information and development of agroecological indicators*. Nutrient Cycling in Agroecosystems 50: 13-22. [This publication describes the use of Hierarchy Theory to link biophysical and socio-economic indicators at different scales].

El-Swaify, S.A., with an international group of contributors. (1999). *Sustaining the global farm – Strategic issues, principles, and approaches*. International Soil Conservation Organization (ISCO). Department of Agronomy and Soil Science, University of Hawaii, Honolulu, Hawaii, USA. [This publication describes the importance of good land management in promoting agricultural systems that are more sustainable than what we have to-day].

English, J., Tiffen, M. and Mortimer, M. (1994*). Land resource management in Machakos District, Kenya, 1930 – 1990.* World Bank Environment Paper No. 5. World Bank, Washington, D.C. [This publication is one of the first to identify that agricultural intensification can lead to and sustainable land management].

FAO (2000). *Land quality indicators and their use in sustainable agriculture and rural development*. Land and Water Bulletin, No. 5. FAO. Rome. [This is one of the early publications in the evolution of the LQI program. It provides useful background information on sources of data].

Ingram, J. and Gregory, P. (1996). *Effects of global change on soils*. *GCTE Activity 3.3: Implementation Plan*. GCTE Focus 3 Office. Wallingford, U.K. [This is a background document describing the research activities under the Global Change Technical Evaluation working group of the IGBP].

Oldeman, L.R., Hakkeling, R.T.A.and Sombroek, W.G. (1990). *World map of human-induced soil degradation.* ISRIC, Wageningen, The Netherlands, and UNEP, Nairobi. [This is the background report of the first global assessment of land degradation].

Pieri, C., Dumanski, J., Hamblin, A. and Young, A. (1995*). Land Quality Indicators.* World Bank Discussion Paper 315. World Bank: Washington, D.C. [This background report laid out the practical foundation for the LQI program].

Smaling, E.M.A., Fresco, L.O. and de Jager, A. (1996). *Classifying, monitoring and improving soil nutrient stocks and flows in African agriculture*. Ambio, 8: 492-496. [This report is the state of the art publication on nutrient balance].

Smith, N.J.H. (1996*). Effects of land-use systems on the use and conservation of biodiversity.* In: J.P.Srivastava, N.J.H.Smith, and D.A.Forno (Eds.). Biodiversity and Agricultural Intensification: Partners for Development and Conservation. Environmentally Sustainable Development Studies and Monographs Series No. 11, The World Bank, Washington, D.C. [This report explores issues in agrobiodiversity, and identifies some potential indicators].

Swift, M. (1997). *Below-ground biodiversity*. In: Alternatives to Slash and Burn. Report of the 6th Annual Review Meeting. Bogor, Indonesia. ICRAF, Nairobi, Kenya. [This report provides a practical and scientifically sound approach for identifying indicators of soil biodiversity].

World Bank. (1997a). *Rural Development. From Vision to Action*. ESSD Studies and Monographs Series No. 12. World Bank, Washington, D.C. [This publication provides a new vision for rural development activities in the World Bank. Along with economic and social performance, the report argues for more environmentally acceptable standards for agriculture].

World Bank. (1997b). *Expanding the Measure of Wealth. Indicators of Environmentally Sustainable Development.* ESSD Studies and Monographs Series No. 17. World Bank: Washington, D.C. [This report presents the argument and supporting documentation that environmental performance standards and indicators should receive equal recognition to economic and social performance in sustainable development].

Biographical Sketches

Julian Dumanski is a retired Senior Scientist from the Department of Agriculture and Agri-Food, Canada, and a retired long-term consultant from the World Bank. He received B.S.A. and M.Sc. degrees in Agriculture Science and Soil Science from the University of Saskatchewan, and a Ph.D. degree in Soil Science (Pedology) from the University of Alberta. Currently he is a Honorary Research Associate with Agriculture and Agri-Food Canada, while continuing as an advisor to the World Bank, the Global Environmental Facility, and other international agencies.

Dr. Dumanski has over 200 scientific and technical publications in the areas of land use research, land evaluation, local and global ecosystem management, environmental indicators, geographic information systems, and pedology. His research has included extensive travel in both temperate and tropical areas, and he has sat on advisory boards of several national and international research institutions. His major contributions include the development of the Sustainable Land Management paradigm, he was one of the senior authors for the global program on Land Quality Indicators, and he was a lead author for the first IPCC report on climate change. His current research activities include the impacts of agricultural land use on global environmental change, and the potentials of carbon sequestration (under the Kyoto Protocol) for mitigation of climate change.

Christian Pieri, a French citizen born in 1939, is Soil Scientist (Institut Agronomique, Paris, 1963), PhD from the University of Nancy, with extensive experience in tropical land management, integrating land productivity and soil conservation. Early 1966, he joined French Overseas scientific organization (Institut de Recherche Agronomique Tropicale, IRAT, and Centre International de Recherche Agronomique pour le Developpement, CIRAD), and has worked at field level as a scientist in more than fifty tropical countries, including Senegal, Mali, Cote d'Ivoire, Mexico, Brazil, Argentina, South China .
He has published more than forty papers in scientific journals focused on soil and nutrient management, soil organic matter balance and on soil conservation. He has published a book on Soil Fertility published in French and in English (A Future for Farming in African Savannas, Springer Verlag publisher,1989), which provides a synthesis of 40 year experience of the soil and land management works done in West Africa.

He joins the World Bank in 1992, where he was for about ten years team leader in activities related to sustainable crop and land resources management. During this period (1992-2001) he has initiated the program "Land Quality Indicators". Supporting Project activities in several Latin American and African countries, C. Pieri has been the key in promoting agroecological farming practices in tropical small farmers' conditions, and experience which is reported in a World Bank document entitled "No-Till Farming for Sustainable Rural Development" (2002).

Since his retirement from the World Bank, C. Pieri is working as international consultant with special emphasis of global impact of land management, particularly to enhance carbon sequestration in small holders' agriculture.

Christian Pieri is winner of the Gold Medal of Academie d' Agriculture (Paris, 1990), and received a special World Bank/ Environmentally and Socially Sustainable Development Vice Presidency for "his excellent contributions to the substantive work program of the land management team" (Ian Johnson, Vice-President, The World Bank, 2000).