TOWARDS A 'SYSTEMS' APPROACH FOR GUIDING AGRICULTURAL ENVIRONMENTAL MANAGEMENT: A SOUTH AFRICAN CASE STUDY OF A SMALL-SCALE MAIZE FARMING SYSTEM

Musvoto, Constansia
Haywood, Lorren and
Oyenike Adeyemo
CSIR - Natural Resources and the Environment,
PO Box 395
Pretoria 0001
Tel : 0128414856
Fax: 0128413659
Email: CMusvoto@csir.co.za

Trotter Douglas
CSIR Natural Resources and the Environment
PO Box 17001
Durban 4013

Matlou , Mmakgabo; ,
Mashabane, Kgoroshi and ,
Smith, Hendrik
ARC - Institute for Soil, Climate and Water
Private Bag X79
Pretoria 0001

ABSTRACT

Environmental management processes which aid integrative understanding of systems can facilitate holistic proactive approaches to development within environmental constraints. This paper describes a social-ecological system approach for identifying environmental management intervention points in an agricultural system, illustrated through a case study of a small-scale maize farming system in South Africa. A review of documented information on the ecological, socio-political and economic components of the system was followed by mapping and analysis of interactions within the system, which was validated through a stakeholder engagement process. The Driving Forces-Pressures-State-Impacts-Responses (DPSIR) framework was used to organise the information and to summarise relationships between components of the system. Two types of drivers: direct and indirect, influenced the state of the environment in the system. Indirect drivers influenced the system in a hierarchical manner, starting by affecting direct drivers at local level and exerting influence from different levels up to national level policies. This clarification of the relationships between state of the environment, direct drivers and indirect drivers could assist decision making by identifying possible points for intervention that are relevant to the function or level of responsibility of different decision makers. The proposed social-ecological system approach can provide a better understanding of the causes underlying the state of the environment and promote more proactive and integrated management decisions through an improved understanding of complex interactions.

INTRODUCTION

Agriculture dominates human use of land at the global scale and is one of the major human activities that alter the environment (FAO, 2002). Agriculture has major impacts on the environment, especially on land, water and biodiversity. In South Africa, concern has been expressed over the degradation of the agricultural environment (Mpumalanga DACE, 2003; DEAT, 2006). Historically, research and management actions to address environmental issues in the agriculture sector have tended to be reactive and focussed towards finding solutions to discrete problems at relatively small scales, often failing to fully consider the complex environmental, social, economic and political landscape in which the problems occur (Philip, Broome, Chornesky, Frankenberger, Johnson, Lipson *et al*., 2004).

Environmental management in the agriculture sector needs to be more proactive and integrative, considering both social and ecological dimensions. Agriculture is a complex social-ecological system in which a suite of factors operating at various scales affects practices and choices;

ultimately, these factors have an impact on the environment. As a human enterprise, agriculture is a fundamental social endeavour that is shaped by human values, social and economic policy, and market forces; thus the future adequacy and environmental impact of agriculture depends on how effectively both the social and ecological elements of agricultural ecosystems are understood and managed (Tilman, Cassman, Matson and Naylor, 2002).

Fully appreciating the interactions between agriculture and the environment requires a 'systems approach'. Ideally, such an approach should cover more than a single environmental sphere or theme and should integrate the full range of the complex interactions between agriculture, environment and social-economic conditions (Priorr, 2003; Philip, Broome, Chornesky, Frankenberger, Johnson, Lipson *et al.,* 2004). The social-ecological system approach is one of the approaches that could be used to address agriculture-environment issues. A social-ecological system has been defined as 'an ecological system intricately linked with and affected by one or more social systems' (Andries, Janssen and Ostrom, 2004).

This paper proposes a social-ecological system (SES) approach for analysing an agricultural system in order to better understand the various influencing factors and to identify potential points of intervention to address environmental issues and, ultimately, agricultural sustainability. Through application of the Drivers, Pressures State Impact Response (DPSIR) Framework (EEA, 1995; UNEP/GRID-Arendal, 2000; Bellini, 2001), relationships and linkages between components of the system and the variables that influence the biophysical environment or ecological component of the system (drivers) are identified. 'Drivers' or driving forces are the socio-economic and socio-cultural forces driving human activities, which increase or mitigate pressures on the environment. 'Pressures' are the stresses that human activities place on the environment, while State, or state of the environment, is the situation of the environment (UNEP/GRID-Arendal, 2000). Impacts are the consequences of environmental degradation. Reactions by society to the environmental situation are the 'Responses'. This framework was used to clarify the causes and effects of environmental issues in an agricultural system. This analysis of an agricultural system using the DPSIR Framework does not account for non-human or biophysical drivers, nor does the Framework adequately represent the fact that a certain state or impact could be due to several causes. Despite these shortcomings, the DPSIR framework facilitates understanding of the relationships between the components of an agricultural system, thus making it possible to better gauge the likely direct and indirect repercussions of an intervention. The focus of this study is on human-driven environmental issues emanating from small-scale conventional maize farming.

THE SOCIAL ECOLOGICAL SYSTEM APPROACH FOR DETERMINING ENVIRONMENTAL MANAGEMENT INTERVENTION POINTS

The study site

A case study of a small-scale maize farming community in Moretele Ward, Dr J.S. Moroka Local Municipality in Mpumalanga Province, South Africa was used to illustrate the development and application of the social ecological systems analysis approach.

The steps

The main steps in the proposed systems approach are (i) system characterization, (ii) mapping components of the system and establishing relationships and linkages among components of the system and production practices, (iii) organising the information through the DPSIR framework, (iv) determining the hierarchy of drivers and (v) identification of intervention points for environmental management (Figure 1).

System characterization - description & definition of characteristics, boundaries & objectives

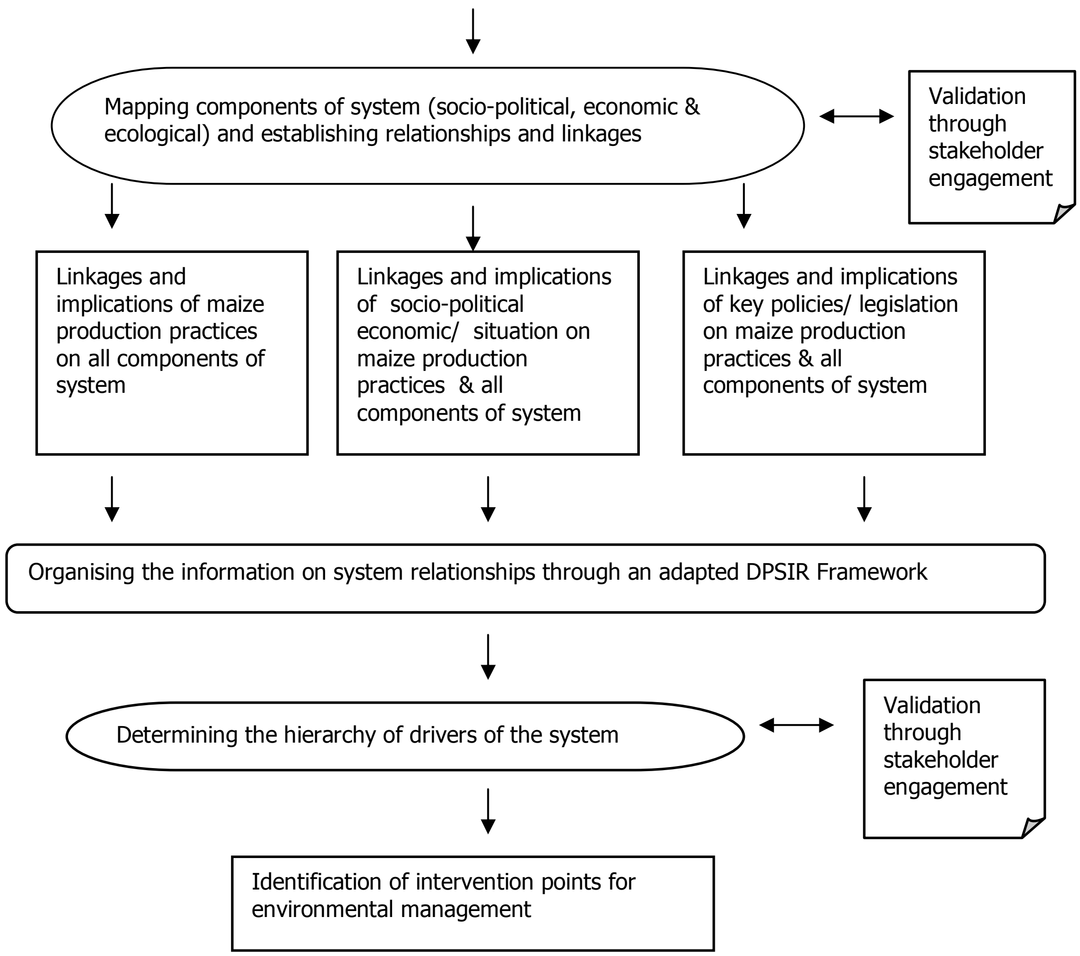

Figure 1: Stages in the proposed systems analysis approach.

System characterization

A full characterisation of the Moretele small scale maize farming system was conducted through a review of literature on the biophysical and social aspects of the system, interviews and discussion sessions with community members and stakeholders, such as, the Mpumalanga Provincial Department of Agriculture and the Agricultural Research Council (ARC). Characterization also involved review of legislation and policies of relevance to agriculture and the environment in a small scale farming context.

Moretele ward is a small-scale farming community comprised of nine villages. Maize is the main crop grown and is produced at a subsistence scale using conventional tillage methods. The maize is planted in October/November, following ploughing of the land in the dry season (June/July) and again shortly before planting. Hand weeding takes place in December, January and February and the crop is harvested by hand in May/June. Maize residues are fed to livestock and soils in maize fields are generally left bare after harvest. Fertiliser, pesticide and certified seed use is low due to most farmers being unable to purchase these inputs, while limited knowledge and information on correct fertiliser and pesticide application also contribute to this low use. Environmental issues in Moretele include soil erosion, overgrazing, woodland depletion and soil fertility decline due to crop production without fertilisers, with agricultural practices in the area being a key contributing factor.

In addition to over tilling the soil, maize fields are left bare after harvest with soil exposed. Most of the residents of Moretele are poor, have low education levels, low access to credit, agricultural extension services and information (Mpumalanga Provincial Government, 2005; Mpumalanga Provincial Government, 2007). Up to 50% of the available arable land in Moretele is not utilised due to inability to afford inputs, progressively declining yields due to lack of fertiliser, theft of crops and crop destruction by livestock due to inability to afford fencing. In addition to local level factors, higher level institutions and policies such as the Land and Agricultural Development Bank of South Africa (Land Bank), which provides loans to small scale farmers (www.landbank.co.za), and the Land Redistribution for Agricultural Development Programme (LRAD) (http://www.land.pwv.gov.za/redistribution/lrad.htm), (implemented from 2001) which provides grants for agricultural purposes were found to have implications for the Moretele small scale farming system.

Mapping components of the system and establishing relationships and linkages

Information on system characteristics was used to map and identify key relationships and linkages between the ecological, economic and socio-political components of the system. Crucial to the identification of linkages was understanding the functioning of the system. This understanding was informed by Phillips, Boyd and Edwards (2001), who indicate that key factors to be understood in the functioning of a farming system are the technologies of production and the social, economic and environmental aspects. Matrices were drawn up to establish linkages between the maize production process and the socio-political, economic and ecological factors (FAO, 1995). The maize production process is linked to the three components of the system as shown in Table 1. For instance, the ploughing of land impacts on the socio-political component of the system through the requirement for labour, on the ecological component through the impacts of tillage on the soil system, and on the economic component through financing the tillage.

Table 1: Matrix of linkages among maize production activities and components of the Moretele maize social-ecological system.

Maize production activity	Implications for the socio-political component	Implications for the ecological component	Implications for the economic component
1. Plough or till land (June/July)	Labour required for hand preparation – implications for other activities - reduce time spent on or forgo other activities	Turning of soil – possible loss of soil organic matter and structure Increased susceptibility to erosion and increased risk of soil loss due to erosion	Money required for hiring tractors/ploughs
2. Plough or till land (Nov/December)	Labour required for hand preparation	Turning of soil – possible loss of soil organic matter and structure Increased susceptibility to erosion And increased risk of soil loss due to erosion	Money required for hiring tractor/ploughs
3. Fertiliser/ manure application	Labour required, but overall impact negligible due to low usage. Low maize	Nutrient mining and continued soil fertility decline	Low returns due to low yields

	yields		
4. Planting maize	Labour required – implications for other activities	Establishing a monoculture – biodiversity reduction	Money required for purchase of seed if 'saved' seed is not used
5. Hand weeding	Labour intensive – implications for other activities	Reduction in biodiversity at field level as weeds are removed Less competition for nutrients	Hiring of labour and financial implications thereof
6. Harvesting	Labour required – implications for other activities Increased food supply and food security	Removal of residues for livestock feeding – leaving soil bare – increased risk of land degradation	Increased income due to savings on food

External factors such as agricultural financing can have repercussions on the whole system through impacts on the economic component.

Organising information on system relationships through an adapted Driving Forces-Pressures-State-Impacts-Responses (DPSIR) Framework

After identifying the linkages between the components of the system, and between components of the system and external factors, the DPSIR Framework (EEA, 1995; OECD, 2003) was used to describe the system. The Pressure, State, Impact components reflect the physical part of the framework, while Driving Forces and Responses are more linked to human factors, being related to decisions taken on how to carry out a productive process and to reactions from different sectors of human society (Bellini, 2001). In this study, the DPSIR framework was modified to differentiate between direct and indirect drivers. A direct driver was defined as a factor that directly influenced the biophysical environment or the ecological component of the system (*e.g.*, tillage). An indirect driver on the other hand was described as a factor that could only influence the biophysical environment through its influence on a direct driver, for example information could change the way tillage (a direct driver) was practised. The validity of the system description based on the DPSIR framework and the hierarchy of drivers was checked with stakeholders in a workshop.

The indirect drivers of the Moretele maize social-ecological system were socio-political and economic factors such as education, skills and income (Figure 2). Maize production activities - such as tillage - were classified as direct drivers, and these would in turn result in pressures on the environment. Some of the key pressures on the Moretele environment include soil erosion and nutrient mining. These pressures result in a state of infertile soils, low soil organic matter, poor soil structure and soil erosion. The impacts of this state are low soil productivity, low maize yields and low incomes. The responses to the impacts have been abandonment of cropping areas, application of cattle manure in maize fields and adoption of reduced tillage. The responses affect the direct and indirect drivers, the pressures, the state and the impacts.

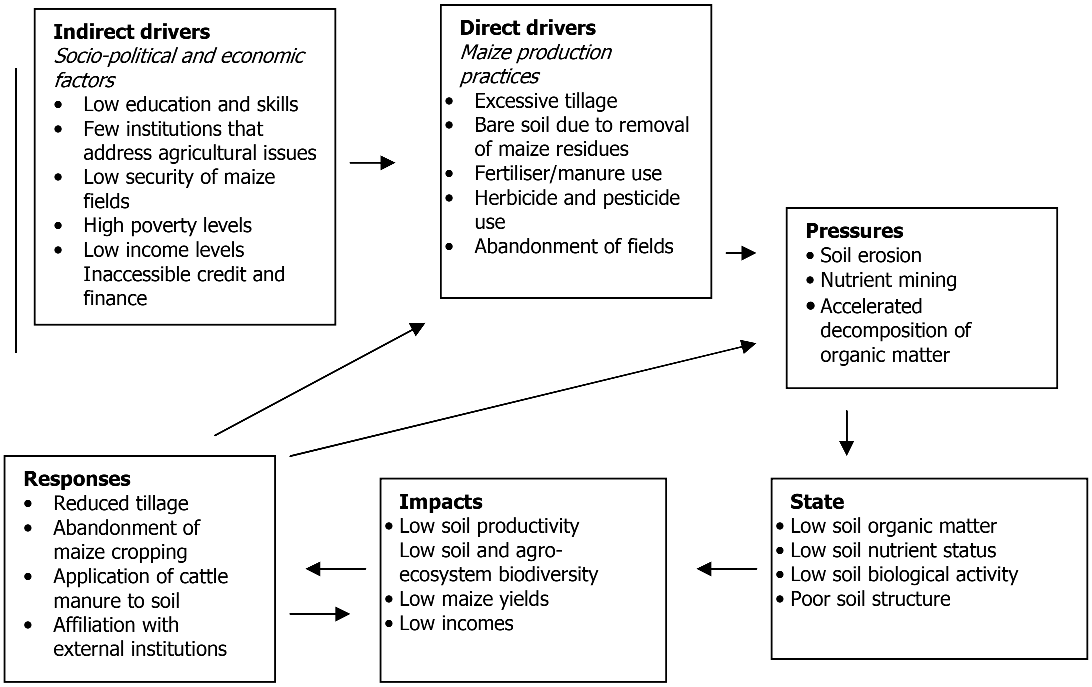

Figure 2: The Moretele maize social-ecological system described using the DPSIR Framework (modified).

Determining the hierarchy of drivers of the system and identification of intervention points for environmental management

The hierarchy of drivers influencing the state of the ecological component (biophysical environment) of the Moretele maize SES is shown in Figure 4. The direct drivers would be affected by a set of factors, designated as level one indirect drivers, and in Moretele these included farming knowledge, information, access to funds and resources, and security of crops and croplands. Level one indirect drivers would, in turn, be influenced by level two indirect drivers, and these include the education levels of farmers, prevalence of poverty, and general access to or availability of information of any kind, for example, on accessing credit. Level two indirect drivers would be influenced by level three indirect drivers and these would mainly be policy level factors.

The hierarchy of drivers shows that there are several possible points at which interventions can be made to address an environmental issue such as soil erosion or nutrient mining. In Moretele, at the direct driver level, interventions could address tillage issues (*e.g.*, frequency and tillage method) the use of fertilisers and/or manures, removal of maize residues from fields after harvest, and the use of pesticides and herbicides. Interventions targeted at level one indirect drivers, on the other hand would need to address issues of crop security (destruction by animals and theft), availability of funds and resources for maize production, and farmers' knowledge and information. For level two indirect drivers, the issues to be dealt with include poverty, education, security, accessibility and availability of information. Implementation of policies and gaps in policies are the issues that would need to be dealt with for the indirect drivers at level three.

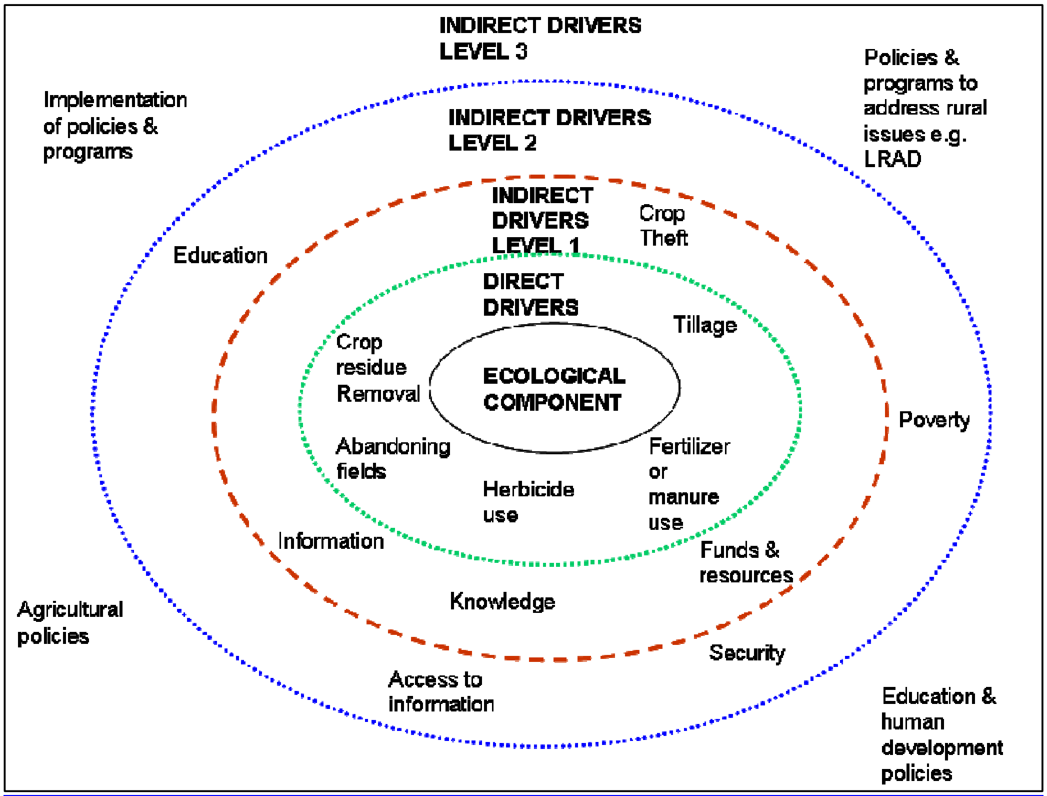

Figure 3: Hierarchy of driving forces in the Moretele maize social-ecological system.

CONCLUSION

The SES approach described provided for a relatively efficient means of integrating issues for environmental management decision making, and this integration is crucial for sustainability. Chan and Huang (2004) indicate the value of a systems approach in addressing economic, environmental and social issues in seeking sustainable development. The DPSIR framework was useful for structuring the linkages between maize production activities and system components and made it possible to separate causative factors from their effects. In addition, elucidating the different levels of drivers revealed the chain of causative factors linked to an environmental issue and could inform decision making on where best to intervene in the chain.

The hierarchy of indirect drivers representing different sectors ultimately impacting on the environment in an agricultural system highlights the need for an approach that considers all sectors in decision-making on environmental issues. The DPSIR framework as used in this study, although capturing the key relationships between the socio-political, economic and ecological components of the maize SES, does not account for the non-human drivers of environmental change. Despite this shortcoming, The DPSIR framework application in this context was adequate as the focus of the study is on human driven environmental issues.

This analysis process could be used to facilitate a more proactive approach to environmental management in agriculture by facilitating the addressing of causes rather than the effects of environmental issues. Decision makers at different levels can use this approach to identify the drivers that can be effectively addressed at their level and with the resources at their disposal.

ACKNOWLEDGEMENTS
This study was funded by a Council for Scientific and Industrial Research (CSIR) Parliamentary Grant. The contributions of Benita de Wet and Chantal Will to the ideas presented in this study are gratefully acknowledged. We thank Peter Ashton for his advice and for reviewing an earlier draft of this manuscript. This study would not have been possible without the co-operation and assistance of the Agricultural Research Council's Institute for Soil, Climate and Water. The Moretele community contributed important information and feedback to the analysis.

REFERENCES
Andries JM, Janssen M, and Ostrom E (2004) A Framework to analyze the robustness of social-ecological systems from an institutional perspective. *Ecology and Society,* vol 9, no 1, p18.

Bellini G (2001). *Agri-environmental indicators to describe agriculture sustainability*. Working Paper 21, Joint ECE/Eurostat Work Session on Methodological Issues of Environment statistics. Ottawa, Canada, 1-4 October 2001.

Chan, S-H. and Huang, S-L (2004) A systems approach for the development of a sustainable community- the application of the sensitivity model (SM). *Journal of Environmental Management* vol 72, pp 133-147.

DEAT (Department of Environmental Affairs and Tourism) (2006) So*uth Africa Environment Outlook.* A report on the state of the environment. Department of Environmental Affairs and Tourism, Pretoria, pp 88-89.

EEA (European Environment Agency) 1995, *Europe's environment: the Dobris Assessment*. European Environment Agency, Copenhagen.

FAO (Food and Agriculture Organization of the UN) (1995) Understanding Farmers' communication networks: an experience in the Philippines. Natural Resource Management and Environment Department. Available (online) at http://www.fao.org/docrep/v9406e/v9406e03.htm (last accessed: September 7, 2008).

FAO (Food and Agriculture Organization of the UN) (2002) *FAO-STAT Statistics Database*. Rome, Italy.

Mpumalanga DACE (Mpumalanga Department of Agriculture, Conservation and Environment) (2003) Mpumalanga State of the Environment Report. Mpumalanga Department of Agriculture, Conservation and Environment, Nelspruit. Available (online) at http://www.environment.gov.za/soer/reports/mpumalanga (last accessed: June 12, 2007)

Mpumalanga Provincial Government (2005) Department of Agriculture and Land Administration. Integrated Resource Information Report, Dr J.S. Moroka.

Mpumalanga Provincial Government (2007) *Mpumalanga Economic Profile*. Department of Economic Development and Planning. Available (online) at http://www.mpumalanga.com/documents/MpumalangaEconomicProfilemar2007.pdf (last accessed: November 20, 2008).

OECD (Organization for Economic Cooperation and Development) (2003) OECD *Environmental Indicators: Development, Measurement and Use*. OECD, Paris.

Philip RG, Broome JC, Chornesky EA, Frankenberger JR, Johnson P, Lipson M, Miranowski JA, Owens ED, Pimentel D and Thrupp LA (2004) Rethinking the Vision for Environmental Research in US agriculture. *Bioscience,* vol 54, pp 61-65.

Phillips M, Boyd C and Edwards P (2001). Systems approach to aquaculture management. In: Subasinghe RP, Bueno P, Phillips M/J, Hough C, McGladdery SE and Arthur, J.R. (Eds.), *Aquaculture in the Third Millennium*. Technical Proceedings of the Conference on Aquaculture in the Third Millennium, Bangkok, Thailand, 20-25 February 2000. pp 239-247. NACA, Bangkok and FAO, Rome.

Priorr H-P (2003) Environmental policy, agri-environmental indicators and landscape indicators. *Agriculture, Ecosystems and Environment*, vol 98, pp 7-23.

Tilman D, Cassman, KG, Matson PA and Naylor RL (2002) Agricultural sustainability and intensive production practices. *Nature*, vol 418, pp 671-77.

UNEP/GRID-Arendal (2000) Cities Environment Reports on the Internet: Understanding the CEROI Template. Available (online) at: http://www.ceroi.net (last accessed: October 20, 2008).