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Integrating landscape ecological principles and land evaluation for sustainable land use*

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Abstract—Many existing methods for appraisal of agricultural areas and farming systems are short of dynamics and spatial analysis. The main objective of this paper is to merge approaches in classical land evaluation, largely based on soil science, and newer approaches in landscape ecology, which are rather based on the relationships between spatial patterns (physiography, land use and farming system design, vegetation etc.) and processes (farming activities, scale changes, geomorphological processes, bio-ecological processes). Rapid changes in rural areas have an impact on both processes and patterns. Planning for sustainable use of these areas should include the assessment of the interrelations between these patterns and processes.

Keywords: landscape pattern, ecological process, land evaluation, land sustainable use.

1 Introduction

Rising populations competing for limited land resources have focussed attention on the need for increasing food production, while preserving the resource base and decreasing land degradation. This has promoted discussion on the sustainability of current land use system.

Sustainable land use has emerged as a global issues in securing enhanced productivity and performance of land resources, consistent with minimizing adverse effects on the environment (FAO, 1993). Many current land use systems are not sustainable as they contribute to the deterioration of the natural resource bases, as a result of erosion, decertification, salinization, contamination with toxic chemical or in other ways(Stomph, 1994). Therefore, there is an urgent to develop and implement appropriate technologies and policies of more effective land management which are sustainable over time. However, many existing methods and systems of land evaluation do not provide enough information to measure current planning needs regarding issues of sustainable lands use and natural conservation. They are short of dynamic and spatial analysis, and do not indicate the ecological, economic and social issues of land use. Landscape ecology develops concepts and principles, such as landscape pattern and ecological processes, connectivity and ecological corridors, that are high inspiring in the design sand the management of land use and landscape, and highly complementary to classical land evaluation. This paper merge classical land evaluation with newer approaches in landscape ecology, which are rather based on the relationships between spatial patterns and processes, and develop an integrative land evaluation approach for sustainable land use.

2 Conceptual frameworks

Land evaluation seek to assess the suitability of land for different uses on the site (field or patch), which greater focus is given to abiotic site qualities, relating to soil, landform and climate. However, the interrelationships between the land use structure and ecological process are not considered. The suitability in field level need to up to the watershed level. The watershed is being recognized by farmers as a logical division of the landscape at which to begin addressing the problems of land degradation. Therefore, apply landscape ecological parameters at the watershed level will deepen and extend the land evaluation. Fig. 1 shows a conceptual framework to integrate the landscape ecological principles and land evaluation for sustainable lands use.

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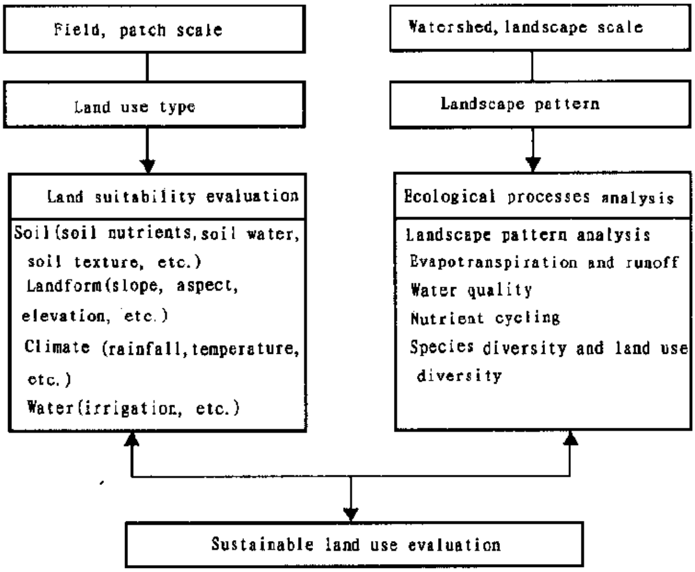

Fig. 1 A conceptual framework for sustainable land use evaluation

The evaluation is to be defined as a set of constraints on locations, sizes, scales and material and energy inputs with respect to land use systems is defined in terms of erodibility and of disconnection of biotic elements, using standard descriptive and deterministic models. A hierarchy of scales will be defined, including land use types, farming units, field units, watershed, landscape in different size. For these hierarchical levels, parameters will be selected that best describe the evolution over time of the selected fragility aspects. Historical data such as aerial photographs, and field sampling will serve as input. Different information layers will be integrated by models and GIS. The final outcome is a rapid appraisal of likely impacts of land use on important environmental aspects.

2.1 Lands evaluation

A systematic way of doing this is set out in framework for land evaluation (FAO, 1976) and detailed procedures are given in guidelines on evaluation for rainfed agriculture, irrigated agriculture, forestry and extensive grazing (FAO, 1983; 1984; 1985; 1991). In simplified form, the procedure is:

——Describe promising land-use types;

——For each land-use type, determine the requirements, e.g. for water, nutrients, avoidance of erosion;

——Conduct the surveys necessary to map land units and to describe their physical properties, e.g. climate, slope of soils;

——Compare the requirements of the lands-use types with the properties of the land units to arrive at a land suitability classification.

2.2 Landscape pattern and ecological processes

There is general agreement on the broad aspects of ecological sustainability, and these relate to the cycling of matter in the form of water and nutrients, the flux of energy, and the role of species richness in the dynamics of the biotic component (Savory, 1988; Hobbs, 1993). Landscape ecological parameters emphasis on an ecological process, rather than states. Landscape pattern determines the flow of energy, materials and organisms among the components of the landscape (Turner, 1989). Analysis of the flow of energy and materials and distribution of habitat in the landscape can indicate the performance of the landscape structure. In this paper we use landscape pattern, evapotranspiration (ET) and runoff, water quality, nutrients cycling and land use diversity as indicators of landscape pattern and process.

2.2.1 Landscape pattern analysis

The spatial patterns observed in landscape is result from complex interactions between physical, biological, and social forces. Most landscape have been influenced by human land use, and the resulting landscape mosaic is a mixture of natural and human-managed patches that vary in size, shape, and arrangement. Landscape patterns indexes have been reviewed by Turner(Turner, 1989). Landscape structure include number, size, shape and distribution of patches and edges among different land cover categories of the landscape because changes in these categories over time determine the dynamic of interactions among the individual landscape components. A number of measures such as species and landscape richness and evenness, habitat diversity edges and fragmentation can be used to quantify the landscape pattern. GIS can be used to identify and analyze the landscape spatial pattern.

2.2.2 Evapotranspiration (ET) and runoff

The distribution of energy and vapor fluxes in a landscape is a function of the landscape structure, climate, and topography. Measurement of these fluxes over a relatively large area can reveal how the surface conditions of our environment change. Since the evapotranspiration (ET) rate is an indication of the ability of plants to use water from the environment, estimation of plant ET rate can help us to determine how well plants adapt and respond to shifts in the structure of the landscape. With remote sensing technology, the energy and vapor fluxes can be estimated rapidly over a large area. The energy balance and mass transferred model suggested by Fuches and Tanner (Fuchs, 1967) can be used to evaluate changes in net radiation and ET rate resulting from the structural changes of the landscape. The main advantage of this approach are that: (a) the energy and vapor fluxes can be calculated in a fine grid of cells over the entire study area; (b) it links the environmental factors which include solar radiation, temperature, precipitation, and soil with the health of vegetation, and (c) it incorporated key surface parameters that can be directly obtained from satellite data.

Estimation of net radiation at the watershed scale can be obtained from (Bartholic, 1970):

$$Rn = Qs - Qsr + Qa - Qar - Obs.$$

Where Rn is net radiation flux density [cal./(cm^2·min)], Qs is incoming solar radiation flux density [cal./(cm^2·min)], Qsr is reflected solar radiation flux density [cal./(cm^2·min)], Qa is incoming thermal radiation flux density from the atmosphere [cal./(cm^2·min)], Qar is reflected thermal radiation flux density [cal./(cm^2·min)], and Qbs is emitted thermal radiation flux density [cal./(cm^2·min)].

Qs can be estimated from GOES visible data and Qsr, Qa, Qar and Qbs by other satellite data such as NOAA, AVHRR and LANDSAT.

The Bowen Ratio method (Bartholic, 1970) can be used to estimated evapotranspiration (E) as shown below:

$$E = -(Rn + G)/[1 + \gamma(\Delta T/\Delta e)].$$

Where G represents soil heat flux density [cal./(cm^2·min)], γ is the psychometric constant, ΔT is the temperature difference between surface temperature T_0(℃) and air temperature Ta(℃), and Δe is the vapor pressure difference between saturated water vapor pressure (e_a' in mb) at Ta and saturated water vapor pressure (e_a' in mb) at To.

In the Bowen Ratio method, net radiation (Rn) can be computed from satellite data, soil heat flux density can be estimated based on literature values, and air temperature (Ta) can be obtained from weather stations, while surface temperature (T_0) can be derived from satellite data, and saturacted water vapor pressure (e_a') and (e_0') can be computed from Ta and T_0, respectively.

Comparison of the distribution of net radiation and evapotranspiration and peak runoff calculated from the models between the perturbed and unperturbed will help us understand how these values change across a landscape as a function of habitat types and what would be the expected landscape structure and function of the perturbed watershed after its restoration and rehabilitation.

2.2.3 Water quality

Nonpoint source (NPS) pollution is related to climate, soil, topography, land cover/use, and management practices. Changes in landscape structure will result of changes in NPS loading including erosion, sedimentation and nutrient runoff. He *et al.* (He, 1993) have integrated AGNPS, an agricultural nonpoint source pollution model, with GRASS and LNDSAT to evaluate the impact of agricultural runoff on water quality in an agricultural watershed. Outputs of the model include spatially distributed estimates of volume and peak runoff, overland and channel erosion, sediment yields, and concentrations of nitrogen and phosphorus. The AGNPS model can be used to evaluate the relationships between land use/cover and the resultant nutrient runoff and sedimentation. The simulated sedimentation and nutrient runoff from both agricultural land and urban land will partially indicate the performance of the watershed landscape structure. The greater the runoff, the more severe the adverse impact on water quality and habitat, which is an indication of unhealthy landscape structure. In addition, the effects of wetlands including their types, number, and sizes on nutrient runoff and sedimentation can also be explored in the AGNPS model. Field sampling needs to be conducted to verify some of the input parameters such as slope length, soil nutrient level(nitrogen and phosphorus), and fertilization level, etc. These data can then be used to correlate with the model simulated peak runoff in the study watersheds.

2.2.4 Nutrient cycling

This indicator describe nutrient stocks and flows as related to different land use structure and landscape patterns. 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. Hobbs and Saunders (Hobbs, 1993) have demonstrated how this index can be developed for several hierarchical scales, including the farm level, landscape level, region level and national level.

Nutrient cycling involves minimizing inputs, fostering biological recycling and limiting loss from lands use system. Loss of soil and hence organic matter and nutrients through water erosion could be reduced by a combination of factors already mentioned by Fu and Gulinck(Fu, 1994): minimum tillage carried out on the contour in combination with water-harvesting techniques and tree belts to decrease runoff, plus occasional rotations of deep-rooted herbaceous perennial to increase infiltration and water use; and the use of browse shrubs or perennial grain crops on soils with high erodability.

2.2.5 Species diversity and land use diversity

Types, sizes, number and distribution of land cover categories across the landscape of a watershed determines habitat characteristics and associated species that live in the habitats. Modification of landscape structure (such as land cover types) and related energy and matter fluxes will likely lead to changes in habitats and species composition. Corresponding relationships, although not necessarily unique, exist between habitat characteristics and biological species. Component ecosystems within the watershed landscape can be surveyed to measure species richness and evenness within habitat categories identified by GIS analysis. These include both stable and rapidly changing components in which biodiversity and integrity will be compared with the use of diversity indices and species abundance models(Magurran, 1988). Generally, anthropogenically perturbed environments shift from a log normal distribution of species abundance plotted against rank, with an increase in species dominance and a decrease in species richness (Magurran, 1988). In perturbed environments, species abundance distributions often reverse through successional series to become geometric and reflect less equability among the species and dominance of a small number of the commonest species. In the original deciduous forests characteristic of the perturbed and control study areas, the distribution of species in rank abundance plots is typically log normal. Comparison of structural(architectural) diversity of the plant communities, vertical diversity using the stratiscope method and horizontal spatial diversity by nearest neighbor distances within and among plant species will indicate the state of the study watershed landscape.

The same measurements can be made in both perturbed and control(unperturbed) watersheds so that the ecological impact of various anthropogenic disturbance can be assessed by statistical comparisons of structural and species diversity measurements and the fit of species abundance plots to the log normal distribution. The log normal distribution will be used as a criterion of comparative watershed vigor and health, and significant departures from this distribution, or a significant fit to a geometric series will both be used as objective criterion to establish that some form of watershed disruption has occurred. These data will then be used to compare with current GIS layers of habitat categories and to assess the degree and nature of long term changes from historical images (Likens, 1987).

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 it is also a useful indicators 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 complexicity 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, pressure or absence of livestock in the production systems and so on. The key research issues are:

——Is current land management contributing to increased land degradation or improving land capacity;

——Are current agricultural management practices contributing to improved global environmental management.

3 Conclusions

Human-induced changes in landscape structure lead to modified spatial and temporal distributions of energy and matter fluxes and types and sizes of habitats at the watershed scale. This paper proposed a framework for developing and integrating landscape ecological principles and land evaluation for land sustainable use and discusses for implementing these indices. Through systematic interactions with stakeholders in the study watershed rehabilitation process, these indices can lead to better understanding of the human impacts on watershed ecosystems, more effective watershed policy decision making, improved knowledge of decision making process and informational needs of policy decision makers in watershed restoration and rehabilitation, and integration of scientific information with management process in land use planning and management.

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