Geo-Information for Planning of Sustainable Land Management:

Hyper-GIS for Sustainable Land-Cover/Land-Use Change and Decision Making in Costa Rica

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1. Introduction

Degradation of tropical environments is a major concern for developing countries. Deforestation and its impacts on soil erosion, water pollution, biodiversity loss, and degradation of scenic values are factors influencing economic productivity, quality of life, and well being. Despite growing public concern and increasing political rhetoric; actions have been relatively ineffective in managing this great problem. Tropical forests are being degraded in critical ecosystems, and old forestlands suitable for timber production are being lost at rates far exceeding reforestation efforts.

The goals of sustainable development in developing countries are not being met, partly because of a lack of access to advanced technology for environmental monitoring and for development of sound and sustainable land management practices. Remote sensing techniques (RS) and geographic information systems (GIS) are unique and important state-of-the-art tools for monitoring the degradation of tropical ecosystems. These tools can help to define priority areas for conservation and development, and can also be used to accurately and efficiently verify the effectiveness of land use planning. Additionally, these tools can play an important role in monitoring natural resources depreciation and loss of essential services provided to mankind by tropical ecosystems.

As these technologies are becoming more accessible to developing countries, old and new problems are being reassessed, and the impact of the interactions between the natural environment and economic development are becoming more apparent. Moreover, existing and newly identified problems are tackled in a more systematic and holistic way.
Costa Rica is a clear example of the needs that many developing countries in the humid tropics have for improved geo-information methods for natural resource assessment and management. Costa Rica's variety of ecosystems is determined by a complex combination of microclimates, aspect, topography and spatial distribution of precipitation. These variables compounded with high variability of soils, and the bridge effect between

the North and South American Subcontinents are responsible for its great ecological richness.

For Costa Rica, integrated resources planning and management, as well as long term effective policies associated with land use zoning and environmental quality control, require objective data about the location and magnitude of natural resources degradation. This geo-information can help to document the importance and urgency of these problems as well as to provide sound solutions in support of the country's strategy for sustainable development (ECODES). This geo-information, if properly channeled to decision-makers, will be of great value to define consistent policies for sustainable development.

The purpose of this paper is to present current efforts by the Research Center of Sustainable Development of the University of Costa Rica (CIEDES-UCR) towards the building and conceptualization of a nation wide geo-information data base that will serve as a local point for integrated resource management in the country.
This effort is concerned with four basic aspects:

- Tropical deforestation and habitat fragmentation
- High mountain 'strategic' watershed preservation
- Biodiversity conservation, bio-prospecting and study of the socio-economic consequences of biodiversity loss
- Regional Dynamics of Land Use / Cover Change: LUCC-Central America.

2. Tropical Deforestation and Habitat Fragmentation

The need for an accurate and precise forest cover inventory to quantify the rate of primary forest loss in Costa Rica is becoming a matter of urgency. As forest resources vanish from the national landscape, impacts on water resources, biodiversity, the carbon cycle and other mechanisms are important to quantify. Moreover, the goals of sustainable forestry and biodiversity conservation strategies defined by Costa Rica can only be achieved with state-of-the-art remote sensing data and GIS techniques that are integrated to fully understand Costa Rica's forest landscape.

Three fundamental questions are addressed:

- What is the current extent of primary forest in Costa Rica?
- What is the degree of habitat fragmentation and which are the most affected areas?
- How can current state-of-the-art technology in remote sensing and geographic information systems help to make an accurate and precise inventory of primary forest in Costa Rica?

The definition of future conservation policies in Costa Rica will depend on accurate and precise answers to these questions. Sound tropical forest cover assessments will be important for determining the rate of loss and the rate of regeneration of abandoned lands. Moreover, understanding of the spatial distribution of forest islands is a key component in sampling genetic/biodiversity resources in fragmented ecosystems, as well as in the definition of new conservation areas which will become part of the Central American Biologic Corridor. A continued deforestation monitoring program will also be

important to evaluate biodiversity loss in ethical and aesthetic terms, direct loss of economic benefits from biodiversity loss and loss of essential services provided by natural ecosystems, and identification of areas for the development of “in-situ” and “off-situ” biodiversity conservation and restoration programs.

3. High Mountain Strategic Watersheds

Watershed protection is a key component in achieving sustainable management of water resources. Accurate geo-information is needed for the implementation of soil and water resources conservation programs. Additionally, accurate spatial information is vital to the implementation of more comprehensive national water balances.

Water is becoming a source of conflict in Costa Rica. To some degree agricultural production, hydropower generation, and demand for clean drinking water have been competing socio-economic forces for decades, but now are taking on an added sense of urgency in the face of uncontrolled urban development and growing tourism. These conflicts are critical to sectors that play key roles in Costa Rica’s economic growth.

Integrated resource management and monitoring of LUCC processes is faciliated by Hyper-GIS technology. A case study has been implemented at the Pacuare River Basin, Costa Rica. The Pacuare river basin is not only important for it potential for hydropower generation but also because of its rich biodiversity and its location at the border between the agricultural frontier and the largest tropical evergreen forest island in the country.

Hyper-GIS and remote sensing were integrated in order to evaluate conflicts between LUCC and water resources. Results indicate that current infrastructure development, especially roads, have contributed a great deal to deforestation in the basin. Current findings indicate that, on average, more than 80% of total deforestation in the basin is taking place within 500 meters of roads in this basin.

4. Biodiversity Conservation and Socio-Economic Consequences of Biodiversity Loss

An understanding of the socio-economic causes of deforestation and biodiversity loss at the local level can play an important role in conserving the biodiversity of Central America’s tropical ecosystems. A clear understanding of the various driving forces and their interrelationships, using state-of-the-art geoinformation technologies, will provide knowledge that is essential for defining more comprehensive conservation policies. Efforts oriented towards biodiversity conservation such as the Central American Biological corridor project, has shown significant gaps in the conservation of threatened species.

The Research Center on Sustainable Development seeks to understand the socio-economic causes of biodiversity loss through a case study in Costa Rica. Costa Rica has experienced one of the highest deforestation rates in Latin America. This deforestation process causes forest fragmentation, soil loss, biodiversity loss and depletion of water resources. Sanchez-Azofeifa (1996) has shown that the average

deforestation rate for central Costa Rica is ~4% per year and that by 1991 only 29% of the original evergreen forest of the country remained.

Despite the importance of the Central American region in terms of biodiversity, there has been a lack of systematic efforts towards evaluation of the socio-economic causes of biodiversity loss. The development of a methodology is a critical first step. The aim is to facilitate multiple comparative case studies aimed at improving our understanding of the dynamics of land management, thereby facilitating regional studies and policy development for in-situ and ex situ biodiversity conservation. Case studies are conducted in two regions in Costa Rica: La Selva region and Monteverde Conservation Area. The methodology developed for these two regions is a first step to be followed by case studies in other Central American countries.

The comparison of these two case studies will enable to develop a solid methodological and theoretical framework to understand the causes and effects of biodiversity loss from socio-economic perspective. Findings will be integrated into a multi-criteria/multi-objective data fusion model (DAFUMOL) using geo-coded information through a geographic information system (GIS). The model will allow not only the integration of the temporal behavior of socio-economic forces but will allow its interpretation over time and space. The model will use socio-economic information allocated in field studies and literature reviews, as well as land characterization and LUCC trends identified by means of remote sensing and digital elevation models. The integration of different levels of ancillary data will permit the development of conceptual models. It is expected that this conceptual model and its integration with DAFUMOL will help development of policies for integrated and sound rural development, and nature conservation.

The following main variables are considered in DAFUMOL: demographic change, poverty and inequality, internal and international markets, macro-economic development polices, and development biases to specific LUCC processes. These variables are selected because of their direct impact on the ecosystem in terms of habitat loss, habitat fragmentation, and ecological stress. The impacts of these variables are currently modeled and quantified as a function of landscape matrix change evident from remote sensing and geographic information processing. In addition, variables such as population density, per-capita income, production income for each land use, time of land tenure, number of families as a function of land use, and the dynamics of land use/cover change at the county level will be collected for this study.

5. Regional Dynamics of Land Use/Cover Change: LUCC-Central America

Land Use and Land Cover Change (LUCC) have been identified significant to a range of themes and issues central to the study of global environmental change. The need to know the current state of land use and cover change processes in Central America is needed to achieve regional sustainable development. This knowledge will permit to evaluate and understand, in a holistic and comprehensive way, processes and interconnections related to biodiversity loss, erosion of agricultural soils, LUCC impacts on water resources and coastal management at national and regional scales.

At present Central America does not have a comprehensive science plan to study LUCC processes. The need to establish research lines, with international quality control standards, has been a matter of concern to the Central American Committee (CRRH) on

Water Resources and the Central American Project for Climate Change (PCCC), because the intrinsic relationship that exists between global change, climate change, LUCC and sustainable development is evident. Formulation of a science plan that integrates across scales and disciplines plays an important role in environmental impacts assessment as carried out by the Central American Commission for the Environment and Development (CCAD).

The LUCC history is different for each Central American country, depending on economic and social forces and cultural background. The inter-relationships between these forces and processes and their consequences for the Central American landscape are almost unknown in the region. Therefore, there is a great need to integrate scientific and political objectives aimed at sustainable development of the region, with sound research oriented programs to form a new reference framework known as LUCC-Central America.

LUCC Central America adopts the guidelines established by the LUCC-IGBP project, as well as its basic objectives. It is expected that this scientific plan will meet the new geo-information needs in the region. In addition, LUCC Central America seeks to generate mechanisms that will help to define planning policies and environmental conservation aiming to the sustainable development of the Central American Region. This program must also address human response to environmental change and the sustainability of indigenous and rural communities.

Projects related to the Central American biologic corridor, tropical deforestation, secondary growth monitoring, conservation of coastal resources, activities implemented jointly (IJI), as well as those related with definition and identification of vulnerable areas are needed for the Central American region. Such projects can benefit from concerted research efforts in the region. The institutional framework established by the International Geosphere Biosphere Program (IGBP), known as the Land Use and Land Cover Change (LUCC) Scientific Research Plan could be used as a reference to define a science plan to study LUCC processes in the region. LUCC provides an interdisciplinary framework with 4 basic objectives:

- To obtain a better understanding of global land use and land cover driving forces.
- To investigate and document the geographical dynamics of land use and land cover.
- To define the links between sustainability and various land uses, and
- To understand the inter-relationships between LUCC, biochemistry and climate.

Two more basic objectives can be accommodated in the research plan to meet the current needs of the Central American region:

- To understand the inter-relationships between LUCC and the response of critical watersheds in the region, and
- To investigate and understand the inter-relationships between LUCC and current efforts of conservation, research and use of Central America's biodiversity resources (Central American Biologic Corridor efforts).

The LUCC program offers a solid base and mechanisms to study and understand what kinds of land use/cover occur in the region, as well as the forces driving change. Finally,

LUCC-Central America offers the opportunity to identify where human intervention can change current LUCC projections.

The implementation of LUCC-Central America will provide scientific advisors and decision-makers with:

- Essential information for decision making within a specific political framework
- Information (data bases) necessary to improve land management systems (i.e. coastal management), therewith improving mechanisms for integrated resources management at the country level.
- Long-term scientific objectives to assist definition of political priorities to cope with global environmental and climate change.

Four main questions are critical for LUCC-Central America:

- What is the current state of land cover in Central America?
- What can we learn from comparative case studies at the regional level?
- How can we integrate international experience in a LUCC science/research plan for the region?
- How can LUCC-Central America contribute environmental planning and sustainable development in the region.?

Implementation of LUCC - Central America will not only require the support of the scientific community, but also of all regional organisms whose goals are to integrate scientific findings into decision making (e.g. Central American Commission for the Environment and Development (CCAD), Regional Committee on Water Resources (CRRH) and Central American Project for Climate Change (PCCC)). In addition, LUCC-Central America must integrate other (foreign) agencies with interests in the region (e.g. US Forest Service, NASA Mission to Planet Earth, ENRICH, IAI, IGBP, IGBP-START, UNDP, UNEP, GEF, etc.).

Four phases must be passed in order to implement a LUCC Science/Research Plan in Central America:

- **Phase 1: Awareness.** Introduction of scientific goals. Definition of a working strategy within LUCC-IGBP to exchange ideas between regional representatives and the international LUCC Community. This phase is currently in operation.
- **Phase 2: Definition.** An international workshop to integrate the regional and outside LUCC community is proposed. This workshop will discuss and define a reference framework to guide LUCC-Central America within the LUCC-IGBP context.
- **Phase 3: Demonstration.** A second international workshop is proposed to demonstrate and discuss LUCC projects in the region, as well as the formulation of priorities and goals of LUCC-Central America.
- **Phase 4: Implementation of LUCC-Central America:** Development of a financial framework for LUCC-Central America which allows to start projects approved during the demonstration phase.