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Land use modelling at the regional scale: an input to rural sustainability indicators for Central America

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Abstract

The monitoring of rural development and land use is a key requirement in order to produce information for policy-makers and planners and aid their understanding of development processes. Environmental and sustainability indicators, when combined with tools for their visualisation, manipulation and analysis are essential components of the monitoring process. By providing these information products and tools policy-makers can be given the opportunity to spatially interrogate the driving forces and the current state of rural development. However it is also vitally important for decision-makers to understand how trends will develop in the short-term future and the possible impacts of their decisions on the development process.

This paper shows how the results of a spatially explicit land use model have been incorporated into a set of rural sustainability indicators to provide information to policy-makers in a form consistent with the information used in the monitoring process. The success of the monitoring process will depend not only on the availability of tools and indicators but also on the skills of the users and an institutional framework that fosters the application of these skills.

Reliable and harmonised data are the key to obtaining useful results from the land use model chosen for this study, however responsibility for these data lies with the appropriate institutions in the countries of Central America. Demonstrating what can be done with 'their' data may provide these institutions with the necessary justification to overcome a lack of political will to invest in data collection, data use and the implementation of standards.

Keywords: Indicators; Central America; Land use model; GIS; Environmental; Sustainability; Rural

1. Introduction

1.1. The issues in Central America

In Central American countries (Panamá, Costa Rica, Nicaragua, Honduras, El Salvador and Guatemala), the agricultural sector constitutes approximately 20% of the regional GDP (1997), employs 40% of the regional labour force (1990–1997) and agricultural exports represent 30% of total regional exports (1998) (CEPAL, 1999) (World Bank, 1999a).

Although natural resources are one of the main bases for development, rural poverty and environmental degradation are characteristic of the region. In Central America 60% of the region's poor (10 million people) live in rural areas (1992–1993) (World Bank, 1999a), incrementing the poverty cycle, causing severe soil degradation, deforestation, and the advance of the agriculture frontier (de Janvry and Garcia, 1992). In the recent past 350,000–400,000 ha of forestland were converted annually because of deforestation and land use change (CCAD, 1998), and 40–60% of the soils were either eroded or degraded (Leonard, 1987 and UNEP, 1991 both cited in Winograd, 1995).

At the same time 28% (1992–1994) (FAO, 1997a) of the total regional land is used for livestock activities,

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while only 15–20% of that land is suitable for livestock use (Winograd, 1989). Domesticated, as well as non-domesticated lands are under increasing pressure because of increasing population and demands for services and products from a fixed natural resources base, increasing use of marginal lands, and scarce resources, and intensification of agriculture on existing cultivated and pasture lands (CCAD, 1998). Land degradation and mismanagement are threatening regional opportunities and the flexibility for increasing services for land and the environment (de Janvry and Garcia, 1992).

1.2. Indicators

Given these problems the national governments and regional institutions, i.e. the makers of policy and takers of decisions, need to have a good understanding of rural development processes. Improvement of policies and their implementation may happen only if there is an integration of environmental, economic and social concerns into development decision-making (DoE, 1996; Hardi and Zdan, 1997; Moldan and Billharz, 1997).

The monitoring of rural development and land use, is a key requirement in order to produce information for policy-makers and planners and aid their understanding of the development processes.

In monitoring the state of the rural environment it is impossible to measure every variable. Indicators have been succinctly defined as "*quantified information which help to explain how things are changing over time*" (DoE, 1996, p. 1), and well chosen indicators also allow the summarisation of complex information (Bossel, 1999, pp. 8–9; Hardi and Zdan, 1997; Moldan and Billharz, 1997).

A set of indicators, which will convey a more concise impression of the state of the rural environment, needs therefore to be chosen (Adriaanse, 1993). Economic and social indicators (such as gross domestic product and literacy rates) have been widely adopted and routinely influence national, regional and global policy decisions (DoE, 1996; DPCSD, 1996). However, comparable indicators to assess, monitor, and evaluate changes and impact in the state and quality of land resources and the environment (sustainability indicators) are lacking and need to be developed.

To be effective, sustainability indicators must fit into a coherent conceptual and analytical framework covering different aspects of the environment and the development processes. The indicator framework must also be designed for use at different spatial extents (regional, national and local) and organisational levels (administrative and ecological) (Winograd, 1995).

1.3. Tools

The development of a common indicator framework is not the final stage. In order to use indicators policy-makers need tools in order to view, manipulate and combine indicators (Langaas, 1995).

With Geographical Information Systems (GISs) it is possible to overlay and combine georeferenced data from different sources, generating the possibility of an *n*-dimension data analysis. This can transform an indicator model from a conceptual, taxonomic framework, into a more dynamic conceptual tool (Winograd and Eade, 1997). GIS and GIS-based indicators, allow the developers of indicators to produce information according to the user needs, incorporating non-georeferenced data (statistics, tables and graphics) into a geographic environment (maps). The elaboration of indicators and land use models, within a GIS environment, will provide decision-makers with tools to monitor rural development. The creation and provision of user-friendly GIS tools is likely to facilitate not only the transformation of *data* into *information*, but will also aid the formulation of strategies regarding the use of data and information and access to these.

However, GISs should not be seen as a panacea. Given that the data are likely to come from disparate sources the chances of misinterpretation due to poor quality data (Burrough and McDonnell, 1998), metadata (Mounsey, 1991) or more subtly via bias introduced into the final images and maps (Monmonier, 1996) are high. This possibility for misinterpretation — or in the worst cases self-deception (Monmonier, 1996) — needs to be taken into account by both the users and developers. GIS are only the tool, a successful product requires users with the skills to properly use the tools available, an institutional framework that fosters the development and maintenance of an environmental monitoring system, plus good raw materials, in this case data.

2. The World Bank–CIAT–UNEP project

2.1. Designing a conceptual framework

A conceptual framework for indicators is necessary to both guide the creators of indicator sets and to help the final users get the most from the information provided. The World Bank–CIAT–UNEP project (hereafter 'the project') utilises a framework that is based on the identification of development components and issues.

Three components of the development process have been identified, i.e. society, economy and environment, which are in accordance with the framework used by the World Bank in their World Development Indicators (World Bank, 1997a). There are however considerable overlaps between these three components and as a result three other components have been included in the framework, i.e. socio-economic, socio-environmental and econo-environmental components.

Eleven major problems or issues that are encountered in the rural areas of Central America have also been identified ranging from "land use" through "fresh water" to "infrastructure" (for other examples of organising indicators by issues see DoE (1996), Statistics Norway (1995) cited in World Bank (1997b)).

The framework allows for further sub-division using pressure (or more recently 'driving force')–state–impact–response (PSIR) (EPA, 1995). This is the conceptual framework that was used in the first stage of the project (UNEP–CIAT environmental and sustainability indicators for Latin America and the Caribbean).

2.2. Creating an indicator set

2.2.1. Criteria for indicator candidates

Using the 'components' and 'problems' framework it is possible to create a set of indicators based on a number of criteria, namely that the indicators should be

1. measurable,
2. relevant,
3. representative,
4. sensitive to changes,
5. specific,
6. have clear cause-and-effect links, and
7. have targets and baselines.

Similarly there are criteria to be taken into account regarding usefulness for the user:

1. validity,
2. limitation in number,
3. clarity in design,
4. applicability,
5. non-redundancy,
6. interpretation,
7. retrospectivity–predictivity

(UNEP/RIVM, 1994; Rump, 1995; Moldan and Billharz, 1997; World Bank, 1997b).

2.2.2. Consultation process

Both the indicator set and the conceptual framework have been created as a result of extensive consultation with the project partners and future users. The consultation process started with the launch workshop of the project. The participants of the workshop included the project partners (World Bank, CIAT and UNEP), delegates from regional organisations (CCAD, IICA, CATIE, etc.), as well as representatives of relevant ministries/departments (agriculture, environment, planning, statistics, etc.) from each of the six countries. The participants had been previously defined as those who had responsibility for producing information, developing indicators and/or using indicators.

As a result of the launch workshop an extensive list of indicators had been created that were applicable at the different spatial extents (regional, national and local) at which the different participants worked. It was evident that some participants were more comfortable addressing particular issues, such as "forests" whilst others preferred to investigate the development process using the three components society, economy and environment. The result was a set of 63 'core' indicators that were devised in order to give a regional and national viewpoint and 88 'complementary' indicators chosen to give a national or local perspective. Both sets could be organised by either development components or by issues and that broadly met the criteria listed in Section 2.2.1.

After the workshop the consultation continued with visits to each of the appropriate institutions in each country. The feedback from these visits implied only minimal changes to the framework and indicator set. The nature of the feedback suggested one of two things. Firstly that the institutions were satisfied with the framework and indicators. Or secondly that they lacked the capabilities to critically review the results of the workshop and were simply content to work with the framework and indicators in order to make a start in developing their capabilities.

More fundamental changes were made to the framework and, to a lesser extent, the indicators, as a result of meetings of the project partners. There was seen by both the World Bank and UNEP to be a demand for a simpler array of indicators and for a modification of the framework to incorporate aggregate indicators or indices. Classically an index is a number derived from a series of observations (such as from share values in a stock exchange). However in the context of the project an index is the combination of two or more indicators to give a single number or value in order to obtain some signals about the rural development process. The United Nations Development Programme (UNDP, 1996) acknowledges that an index cannot provide all the information that is given in a complete set of indicators let alone which is necessary to understand a complex reality, a point of view endorsed and expanded on by Bossel (1999). However indices remain very useful at regional and national level and there is a demand for them from policy-makers.

As well as the development of indices the project partners were of the opinion that in order to make the framework more understandable to users the number of core indicators should be reduced. The suggested improvement was to reduce the number of core indicators to one indicator for each component/issue for each of the four PSIR categories giving 24 indicators in the case of components or 44 in the case of issues.

The end result is a small set (11) of indices, a larger number (44) of core indicators, and complementary indicators (109).

2.3. *The need for land use models*

As mentioned above, monitoring is essential in order to provide enough observations so that trends in the development process can be analysed, and policies formulated. Trends require observations that are normally only available for the past up to the present. However it is also vitally important for policy-makers to understand how these trends will develop in the short-term future, for instance will the amount of land used to grow crops for export continue to increase and if so by how much? (Fig. 1). Policy-makers have the opportunity to both influence the trends and/or to react to them in the form of strategies and policies. These can subsequently be simulated in the form of

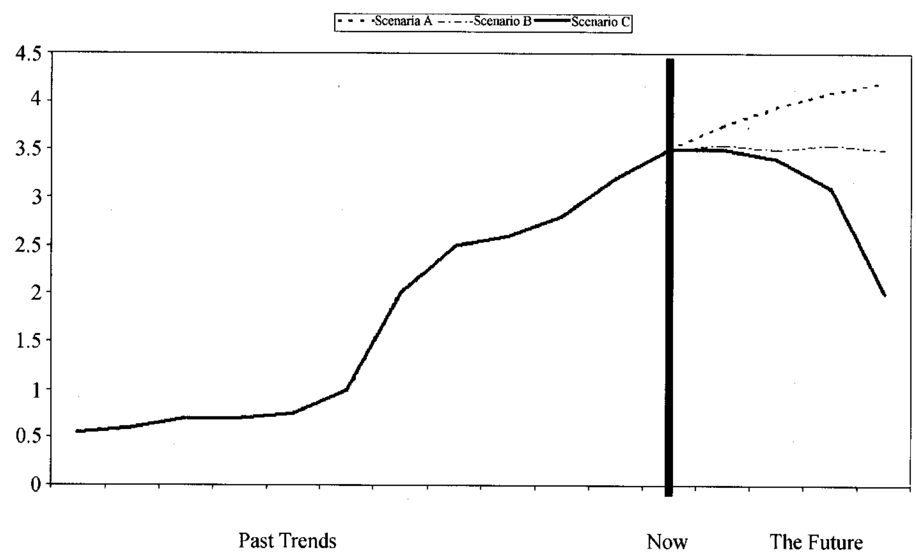

Fig. 1. Projecting trends into the future.

Table 1
Indicators identified that are related to land use change

Name	Component/issue	Category	Direct/indirect
Indices			
(1) Land use index	Environmental/land use		Direct
Core indicators			
(2) Land use change (ha/year)	Environmental/land use	Pressure	Direct
(3) Distribution of crops (ha)	Environmental/land use	State	Direct
(4) Areas affected by erosion, compaction, and salinisation (ha)	Environmental/land use	Impact	Indirect
(5) Land use projections (ha)	Environmental/land use	Response	Direct
(6) Deforestation (ha/year)	Environmental/forests	Pressure	Direct
(7) Forested surface (ha)	Environmental/forests	State	Direct
(8) Forest fragmentation (% of total)	Environmental/forests	Impact	Direct
(9) Reforestation (ha/year)	Environmental/forests	Response	Direct
Complementary indicators			
(10) Agricultural land necessary to feed the population (ha)	Environmental/land use	Response	Indirect

scenarios, which can be incorporated into a model in order to give policy-makers an idea of the possible implications in terms of land use change.

In the case of the project a number of the indicators have been identified that are directly or indirectly related to the change of land use in the near future (Table 1).

2.3.1. Land use index

The land use index is a combination of two indicators: *actual* production systems and *potential* production systems. An actual production systems map has been created for the region (Winograd and Farrow) using agricultural census data percentage figures for three land use classes, namely annual crops (e.g. maize (*Zea mays*), beans (*Phaseolus* spp.), rice (*Oryza sativa*), sorghum (*Sorghum vulgare*)), permanent crops (e.g. coffee (*Coffea* spp.), bananas (*Musa* spp. and hybrids), sugar cane (*Saccharum officinarum*), oil palm (*Elaeis guineensis*)) and pasture (grassland and forages for livestock production). The result is an actual production systems map with six classes (Table 2).

The potential production systems map (Fig. 2) is derived from potential land use maps that have been created in their respective countries (see Appendix A). Soil scientists generally define the classes within these maps and as a result the classes show potential suitable crops or management practices according to soil constraints. These maps have then been re-interpreted in terms of the four agricultural production systems in Table 2 (annual crops, permanent crops, mixed system and pasture). In some cases (i.e. for some countries) this is straightforward whilst in others the potential land use classes do not fit neatly into the definition of production systems.

The land use index is created by simply overlaying the actual production systems map with the potential

Table 2
Production system classes

Production system	Description
Annual crops	Mosaic where majority of cell is annual crops
Permanent crops	Mosaic where majority of cell is permanent crops
Mixed system	Mosaic of annual crops, permanent crops and pasture where no cover type comprises more than 60% of total area
Pasture	Mosaic where majority of cell is pasture
Highly altered	Mosaic where natural cover is the dominant cover but where there is significant amount of productive use
Less altered	Mosaic where approximately 70% of the cell is comprised of natural cover and no other cover is dominant
Natural	90–100% of the cell is comprised of natural cover

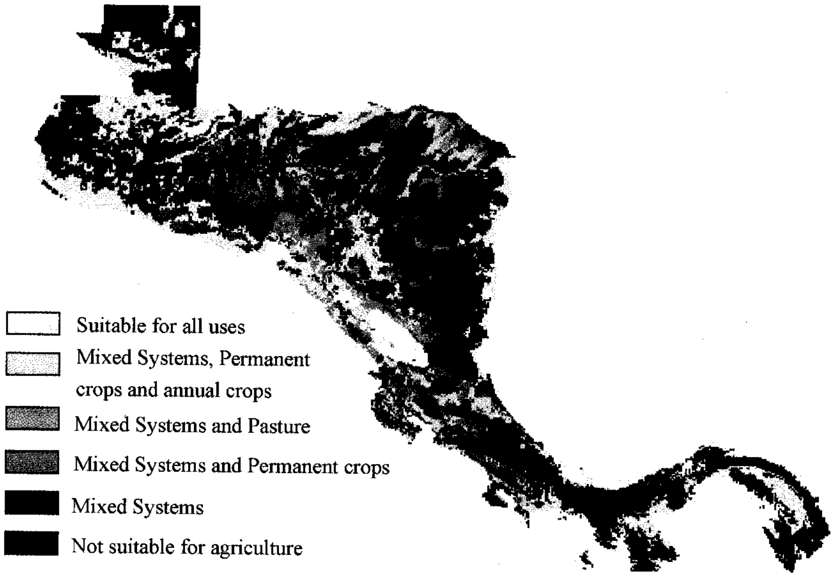

Fig. 2. Potential production systems.

production systems map, this gives four broad classes (Table 3).

2.3.2. *Land use change*

Land use change is generally shown in terms of a change in area for a particular land use/cover class over a specific period of time. Hotspots of change, i.e. where change is rapid or great, can also be calculated. For the project this particular indicator can be represented in terms of a particular crop or of a production system (Section 2.3.1).

2.3.3. *Distribution of crops*

Distribution of crops can be shown either explicitly (unlikely given that the extent of the project is the whole of Central America) or as a percentage area of an areal unit.

2.3.4. *Areas affected by erosion, compaction, and salinisation*

Areas affected by erosion, compaction, and salinisation can be shown either explicitly or as a percentage area of an areal unit. The link to land use, whilst strong, is indirect, a particular land use and land management practices might lead to degradation but more information other than just land use is required (de Koning et al., 2001).

2.3.5. *Land use projections*

Land use projections is probably the simplest indicator to understand and of all the indicators this is the only one that requires a land use model. This indicator can be shown either explicitly in the form of land use maps with generally few classes or as a percentage area of an areal unit with probably more detailed classes.

Table 3
Land use index classes

Land use index class	Description
Appropriate use of the land	The land has the capacity to support the actual production system
Inappropriate use of the land	Land used for a particular agricultural production system where other production systems (e.g. forestry) would be more suitable
Inappropriate agricultural production system	Land used for a particular agricultural production system where an alternative agricultural production system would be more suitable
Potential for agriculture	Land with the potential to be used for an agricultural production system but where these lands are used for other purpose, e.g. secondary forest

2.3.6. Deforestation (ha/year)

Deforestation is one of the most emotive indicators in the set and is seen as a key indicator especially given the carbon sequestration and trading initiatives already underway in Central America. The data that exist for deforestation are generally given per country (WRI, 1998; World Bank, 1999a; FAO, 1997b). Georeferenced maps are not available for all of the countries in the region. Both gross deforestation values can be shown (in terms of % loss per areal unit), and also the deforestation as a percentage of original total area.

2.3.7. Forested surface (ha)

This indicator is the state indicator for the forest issue and in this respect is similar to distribution of crops. Indeed this indicator can also be shown either explicitly or as a percentage area of an areal unit, however given the fact that forests are less dynamic than crop locations it is far easier to obtain spatially explicit data regarding forest surface.

2.3.8. Forest fragmentation (% of total)

Forest fragmentation is the impact of land conversion or forest exploitation decisions. Fragmentation can have a subsequent impact on the viability of many plant and animal species. Fragmentation is difficult to measure since it is the change in form of the forest which is important rather than a gross change in forest surface.

2.3.9. Reforestation (ha/year)

Reforestation is also a difficult indicator to measure, or at least to value. The value of reforestation varies according to the location of reforestation, the amount of reforestation and the type of reforestation. Like deforestation both gross reforestation can be shown (in terms of % increase per areal unit), and reforestation as a percentage of original total area.

2.3.10. Agricultural land necessary to feed the population (ha)

Population growth and consumption pattern and agricultural productivity estimates are the information required to calculate this indicator. The land use model itself will not give results for the first two variables but, depending on the model, may provide results essential in providing estimates of agricultural productivity.

2.4. Criteria for choosing a land use model

The model must be able to give results that can be used as inputs to the indicators described in Section 2.3.

The model itself must be (i) spatially explicit; (ii) applicable at the regional extent; and (iii) understandable and feasible.

2.4.1. Spatially explicit

'Where?' is a question that policy-makers have to ask in order to fully understand the development process and make informed decisions; it is not enough to know simply how much change is occurring. Similarly it is very important to understand the spatial distribution of the driving forces of change.

Atlas CD, the software product from first phase of the project (UNEP–CIAT environmental and sustainability indicators for Latin America and the Caribbean), includes a land use model. Although based on spatially defined lifezones it does not distribute results within lifezones and it does not take variations within lifezones into account during the run of the model (Winograd, 1989). At the planning phase of the current stage of the project it was felt desirable to use spatially explicit *modelling* to give spatially explicit *results* at a more suitable resolution for decision-making in Central America.

2.4.2. Applicable at the regional extent

The region is comprised of six different countries with different consumption and production patterns (World Bank, 1999a) and at slightly different stages in the development process. This factor, the spatial extent and the 34 million actors involved (CCAD, 1998) mean that any model must take into account multiple goals, external macro-economic influences and regional agreements. The model will therefore have to be able to cope with broad regional scenarios.

Given the statements above it is unlikely that goal based (i.e. economic optimisation) models, such as those developed for the Atlantic Zone of Costa Rica (Bouman et al., 1999), could be developed for the region (Seré, 1995; Rivas (CIAT), Estrada (CIAT), Johnson (CIAT), pers. comm.). It must also be remembered that the aim of the project is to help policy-makers in Central America understand the development process. The model should therefore give results that could be used to help in the better definition of targets, the model could therefore be seen as goal orientated but not goal driven.

2.4.3. Understandable to users and feasible

For the project the results of a land use model will be further processed and will be visible to end-users in the form of indicators. In order to ensure that the results are not used inappropriately it is essential that the model is understandable to members of the project team. The project has a fixed timetable and budget and the collection of data and subsequent running of the model and processing of results would have to be undertaken in a fixed time.

2.5. The CLUE modelling framework

The conversion of land use and its effects (CLUE) modelling framework has been chosen as the model to be used to provide results for the World Bank–CIAT–UNEP project. Significant in the reasons for this decision was the fact that CLUE had already been applied, albeit separately, to two of the countries in the region — Costa Rica and Honduras. What is more, through the application of CLUE to Honduras there exist good institutional links between CIAT (the operational centre of the project) and Wageningen Agricultural University (the developers of CLUE).

It is not the purpose of this paper to give a full explanation of the CLUE modelling framework. An explanation of the original CLUE (Costa Rica) model can be found in Veldkamp and Fresco (1996a), whilst for CLUE Central America refer to Kok and Veldkamp (2001). However, it is useful to outline the reasons for choosing CLUE in relation to the criteria in Section 2.4.

2.5.1. Spatially explicit?

The CLUE modelling framework gives results at a spatial resolution consistent with the data that are used in the modelling process. The modelling process itself (i.e. the statistical analysis of driving forces and the subsequent allocation of land use classes) is also spatially explicit.

Another related issue is that of scale dependence with regard to driving forces (Wiens, 1989; Levin, 1992; Nelson, 2001). CLUE statistically analyses driving forces at a number of arbitrary scales allowing the allocation procedure to take into consideration both bottom-up and top-down processes (Verburg et al., 1999b).

2.5.2. Applicable at the regional extent?

Although CLUE has never been applied to more than one country at the same time it has been used in areas as diverse as China (Verburg et al., 1999a) and the Northern Atlantic Zone of Costa Rica. This demonstrates the flexibility of the framework and gives confidence that it could be applied for more than one country.

CLUE is a projectory model and there are no preset goals or targets. Instead it is based on the assumption that land-use is determined by a combination of biophysical and socio-economic driving forces (Veldkamp and Fresco, 1996a; Kok and Veldkamp, 2001). By developing scenarios a number of possible futures can be simulated with the objective being the indication of land use changes (Veldkamp and Fresco, 1996b).

2.5.3. Understandable to users and feasible?

Members of the project team are able to understand how the model works, making it more likely that the results will be well utilised with regard to the indicator set.

Given the experience of running CLUE in the region the data requirements have been appraised at an early stage. The fact that the model relies on data that are essential for many other indicators implies no extra data collection costs to the project.

2.6. CLUE for Central America (CLUE-CA)

2.6.1. Data requirements

The CLUE modelling framework statistically analyses the land use pattern with respect to potential spatial determinants of land use. In order to do this a land use map covering all six countries is required as well as maps of the candidate determinants.

These maps should be harmonised thematically (e.g. the same land use/cover types in each country), temporally (i.e. 1996, the start year of the model) and spatially.

Despite an exhaustive data search this requirement was not immediately satisfied by the available land use/cover data (see Appendix A). Ideally for

CLUE-CA land use/cover maps should be in the form of an area percentage per cover type per administrative unit, i.e. from an agricultural census. However not all of the countries have undertaken agricultural censuses at the same time, and in the case of El Salvador an agricultural census has never been undertaken. Land use/cover maps (generally derived from remotely sensed data) can be used to update or provide greater spatial precision to the maps derived from an agricultural census. However these are not available for all countries and those that exist are from different years and do not have the same classes. Nevertheless enough data were available in order to create a land use map for 1996 (see Kok and Veldkamp, 2001 for a discussion of the data preparation processes) with six land use/cover classes (annual crops, bananas, coffee, sugar cane, pasture and natural areas).

Maps of potential spatial determinants at the same spatial resolution as the land use map are required. In general the biophysical datasets are easier to manage than land cover data since they are more often mapped at the regional extent with consistent classes. Socio-economic driving forces however can be more problematic. Population censuses have been carried out at different dates, although the spatial aggregation units are the same, i.e. third administrative level. These were updated to 1996 figures using FAO national statistics (Kok and Veldkamp, 2001).

2.6.2. Formulating scenarios

Section 2.4.2 outlines the need for a land use model that provides results applicable at the regional extent and for regional policy-makers. Section 2.5.2 showed that regional strategies and policies could be incorporated into the CLUE modelling framework by means of scenarios. These scenarios have to be plausible and, following Section 2.3, can be of two generic types. Firstly scenarios that incorporate policies or strategies that are currently under discussion and which therefore have a realistic possibility of being implemented. Or secondly, scenarios that allow the exploration of what could happen under circumstances outside of the direct control of policy-makers.

Four scenarios have been formulated for CLUE-CA, of which one has six options:

1. Base scenario: (a) 1% growth in GDP, allocated nationally; (b) 3% growth in GDP, allocated nationally; (c) 5% growth in GDP, allocated nationally; (d) 1% growth in GDP, allocated regionally; (e) 3% growth in GDP, allocated regionally; (f) 5% growth in GDP, allocated regionally.
2. Sustainable scenario: 5% growth in GDP, allocated regionally.
3. Protected areas scenario: 3% growth in GDP, allocated regionally.
4. Natural hazard scenario: 1% growth in GDP, allocated regionally.

2.6.2.1. 1a–f base scenario. Yearly economic growth (in terms of GDP) in Central America has averaged at 2% for the 15 years preceding 1996 (the base year) and 4% in between 1990 and 1995, although this included practically no growth in Honduras (World Bank, 1999a). The rate of growth of GDP will have an impact on the demand for agricultural products and, as a consequence, on the use of land within Central America. Three different demand scenarios (1a–c) have therefore been formulated based on plausible increases in GDP in the region during the 15 year model run, i.e. 1, 3 and 5%.

These modifications to the scenario will result in different areas for different land covers that have to be allocated in the region. In CLUE-CA demands are calculated for each country and the resulting areas are allocated within each country's boundaries. However there is a variation whereby the allocation of different land covers is not restricted to within the borders of a particular country (1d–f), i.e. the demand in one country can be met in part by agricultural products from another country. This variation has been included so as to mimic the effects of future integration of the markets of Central America which is a credible scenario given (IADB, 1998).

2.6.2.2. Sustainable scenario. A sustainable scenario is necessary in order to explore viable solutions and potential remedies to the situation in the region that is very complex (Section 1.1). At the same time the development in the region depends in part of the use of the natural resources available in the countries. The 'sustainable' scenario implies that expansion of agricultural area at the expense of natural vegetation will be minimised. To optimise agricultural production and yields and ensure stability, productions systems will be located in the most appropriate areas and the crops grown as part of that production system will be those that have the greatest potential yields.

This scenario implies economic growth at the upper end of the plausible spectrum (5%), increased export, import, and intra-regional trade as well as a hypothetical technological improvement leading to increased yield per year and a reduction of waste losses for each crop. The most realistic strategy for managing many subtropical and tropical areas is the rehabilitation and restoration of altered and deteriorated ecosystems. Another strategy is to give priority to productive integrated systems (mixed systems, agro-forestry, extractive activities, etc.).

2.6.2.3. Protected areas scenario. This scenario is a conservative response to the possibility of what is known as the Meso American Biological Corridor (MBC) (CCAD, 1998; World Bank, 1999b). It is conservative in the sense that no new areas will be protected, which is one of the proposals of the MBC. Demand is projected to develop as in the base scenario with 3% GDP growth, but most importantly no agricultural areas are allowed in areas that have a protected status.

2.6.2.4. Natural hazard scenario. Based on data collected after hurricane Mitch and its effect on Honduras and Nicaragua in particular and Central America in general. In this scenario certain lowland areas will be flooded and production from those areas will be restored gradually from zero production over the course of 5 years (Kok and Winograd, 2001).

2.7. Why just the results?

It might be argued that, since this is a user-driven project, the users should have full access to CLUE-CA. However this is both undesirable and impractical.

It is undesirable from the point of view that the users and partners have already been consulted with regards to formulating scenarios. Putting these scenarios into practice requires a great deal of experience and the possibility that end-users become confused and disillusioned could be high.

It is impractical because model run-times would be too long for the average policy-maker and the results would need to be further processed and analysed.

Another reason for just including the results of the model is that the objective is to incorporate the results into the indicators listed in Section 2.3, it should not be forgotten that the project is fundamentally concerned with providing information in the form of indicators.

2.8. How to use the results

The results of the CLUE modelling framework are given for 1972 $15 \times 15\,km^2$ grid cells into which the region has been split. Each cell has area percentage values of each of six cover types: annual crops, bananas, coffee, sugar cane, pasture and natural areas. These results are given for every year of the 15 year model run (1996–2010), and for each of the nine scenarios.

This works out at $1972 \times 6 \times 15 \times 9$ (1,597,320) pieces of data. These then have to be processed to provide inputs to the indicators listed in Table 1.

2.8.1. Land use index

The land use index is a combination of actual and potential production systems (see Section 2.3.1). The 'potential production systems' indicator is assumed to be constant for the duration of the model run (since the original potential land use maps are generally based on bio-physical constraints which are assumed to be constant). Maps of possible future production systems, derived from the model results (Section 2.3.1), replace the 'actual production systems' indicator. The index can be calculated for every year of the model run and for each scenario (Fig. 3).

2.8.2. Land use change

The land use change indicator is relatively easy to calculate from the results of CLUE-CA, and simply involves comparing figures for each cover type for each cell between the start and end of the model run (Fig. 4). It is possible to monitor the changes in area for a particular cover type for every year of the model. However interpreting this information is extremely difficult.

Changes in production systems can also be calculated although because each cell is considered homogeneous the number of change possibilities is more difficult to map than a simple change in percentage for a particular land cover type.

Showing land use change (in terms of cover types) in tabular or graph form gives no more information

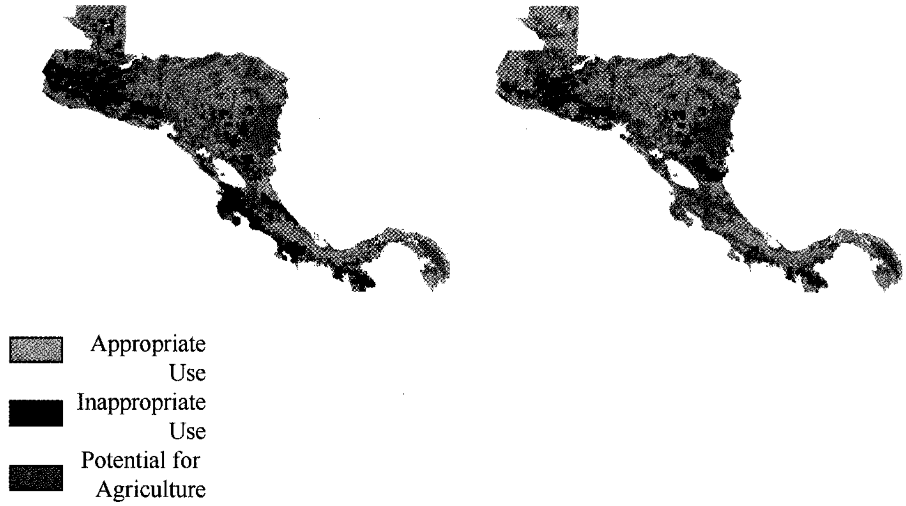

Fig. 3. Land use index maps 2010: protected areas scenario and sustainable scenario.

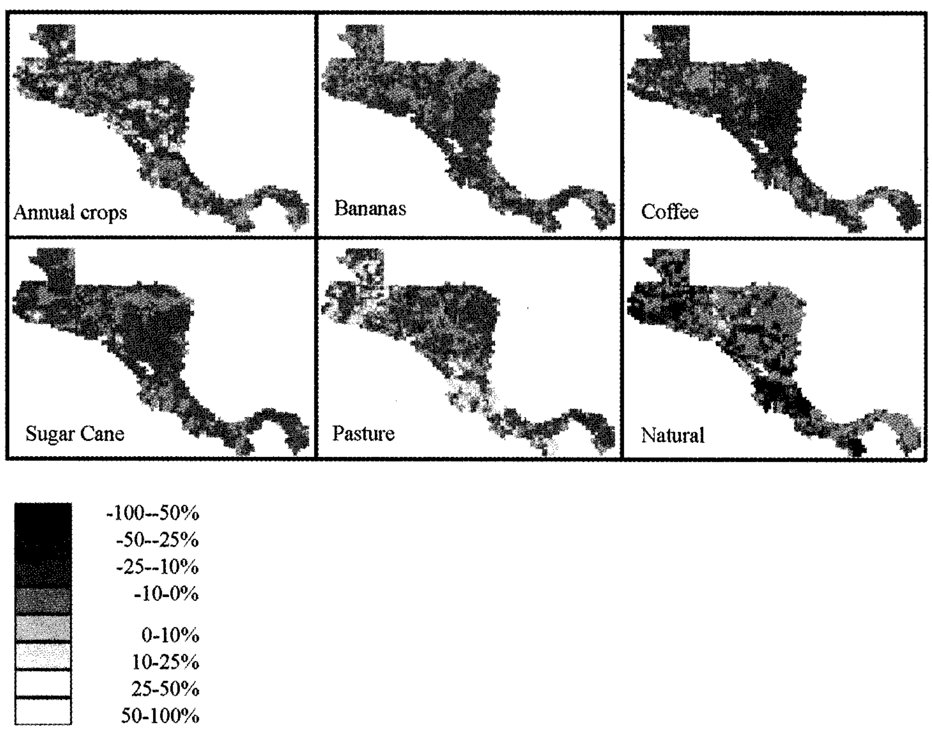

Fig. 4. Land use changes 1996–2010: sustainable scenario.

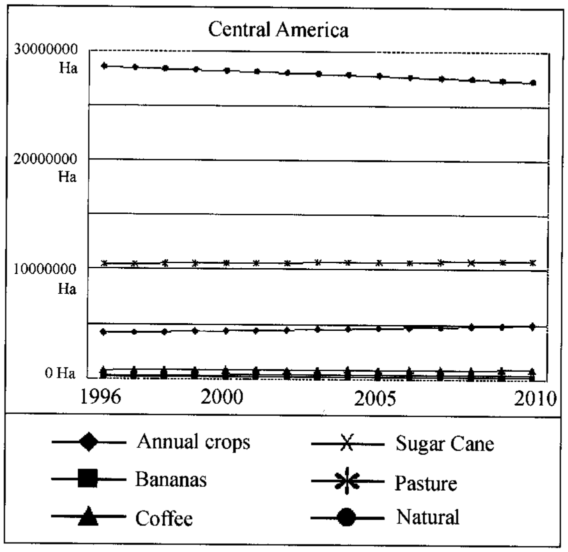

Fig. 5. Land use change figures for Central America: baseline scenario (with 3% GDP growth).

than is provided by the demand model of the CLUE framework (Fig. 5). This tabular information may be useful in its own right especially for policy-makers who will be comfortable with graphs. However it gives neither an impression of where the changes are taking place, nor what the implications are of any changes in land use. If land use change data are to be shown in tabular or graph form then it is more appropriate to show production systems, firstly because it is difficult to visualise these changes in a map, and secondly because the production systems describe the mosaic of cover types in each cell. Production systems figures are not given by the demand module of CLUE-CA but are derived from the results of the allocation process. They therefore give more information about the land use structure of the region than cover type figures alone (Fig. 6).

2.8.3. Distribution of crops

The purpose of this indicator is to show the general areas where specific crops are produced. However there is a lack of resolution in the results obtainable from CLUE-CA. From the six cover type area percentages that the model provides the permanent crops (bananas, coffee and sugar cane) and pasture could be used as an input to this indicator. However it would be impossible to split up the annual crop

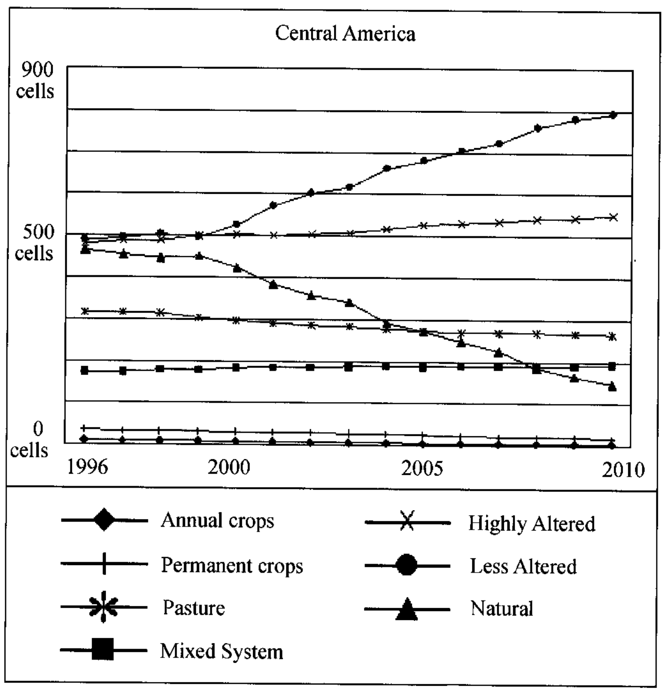

Fig. 6. Production system change figures for Central America: baseline scenario (with 3% GDP growth) allocated regionally.

cover type into its constituent parts, i.e. beans, maize, rice, etc.

A more general problem concerning this indicator is the lack of consistent crop data for the region in temporal, thematic and spatial terms. The purpose of the model results is to provide some pathways to compliment the information available on trends. However if the data are not available to deduce trends then it is inconsistent, and more than likely extremely difficult, to provide this information for the future based on the same historical data.

2.8.4. *Areas affected by erosion, compaction, and salinisation*

The CLUE modelling framework does not give results that could be used directly for this indicator. Any results would have to be combined with other types of data. The only way to derive information on degradation from land cover data is in combination with some information regarding how susceptible the land is to degradation and what land uses are viable in order to avoid degradation. Unfortunately these data do not exist for the whole region. However by looking at the location of production systems, derived from the results of CLUE-CA, in relation to potential production systems then the areas where land is being used "inappropriately" can be determined. Inappropriately used areas may be more likely to suffer from degradation than areas used appropriately. This is one of the classes shown in the land use index (Section 2.8.1) (Fig. 3) and this index could be used to use to indicate possible future areas of degradation. However given the quality of the data the land use index can act only as a very general 'red flag' and as a comparison between scenarios.

2.8.5. *Land use projections*

This is the primary indicator for showing the results of CLUE-CA. There are a number of options regarding the visualisation of this indicator. The simplest

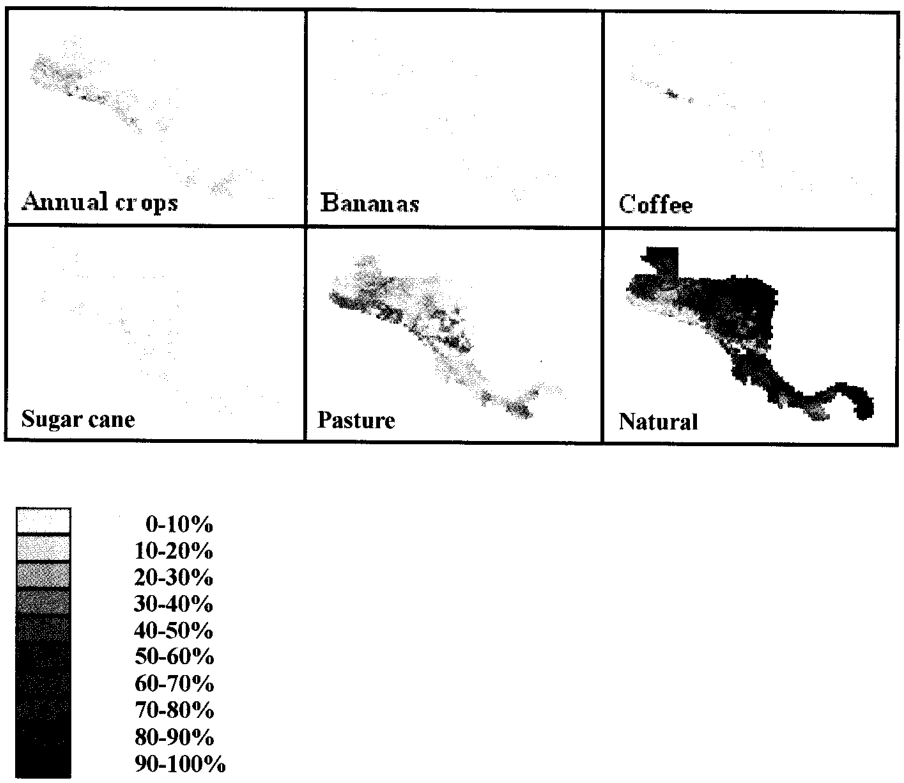

Fig. 7. Land use projections 2010: sustainable scenario.

(in terms of processing the results) is to show the area percentage of each cover class for each scenario (Fig. 7). This will result in 810 maps! This number can be reduced by showing only the final year of the model run, however this still results in 54 maps. Comparing the results for scenarios will be difficult, especially for users with little experience of analysing information in a spatial format.

One way to reduce the number of maps is to combine the cover classes so that each cell has a single class value. This would make cross-scenario comparisons easier as well as allowing comparisons using tables. The results of CLUE-CA can also be used to create a map of possible production systems (Fig. 8). The only complicating factor is how to handle the natural areas that are found within the model cells. To achieve this the production systems classes can be expanded to include non-agricultural classes (Table 1).

2.8.6. *Forested surface*

This indicator, like that of crop distribution is limited in the sense that the historical data are not consistent for the region. However the problems are considerably less severe because the location and extent of forests are less dynamic than those of individual crops. Generally the resolution of the data will be different since for the historical data georeferenced maps are available whilst CLUE-CA gives area percentages for grid cells. Nevertheless the results can be used in their own right especially for comparing scenarios.

2.8.7. *Forest fragmentation*

The purpose of this indicator is to assess the degree of fragmentation that exists at present and how this has changed. Fragmentation of forests has important implications for fauna and flora. However, what constitutes fragmentation differs according to species. For instance some mammals require blocks of 10,000 ha per individual, whilst insects may only require 1 ha (Reid et al., 1993). To measure this type of fragmentation would require a greater resolution than the CLUE-CA model delivers, since a cell size of $15\times15\,km^2$ gives a block of 22,500 ha and it is not possible to determine the land use structure within the cell. The cell size used in CLUE-CA is dependent on the

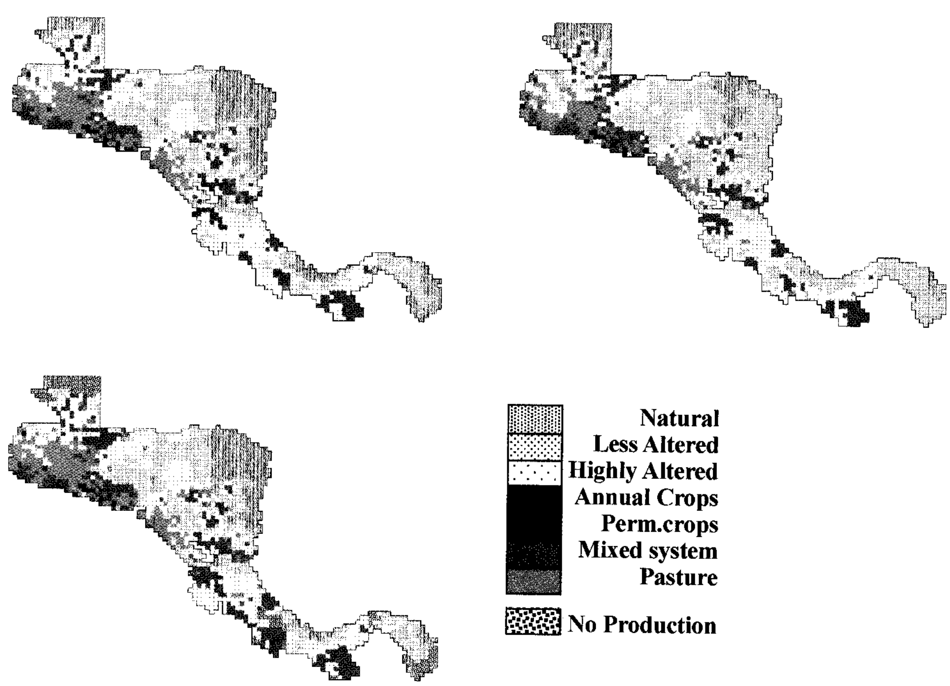

Fig. 8. Production systems maps 2010: baseline scenario (with 3% GDP growth) allocated nationally, baseline scenario (with 3% GDP growth) allocated regionally and baseline scenario (with 3% GDP growth) allocated nationally but with protected areas.

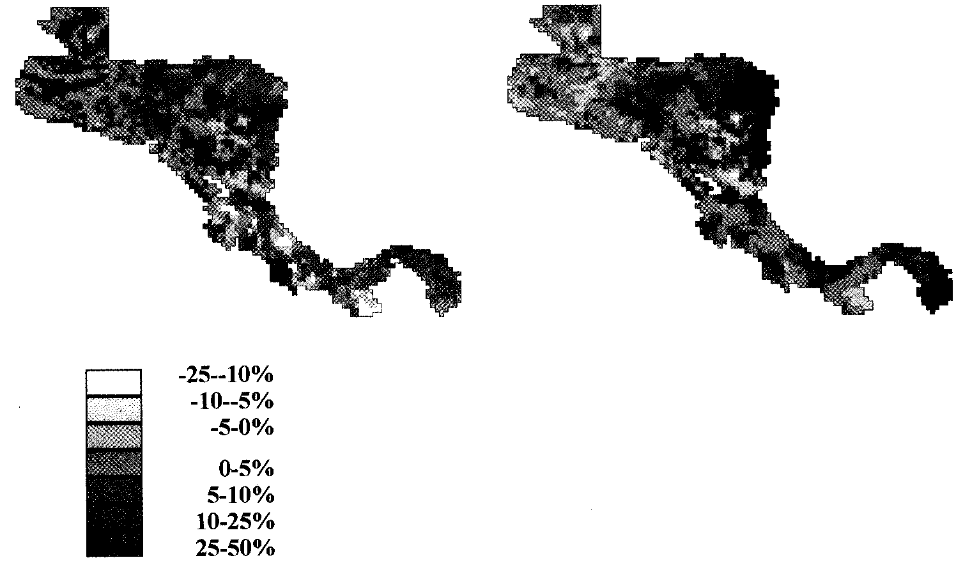

Fig. 9. Deforestation/reforestation total maps 1996–2010: baseline scenario (with 3% GDP growth) allocated nationally, baseline scenario (with 3% GDP growth) allocated regionally.

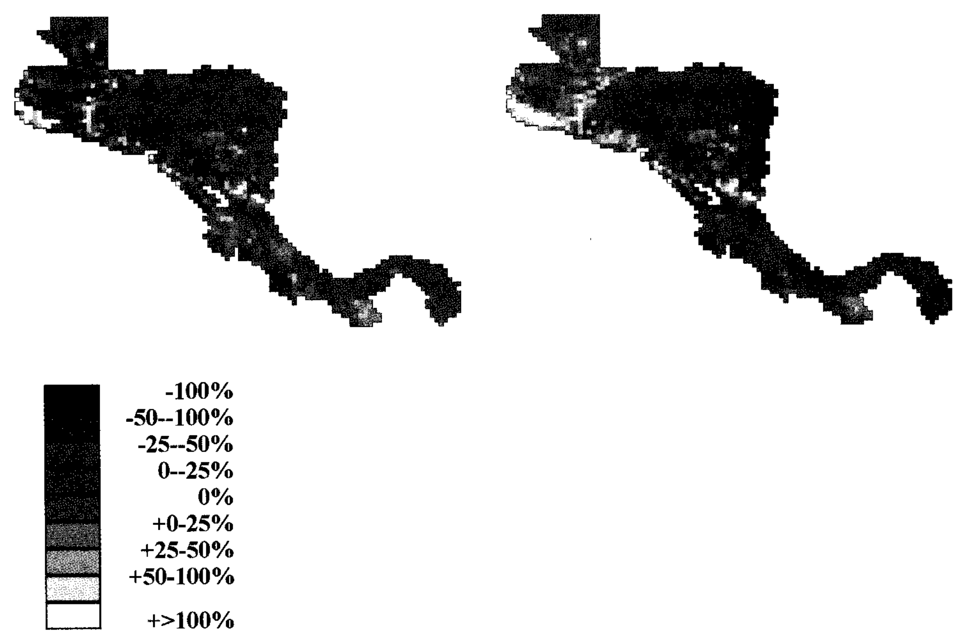

Fig. 10. Deforestation/reforestation % maps 1996–2010: baseline scenario (with 3% GDP growth) allocated nationally, baseline scenario (with 3% GDP growth) allocated regionally.

source data, and only an improvement in the resolution of this source data will allow for the investigation of forest fragmentation.

2.8.8. *Deforestation*

It is possible to obtain deforestation figures from the results of CLUE-CA on a cell by cell basis, and by calculating the changes in natural area percentage between the start and end of the model run. Both gross deforestation values can be shown (in terms of % loss per cell) (Fig. 9), and also the deforestation as a percentage of original total area (Fig. 10).

2.8.9. *Reforestation*

Any reforestation data are similarly aggregated to individual countries. Like deforestation the results of CLUE-CA can be shown by calculating the changes in natural area percentage between the start and end of the model run (Figs. 9 and 10). It is impossible to tell from CLUE-CA how much of any increases in natural areas are the results of tree planting (reforestation) and how much is natural re-growth due to abandonment (afforestation).

2.8.10. *Indirect indicators — agricultural land necessary to feed the population*

The results of CLUE-CA will automatically show the actual amount of agricultural land necessary to feed the population under different scenarios. The demand module takes into account the differing levels of income, inputs, technological improvements, food imports/exports, etc. and calculates the amount of agricultural land accordingly. This area is then allocated throughout the country/region.

While the results of CLUE-CA cannot be used for this indicator they could potentially be used to explore the question of intensification and expansion of agricultural land.

The land use index (Section 2.8.1) addresses the issue of productivity and yield by showing how appropriately the land is being used. Since potential production systems are generally derived according to biophysical constraints and opportunities (MAG, 1996) the appropriate use of the land suggests that yield is being maximised. Similarly those areas with potential for agriculture may possibly be used more productively (in terms of food energy yields for the population). Different scenarios show different patterns of appropriate or inappropriate land use (Fig. 3).

3. Discussion

The purpose of the World Bank–CIAT–UNEP project is not to analyse the indicators that have been compiled. Instead the objective is to provide policy-makers with information in the form of indicators, and tools with which to view and query these indicators.

Similarly it is not the purpose of this paper to discuss in depth every nuance of every indicator that has benefited from the input of the results from CLUE-CA. However examples of these indicators show how users could interpret the results from CLUE-CA.

Fig. 8 shows production systems for three scenarios, baseline scenario (with 3% GDP growth) allocated nationally, baseline scenario (with 3% GDP growth) allocated regionally and baseline scenario (with 3% GDP growth) allocated nationally but with protected areas. All three scenarios assume the same growth rate and the areas of the six cover types (calculated by the CLUE-CA demand module) will be the same for each scenario. The differences between these three scenarios are due to the manner in which the cover type areas are allocated. This allocation procedure can have a big impact on the production systems derived from the % of cover types in each cell. It can be seen that the locations that have 'natural' production systems are very different when comparing the national allocation and the regional allocation. The areas with greatest differences would appear to be the Petén region of northern Guatemala, the Atlantic coast regions of Honduras and Nicaragua, and the Darien region of Panamá. This example clearly shows how policy-makers could compare the results of two scenarios to see what the possible impacts of closer integration might be and where these impacts might occur.

The third scenario in Fig. 8 assumes that all protected areas will be non-productive. This means that there is less area in which the allocation module in CLUE-CA can distribute the annual crops, permanent crops and pasture. In the protected areas scenarios all cover type areas are distributed nationally. By comparing the production systems of this scenario with the baseline scenario (also distributed nationally) it can be seen that the greatest area of difference appears to be in Costa Rica. The area of the country with a pasture production system changes significantly even though the actual area of land under pasture does not change. This does not necessarily imply that pasture is moving from the protected areas to other areas but simply that in the baseline scenario the cells defined as protected areas are able to incorporate pasture.

Fig. 3 also shows how scenarios can be used to assess the potential impacts of decisions taken by policy-makers. Two scenarios are shown, the first is protected areas scenario and the second is the sustainable scenario. When comparing the scenarios clear differences can be seen between the areas that are used appropriately and those that are not, or that have potential to have agricultural production. The two scenarios shown in Fig. 3 are extreme, and for many other cross-scenario comparisons it is difficult

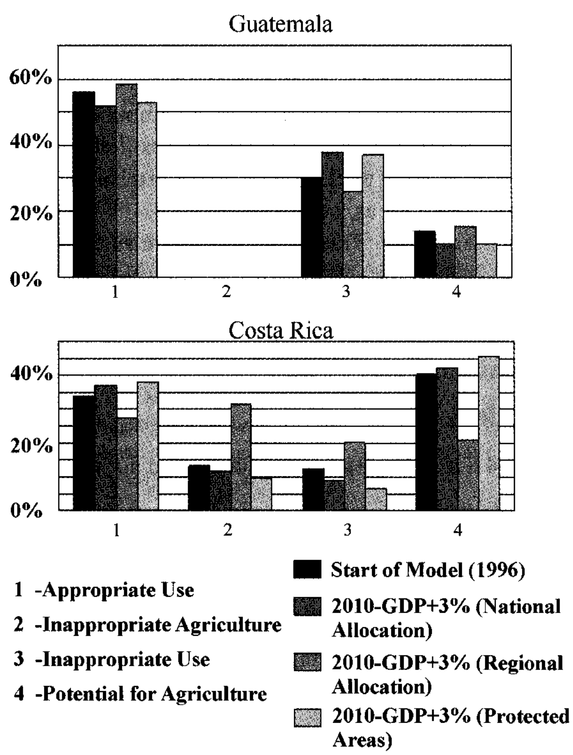

Fig. 11. Land use index figures for Guatemala and Costa Rica from three scenarios: baseline scenario (with 3% GDP growth) allocated nationally, baseline scenario (with 3% GDP growth) allocated regionally and baseline scenario (with 3% GDP growth) allocated nationally but with protected areas.

to get an impression of the changes. It may therefore be more useful to show these comparisons in the form of tables, and, as mentioned in Section 2.8.2, policy-makers may prefer to view the information in this format. Fig. 11 gives a broad national view of the differences between the scenarios. This table includes another class that is not shown in the map, i.e. "inappropriate agriculture". In this figure it can be seen that this class is not found in Guatemala, this is due to lack of thematic resolution in the potential production systems map of Guatemala (Fig. 2). In the case of Guatemala only two potential land use classes are shown, one of these where there is potential for all production systems and the other where there is no potential for any agricultural production.

4. Conclusions

The example above highlights a very important issue, i.e. when using a projectory and empirical model the data that are used as inputs are constraints to obtaining accurate results. It is fair to say that in the case of CLUE-CA the data available are at the limits of being suitable. However there was neither a better data set at the time of collection, nor is there likely to be in the near future. Lack of resources and political will are the causes of the availability problems of agricultural census data. Looking to the future, national land use maps (probably derived from satellite data) offer hope for harmonisation in temporal and spatial terms. However they are unlikely to give the thematic resolution that is available from an agricultural census. It should also be noted that CLUE works best when land cover types are given as percentages for specific areas, rather than homogenous land cover areas. Rather than wait forever for the perfect data set it was decided to use what was available.

It should also be noted that the data used in CLUE-CA have come from the same institutions as the policy-makers we are targeting with the indicators and tools. Demonstrating to these users what can be done with 'their' data has the effect of giving ownership to the indicators, as well as reinforcing the importance of introducing data quality standards.

This is the first time that the model has been applied for more than one country however it is obvious that the lack of harmonisation, and the measures taken to overcome it, have introduced errors into the data. Without more knowledge about the original data it is difficult to assess the reliability of the end results, especially where the results have been interpreted and combined with other (possibly unreliable) data, as in the case of the land use index (Section 2.8.1). However sensitivity analyses were undertaken and the model has been successfully validated for Costa Rica and Honduras (Kok et al., 2001).

In conclusion it should be remembered that this is the second stage in the use of land use models and indicators by the project team. Despite the fact that not all of the indicators defined as potential recipients of inputs received these inputs, the results of CLUE-CA definitely add a new dimension to the indicator set. Providing these indicators in combination with easy to use information systems will give decision-makers in Central America the tools to aid their understanding of rural development processes.

The work undertaken to develop the land use models and subsequent indicators was achieved only with the full collaboration of academic, research/development and policy-making institutions. The success of this partnership bodes well for future collaborations.

Acknowledgements

The work described in this paper has been carried out in collaboration with the CLUE group of Wageningen University in order to provide information for the project "World Bank–CIAT–UNEP Indicators of Rural Sustainability: An Outlook for Central America". The authors would like to acknowledge the funding and support received from the Centro Internacional de Agricultura Tropical (CIAT), the World Bank, and the United Nations Environment Program (UNEP). For more information on this project please refer to the project website: http://www.ciat.cgiar.org/indicators/index.htm.

Appendix A. CLUE-CA data inventory

Required data. Land use with information on annual crops, permanent crops, pasture, forest and secondary vegetation per administrative unit.

Actual data available:

Guatemala

- Geo-referenced forest map 1992. No non-forest classes.
- 1979 agricultural census. Data at third admin. level.

El Salvador

- Geo-referenced land use map 1993.
- Very comprehensive classes, includes temporary, permanent crops plus pastures.
- No data quality assessments and there is nothing to compare this map with.

Honduras

- Geo-referenced forest map 1995. No non-forest classes.
- 1993 agricultural census. Data at third admin. level.

Nicaragua

- *Land use map 1992*. This has two classes of interest: perennial crops and 'agro-pecuario'. The digital version of this map has a number of errors, for instance Lake Managua is classified as agricultural land whilst there are coastal areas that are classified as water bodies.
- *Encuesta 1995*. This source therefore suffers from the relative coarseness of the resolution (regions — between second admin. level and country level) as well as the fact that the figures are only estimates.

Costa Rica

- 1984 agricultural census data at third admin. level.

Panamá

- 1990 agricultural census data at third admin. level.

Required data. Population with information on rural and urban density per administrative unit.

Actual data available:

Guatemala: 1994,
Honduras: 1988,
El Salvador: 1992,
Nicaragua: 1995,
Costa Rica: 1984,
Panamá: 1990.

Required data. Climate with information on rainfall, temperature and length of dry season.

Actual data available. CIAT climate database with monthly temperature and rainfall data for 1363 stations within Central America. Rainfall surface created using inverse distance weighting interpolation method. Dry season surface created from precipitation figures, where 60 mm constituted a dry month. Temperature was not included because of the strong correlation to altitude.

Required data. Digital terrain model with information on altitude and slope.

Actual data available. USGS GTOPO30, 1 km resolution Digital Elevation Model. Slopes were derived from this source.

Required data. Soils with information on drainage, soil depth and soil fertility.

Actual data available. FAO — soils map of the world. Values for drainage, depth and fertility were added by hand using information from FAO soils handbook.

Required data. Yield at sub-national level.

Actual data available. None.

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