GIS-based rationalization of indicators and eco-balances for a sustainable regional planning

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1. Abstract

Sustainable Development as a concept is generally widely accepted. The crucial issue is its operationalisation. This paper starts from the assumption that both words are intuitively tight together implying that there is “development” and consequently “change”. Therefore it is hypothesised that these changes will leave footprints on the earth’s surface and we still will be able to detect and measure subsequently the resulting “manifestations” within the environment. When utilising technology such as GIS and remote sensing it turns out that many existing approaches are not spatially explicit and are limited in their ability to regionalise indicators and eco-balances which is necessary for a decision making at least at national and sub-national scales. The examples are mainly focusing on land use which is a kay factor of human-driven alterations of landscape throughout the world.

2. The operationalisation of sustainable development needs spatial thinking and spatially explicit approaches

Sustainable Development as a concept is generally widely accepted. The crucial issue is its operationalisation. Both words are intuitively tight together implying that there is “development” and consequently “change”. I hypothesise that these changes will leave footprints on the earth’s surface and we have to detect and measure subsequently the resulting “manifestations” within the environment. Sustainable Development is a concept for a process of change in which attitudes and behaviours are modified so that, in endeavours to meet needs, achieve aspirations and preserve options for future generations, individuals and communities will enhance and maintain their well-being. Sustainability reflects the long-term conditions of a system.

There is much work on the international level of biodiversity and sustainable development since the Rio-conference. But there is a need for a specifically spatial approach to differentiate biodiversity and sustainability in practice. Because of limits to population and economy growth, accessible resources are limited spatially and finite quantitatively. This is also relevant to the technically driven disciplines Geographic Information Science and Remote Sensing (RS). General aims must be to maximise natural economic effectiveness and efficiency and attain and maintain a necessary balance among resource accessibility, requirements, and capacity to meet requirements. Specifically, we need rules for GIS and RS to consider qualitative aspects and to integrate qualitative and quantitative information.

The need for spatial data and spatial tools lead to a conceptual framework in dealing with geographic objects. Meanwhile dozens of text books on GIS and remote sensing exist and both technologies are somehow ‘mature’. Although it seems to be clear that data are representations of the real world, implying abstraction and simplification, advances in digital representations and cartography transfer results to end users which are often regarded as being ‘the truth’. A nice colourful map with sharp boundaries plotted on a high quality professional printing device increases an unreflected usage of results (Blaschke 2001). GIS and Remote Sensing are regarded as mature technologies and methodologies, respectively. Their common capabilities cover a wide range of the needed monitoring and management task. Achieving information, analysis, monitoring and management are highly related, but the state of the art of GIS progress is different. In natural resource management GIS is a cost-effective means of analysing data in support of e.g. forestry applications, notably timber yield estimations. Three operations are particularly significant in explaining this early interest in GIS applications for natural resource management: area measurement, superimposition and analysis of maps of different themes (e.g. soils and forest types), and the generation of buffers of specified width around map features, such as streams. This means that data analysis often is complex and highly correlated with management tasks.

3. Spatial information for decision making

Decision makers have to decide what we must adapt to, what we must control, what we should alter, and what we should leave as is. The behaviour change required by Sustainable Development offers possibilities for achieving a better quality of living surroundings. The concept of Sustainable Development appears more and more in the limelight of the international communities’ activities. This is very good, but it also leads to the fact, that many politician are using this term unreflectedly and at a superficial level. In the Brundtland Report it is stated, that the capacity for technological innovation needs to be greatly enhanced in developing countries so that they can respond more efficiently to the challenges of sustainable development. Other authors look more critically on technology-driven methods and favour political-oriented approaches.

GIS cannot be a solution to environmental problems but a powerful tool. In the right hands, it can be a catalyst for effective and sustainable environmental management (Blaschke 1997, 2001). In landscape ecology, these tools are more and more used adequately, while in population analysis still the potential seems to be much higher than the benefit for current applications. For many nature conservation tasks, there is a need for legislative measures of biodiversity and for an effective use and co-ordination of current data of biodiversity to deploy the available human resources. We need data collection strategies as well as concepts for compiling and transforming existing data. Metadata is becoming increasingly important. Documentation what data sets are found where, what they contain, and how they are put together forms the basis for the development of data directories. Long-time efficient - in other words: sustainable - use of heterogeneous and never complete data of complex ecosystems needs a responsibility for data acquisition, management and documentation and the rights to determine the conditions under which data are accessed and used ("Custodianship").

4. Land use as a key concept: footprints of development

Land use is concerned by settlement planning, traffic engineering, tourism and agriculture. It is difficult to predict future land use – the development of population, needs, the further opening of the market (e.g. in eastern Europe). Nevertheless the development must be supported by flexible tools, which allow for planning and optimisation land use sustainability. Because of the rapid development of information instruments and tools for sustainable development there is an increasing need for evaluations, inter-comparisons and appropriate harmonisation on a regional level in a European context. Only the diversification of underlying activities, land use and landscape management, and the involvement of the people concerned give the opportunity to be prepared for the future. The author believes, that we today have the technical possibilities to diversify these needs and to rank and regionalise them.

GIS covers a wide range of the needed monitoring and management tasks reflecting the long-term conditions of a system. Although in natural resource management GIS is a cost-effective means of analysing data in support of e.g. forestry applications, there is little experience in a spatially explicit use of environmental indicators for sustainable land use planning. Once environmental indicators are defined, they will be divided into regional indicators that cannot be differentiated within a given area (e.g. administrative boundaries) and spatially explicit indicators. Using fuzzy rules and techniques such as pycnophylactic interpolation, these two different spatial levels of information will be integrated. Thus, employing geostatistical analysis and developing a new set of ‘regionalisation metrics‘ different grades of sustainability will be calculated based on an heterogeneous set of indicators using their spatial dimension as a connector. One main goal must be to enable stakeholders and non-expert users to facilitate spatial analysis and make results available to the public.

5. Indicators and eco-balances

Notwithstanding all harmonisation and standardisation attempts, a huge variety of indicators for sustainability exists. They focus on environmental, economic, societal, psychological, communicative, and political processes. Many of them are already introduced and routinely used in some European countries and the USA.

One of the most influential environmental indicator model stems from the OECD (1994), in which 30 classes of indicators (OECD Core Set) are differentiated and integrated in the so-called Pressure-State-Response (PSR) framework. It is stressed here that the most basic criteria of this indicators design are policy relevance, analytical soundness, and measurability. Pressure includes all the human activities (e.g. energy, transport, agriculture) damaging the environment, state means the conditions of the environment and the natural resources, and response describes mainly the individual, collective and societal actions (1) "to prevent human-induced negative impacts on the environment", (2) to "halt or reverse environmental damage", and (3) to "preserve or conserve nature and natural resources" (OECD, p. 12).

Unfortunately, most of these indicators are not spatial in nature and some pressure-response systems are only valid for certain regions. Let us focus again on land use: As increases in the populations of developing countries place pressure on the land so does land consumption for economical activities and housing in the developed countries. This “land consumption” pressure has been among the causes of misuse or poor management of soils, exacerbating other processes that lead to soil degradation in developing countries but is has much different consequences in countries like Austria and Germany: What most pressure-response models do not explicitly take into account is the fragmentation and isolation effect of remnants of both agricultural and natural areas dissected by roads and residential areas. While in developing countries mainly farmland must be carefully conserved and managed so as to preserve and enhance its productive potential most developed countries mainly in Europe have too much agricultural production.

Erosion by wind and water, salinity, reduced organic-matter content, poor cropping systems and nutrient removal in harvested crops are major causes of the degradation of cultivated soils. Non-agricultural uses, such as urbanization, industrialization, mining, roads and housing, have permanently removed much high-quality land from agricultural use. Such land loss, added to land degradation, increases the pressure on woodlands and forest areas. Deterioration or destruction of these in turn can have serious consequences for agriculture, including accelerated loss of soil quantity and quality.

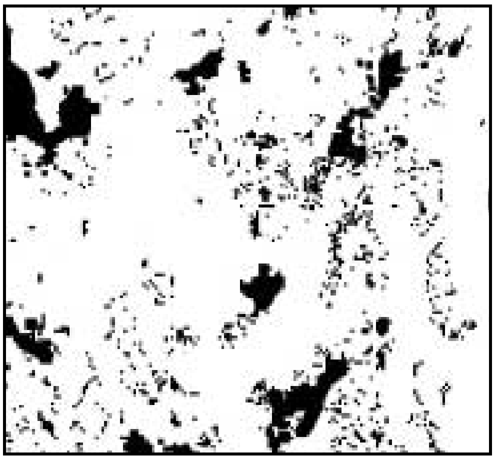
Another example is soil and agricultural productivity. Arable agricultural lands differ greatly in quality. With similar inputs, crops grown on land that is only marginally suited for arable agriculture will yield perhaps half as much or less than those grown on neighbouring good land. In general, and particularly in densely populated rural areas of developing countries, the quality of remaining undeveloped land is inferior to most land now in use for agriculture. On all continents, farmers have made local improvements in soil quality to increase productivity. Globally, however, the productivity of land under crops (and pasture) has declined for various reasons, including greater use of land that is only marginally suitable for the kind of agriculture practiced on it.

Use and production of new tools and models can enhance the integrated and sustainable development. Some first results from two several ongoing EU-projects demonstrate that an optimisation of the specific potential of each area, including all regional level, the diversification of activities, land use and landscape management, and the involvement of the people concerned give the opportunity to be prepared for the future (Blaschke 2001, Lenz et al. 2001). Within an international consortium of research partners, the potential of a rationalisation of indicators is currently extensively investigated. Several GIS-based planning tools have been developed with the aim to assist decision making in regional development. Consequently, GIS is becoming the core of a decision support system which shows the impact of change scenarios on the indicator set developed using the regional eco-balance approach.

6. Regionalisation of indicators and regional eco-balances

Understanding land-use changes and their ecological implications presents a fundamental challenge to ecologists (Dale et al. 2000, Turner et al. 2001). Throughout the world, land cover is altered principally by direct human use – by agriculture, raising of livestock, forest harvesting, settlement, construction, mining etc. Land-use activities change landscape structure by altering the relative abundance of natural habitats and introducing new land-cover types. Introduction of new cover types can increase biodiversity by providing unique habitats, but natural habitats are often reduced. Land-use activities may also alter the spatial pattern of habitats, often resulting in fragmentation of once continuous habitat and in reduction of biodiversity. Natural pattern of environmental variation can also be altered by landuse, especially if disturbance regimes are changed (e.g. flooding in riparian forests, wildfire in grasslands etc.). A recent report from a committee of the Ecological Society of America adressed the ecological implications of land use (Dale et al. 2000). Six principles of ecology with particular implications for land use were identified. These principles deal with time, species, place, productivity, disturbances, and the landscape. The recognition that ecological processes occur within a temporal setting implies that change over time is fundamental to analysing the effects of land-use. In addition, individual species and assembladges of species have strong and far-reaching effects on ecological processes. And even the shape, size and spatial composition of patches of different habitats or land-use classes on the landscape influence the structure and functions of ecosystems.

These facts necessitate to encounter a spatial approach to indicators. It is strongly suggested to researchers from various field dealing with environmental indicators to embedd the ideas and findings of landscape ecology in their research. Landscape ecology is a relately young discipline. With its roots in various different fields, landscape ecology is among other objectives coined by its spatially explicit approach. Parallel to recent development in GIS, remote sensing and the wide accessebility of advanced computer technology landscape ecological research developed a specific approach, sometimes called landscape metrics. Increasing numbers of projects focus on the analysis and description of spatial geometry. Landscape ecology is currently very much concerned with the problems of understanding landscape elements, their composition and interrelations. This is an important field and has not gain a comprehensive commonly agreed methodoly although there is an increasing amount of theoretical and empirical research. But dealing with landscape elements, defining them, measuring and modelling their sizes, shapes and spatial distributions is only the very obvious frontside of an inherent and scientifically more difficult task: Landscape ecology deals with the problems of understanding, modelling and managing complex systems in the physical environment (for an overview see Forman and Godron 1986, Forman 1995, Turner et al. 2001). The spatial indices describing patches and their spatial compostion and whole landscapes is commenly called ‘landscape metrics’. Landscape metrics evolved over the last years ten to fifteen years in North America and focus explicitly on spatial pattern of landscapes and ecosystems with a recent expansion in the German speaking countries (see Blaschke 2000).



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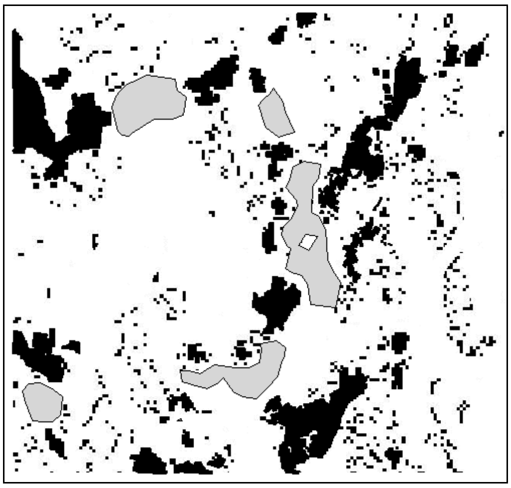

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Fig. 1: One small examples illustrating the importance of spatial configuration (simplified from Blaschke 2000).

Figure 1 shows an example of spatial planning to increase connectivity of remnant forest patches in an european cultural landscape (Province of Salzburg, Austria). Connectivity of some relevant larger patches should be increased with limited resources. Therefore, suitable areas with a high potential of increasing the connectivity of existing patches had to be identified (for an easier understanding, forest stands are black, all other land use classes are white). b: most suitable areas to increase connectivity. There are many more examples which underpin the importance of WHERE patches are, which SHAPE and FORM or even GESTALT they exhibit and HOW FAR the distance to the next patch of the same or another land use class is. These are just examples from a wide variety of interesting and challanging research questions to again show the shortcomings of many existing indicators which originate from ‘non-spatial’ disciplines (see also Wiens 1997, Farina 1998).

The approach of regional eco-balancing combines the classical landscape planning (predominantly for the protection of environmental compartments and recreation properties as zones in landscapes) with a balancing of a distinct, but - in terms of environmental protection - broad set of environmental indicators for (effect) eco-balances. Hence the latter becomes spatially related. By taking on board stakeholders and establishing an information system a high practical relevancy and acceptance of the final users can be achieve. This has been proven in some case studies which balance environmental impacts in a map scale of 1:10.000 - 1:50.000, in order to provide a district administration with tools for an environmentally sound and sustainable development of their region (Lenz 1999). Lenz points out that eco-balancing is already a classical tool of ecological planning, but the term was successfully (re) introduced by business management because of the origin of balances in economy. If there are classical ecological planning units and procedures (e.g. regions, landscapes, watersheds, and related tools like land consolidation) then we should consider the already developed approaches as well as the high importance of having „state of the art“ sustainable indicators. These indicators and the further quantification of their status are the basis of the quality of every eco-balancing, besides the tools provided by environmental informatics.

7. Outlook

With computers becoming more widely available and inexpensive worldwide, the proposed spatial approach is being used or adapted in software everywhere in the world including developing countries. This allows for a worldwide storage, retrieval and appraisal of data on land resources. The system's special usefulness derives from its capacity to "overlay" map layers featuring a locale's different characteristics such as topography, land use, infrastructure, soil types, water availability and population. Advances in soil science, surveying, photogrammetry and remote sensing underlie the evolution of the GIS.

Despite the key roles played by soil and water in agriculture, many developing countries have not given a high priority to preventing the misuse and degradation of these resources, nor to enhancing them where feasible. Science and technology can provide the tools: surveys of quantity and quality, assessments of potentials, methods and inputs for protection and development, means for monitoring and evaluation. But to put these tools to work requires national action commensurate with the severity of problems.

Technologies for land with high potential for agricultural production have benefited from research but knowledge on how to improve production on marginal land remains inadequate. Some so-called improved technologies tend to expose farmers to greater risks and so have met with only limited acceptance and use, especially by poor farmers in marginal areas. Recent research and development efforts have led to better technologies that can also help reverse soil degradation. However, the correct use of land has emerged as the best means of avoiding the problem. Better tools have been created to provide the information essential for planning and monitoring the proper use of land.

Table 1: Indicators, balance- and system-units and possible calculation rules (for farm types, municipalities, districts and regions) only shown for the example of 'AREA'

	Balance units	System units
'Area consumption'	municipality/region	land use type
'Resource consumption raw materials' (e.g. mining)	areas with raw material resources	mining areas, effected groundwater; natural regional (sub) units

	Calculation rules (examples)
'Area consumption'	Area of soil sealing, volume of dumps; ratio area consumption to soil quality / yield potential and habitat quality
'Resource consumption raw materials' (e.g. mining)	Amount and rate of material mining; degree of refilling: biotope restoration and construction; construction of lakes; impact on groundwater

Explanations for Table 1:
Indicators or key parameters in case of an eco-balance are used to express the state and the eventual deviation of the actual environmental situation from an environmental quality standard.
System units are areas (systems) of the same parameterisation, e.g. agricultural sites or habitat types. Hence they are the smallest homogenous areas to be balanced. In order to get a balance for an administrational or natural unit they have to be summed up.

References

Blaschke, Thomas (1997), 'Sustainability with GIS? Towards a proactive nature conservation approach.' In: Johnston, J. and Gomarasca, M. (eds.), *New Developments in GIS*, Ann Arbor, 198-209.

Blaschke, Thomas (2000), ‚Landscape Metrics: Konzepte und Anwendungen eines jungen Ansatzes der Landschaftsökologie im Naturschutz’. In: *Archives for Nature Conservation and Landscape Research* (39), 267-299.

Blaschke, Thomas (2001), ‘Environmental Monitoring and Management of protected areas through integrated ecological information systems – an EU perspective’. In: Rautenstrauch, C., Patig, S. (eds.): *Environmental Information Systems in Industry and Public Administration*. Idea Group Publishing, London, 75-100.

Dale, Virginia, Brown, S., Haeuber, R.A., Hobbs, N.T., Huntly, N., Naimann, R.J., Riebsame, W.E., Turner, M.G., Valone, T.J. (2000), ‘Ecological principles and guidelines for managing the land use: A report from the Ecological Society of America’. *Ecological Applications* (10), 639-670.

Farina, Almo (1998), *Principles and methods in landscape ecology*. Chapman & Hall, London, pp. 235.

Forman, Robert, T. (1995), *Land mosaics. The ecology of landscapes and regions*. Cambridge University Press, Cambridge. pp. 632.

Forman, Robert and Godron, Michel (1986), *Landscape Ecology*, Wiley and Sons, Chichester. pp 619.

Lenz, Roman (1999), ‘Landscape Health Indicators for Regional Eco-Balances’. In: Pykh/Hyatt/Lenz (eds.): *Advances in sustainable development: Environmental Indices – Systems Analysis Approach*. EOLSS Publisher, Oxford: 12-23.

Lenz, Roman, and 8 partner organisations (2001, unpublished), EIRIE: *European-wide Inter-comparison for Regional Indicators and Eco-balances as tools for sustainability*. Proposal submitted to the European Commission in the EESD programme: Energy, Environment and Sustainable Development, Part A: Environment and Sustainable Development

Turner, Monica, Gardner, Robert, o’Neill, Robert (eds.) (2001), Landscape Ecology in Theory and Practice. Pattern and Process. Springer, New York.

Wiens, John (1997), ‘The emerging role of patchiness in conservation biology’. In: Pickett, S et al. (eds.): *The ecological basis of conservation. Heterogeneity, ecosystems, and biodiversity*. Chapman & Hall, New York, 93-106.