Satellite Images for the Detection of Changes in Rural Landscapes: a Landascape-Ecological Perspective

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ABSTRACT

Environmental and ecological impacts are not only the results of changes at individual sites, but also of changes in spatial patterns in relation to different functions in the landscape. Remote Sensing images deserve a greater role as information source for the deduction of different functional characteristics at the landscape and regional scale. In this paper, SPOT and TM images, and a limited number of spatial operands are the heuristic basis for the landscape ecological interpretation of rapidly changing rural landscapes in Belgium and in Normandy (France). Both areal (grassland and crop types) and linear (hedgerows) features and their spatial patterns determine to a great extent major environmental characteristics. Spatial descriptors applied on classified images are a useful tool for modelling habitats of species such as the Barn Owl (*Tyto alba*) and the Badger (Meles meles]. As the detectability of ecologically important features such as hedgerows is limited, using 20 m resolution images, one should evaluate the sensitivity of landscape system parameters, such as connectivity, to image resolution. Results of analysis performed on satellite based land use maps are compared with those obtained from aerial photographs.

INTRODUCTION

Environmental impacts of land use changes are not only to be expected on the site of the change, but may affect larger areas through complex pattern-process interactions. Renewed approaches in landscape ecology increasingly deal with such interactions (Forman & Godron, 1988; Zonneveld, 1991). For instance, the density, size and mutual distance of habitats affect the survival and migration possibilities for wildlife. Agricultural systems can also be described in landscape-ecological terms, not only because of their relation to soils and other site conditions, but also because of their environmental and economic behaviour that is conditionned by factors that have a spatial characteristic, such as connection (road systems, transport), field fragmentation, barriers (e.g. buffer strips, fences etc.) (Gulinck, 1991). Even, the behaviour and the aesthetic experience of humans in the landscape is a process that is influenced by specific spatial arrangements of observed landscape elements (Steinitz, 1990).

Next to a set of models concerning pattern-process relationships on the earth's surface, landscape ecology provides clues to practical problems in land use planning and management. One of the major bottlenecks in landscape ecology is that it is information intensive, operating at different scale and time levels and recognising the fundamental role of spatial heterogeneity.

Quattrochi & Pelletier (1991) give an overview of the possibilities of remote sensing for landscape ecology based on the analysis of the relation between the concept of scale in landscape ecology to that of resolution of remote sensing systems. The hierarchy theory, which states that there are certain spatial levels in which certain processes occur (O'Neill et al., 1986; Woodmansee, 1990) can be helpful to design the information gathering process in landscape ecology, including the way in which remotely sensed data can be used. For instance, the dispersion of birds can be influenced by the pattern of woodland patches across kilometer areas, fully in the reach of remote sensing systems such as SPOT. In this sense, it is interesting to investigate which kind and scale of spatial (landscape) patterns can be analysed using specific remote sensing images, in function of certain ecologically relevant processes and planning issues.

In this paper we present some pathways of research, whereby SPOT images can be used to endorse landscape ecological research, or as basic information source in landscape planning and in the modelling of environmental impacts of land use changes. The resolution of these images is an a priori restriction to the scale level at which this can be done. So emphasis will be put on phenomena at the

"landscape scale" and at the regional scale, scales at which typically also land use and its changes are described. Fig. 1 depicts a conceptual model of the relation between remote sensing and landscape ecology.

1. BASIC LANDSCAPE TYPOLOGY USING SPOT IMAGES

In our research we have adopted the philosophy whereby the basic image analysis and classification can be relatively relaxed in terms of land cover discrimination. The emphasis is on pattern and on stable land cover types. The major limitation is the detection of fine grain landscape features such as small woods, hedgerow networks etc, that may have an important landscape ecological rôle. But given the hierarchy concept, it can be assumed that the omission of spectral, temporal and spatial details may be relatively irrelevant at certain abstraction levels. This sheds a specific light on the problem of classification accuracy. The issue in this sense is not so much how detailed the information should be, but rather how coarse the information is allowed to be for specific levels of landscape ecological applications. A further relaxation lies in the fact that the growing archives of images steadily increase the possibilities for landscape analysis, since landscape changes are generally measured in time periods of years, whereas applications such as agricultural crop discrimination need images at critical phenological stages within a single growth season.

Two levels of land cover classification are applied:

i) based on per pixel maximum likelihood algorithm: areal classes such as cropland, grassland, woodland

ii) based on specific image analysis techniques such as edge detection and contextual analysis: the improvement of the classification of linear features such as roads and hedgerows.

The research started as an analysis of visual characteristics of open spaces. The reason of this choice was among other, the fact that rural areas in northern Belgium are subject to dramatic changes because of badly controlled urbanisation of the countryside. This is very much a man-oriented approach, in which the position of an observant in the landscape is a basic parameter. It was further assumed, based on litterature concerning environmental psychology, that the best approximation of perceived landscape qualities was through the analysis of characteristics of size, shape and complexity of open spaces.

Hence the development of a basic landscape typology which assumes following steps:

- a basic land cover dataset, agglomerating the basic image classification results into:
  - "mass" classes: woodland, urban features
  - "space" classes: crops, grassland, open water
- the definition of basic landscape "objects", units composed of contiguous pixels of the same class
- the selection of basic spatial operands: it is assumed that most spatial characteristics can be indexed using the criteria:
  - distance between pixels or objects
  - connectivity between pixels
  - texture (possible arrangements of pixels or objects of specific type within windows of specific size) - texture measures yield landscape charac-

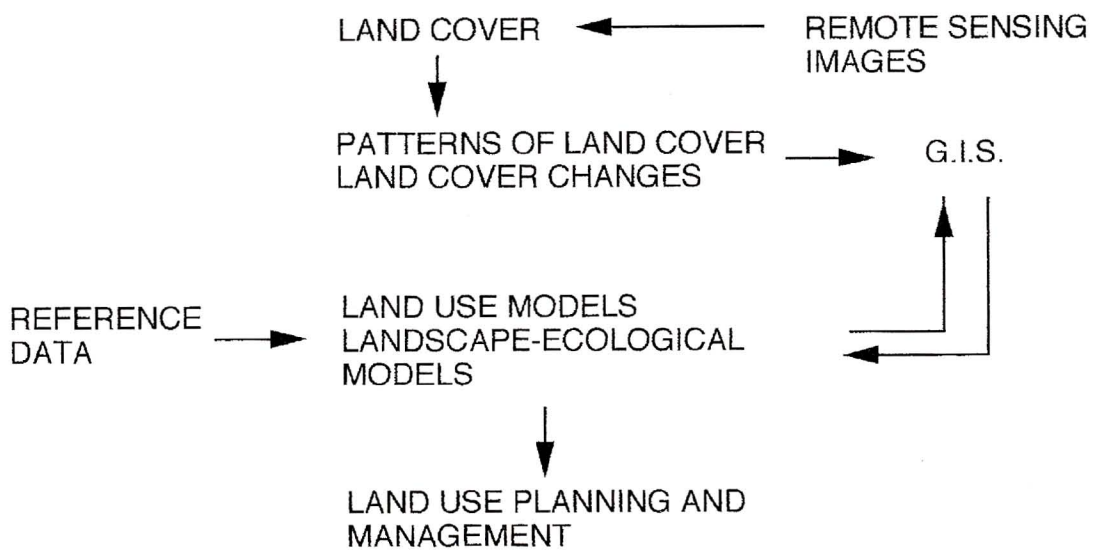

Fig. 1 - Conceptual model of the relation between remote sensing image analysis and theoretical and applied landscape ecology.

teristics such as land cover diversity, fragmentation, dominance, contagion
  - polar or radial signature (distance relations of pixels or objects towards a central point, sampled at specific angular distances) - polar measures yield characteristics such as viewshed size and form, visual complexity
- the definition of landscape characteristics that are i) nontrivial in general terms of landscape analysis and planning and that ii) can be derived profitably using the spatial operands described here above:
  - the size of spaces
  - the form complexity of spaces
  - the angular variation in land cover
  - the number or diversity of land cover types
- the scale division of these landscape characteristics in such a way that they yield the "best" discrimination between landscapes.

This last point can be questioned in the sense that here we indeed force a classification system into existing concepts or perceptions of regional landscapes in Belgium. It is however greatly helpful in learning the range of spatial landscape conditions that can be modelled based on remotely sensed information and in learning the impacts of classification errors, window sizes, sampling sizes etc. These factors have been described in earlier papers.

The resulting landscape typology or variants are the basis of assessment of visual and ecological qualities, and can be used for as an evaluation basis for landscape changes (Dufourmont et al., 1991).

2. HABITAT MODELLING AT REGIONAL LEVEL

Remote sensing images such as SPOT can principally be used in providing basic input information for landscape models based on the heterogeneity principle. Yet, concepts such as heterogeneity are ill defined and scale sensitive, and even scale itself has no unique meaning (Turner & Gardner, 1991). The above described methodology can be tuned for finding landscape patterns that fit the requirement of species, or eventually also populations and communities. Pilot species in our study are the Barn Owl (*Tyto alba*) and the Badger (*Meles meles*).

We start from a dataset that is discrete with respect to its grid format, the basic land cover classes and the delineation of landscape objects.
Since the methodology is fully described in other papers for the Barn Owl (Andries et al., subm., Dufourmont et al, 19919911), a short list of the steps will suffice here:

- Acquirement of reliable data on presence of nesting sites over a sufficiently large area
- Definition of quadrats or circular areas of certain size around the nesting locations
- Application of the structural landscape descriptors (areal size, etc. as given above) in these areal units, based on the basic land cover classification derived from SPOT or TM data
- Canonical correlation analysis for finding the spatial characteristics that best discriminate between nesting and non-nesting sites
- Using the results as a probability model for extrapolation to areas outside the test-region
- Validating the results and sensitivity analysis.

The results are promising. In fig. 2 the result is given for the Badger. The study area is located in the south of the Province Limburg (eastern Belgium), an agricultural area characterised by extensive loess plateaus and grassy valleys with Secundary outcrops of chalk. SPOT data used were K44-J247 XS, May 1st, 1990. So far, decisions on the size of the areal units, angular sampling rate, division of spatial parameters into classes etc. were tentative. Optimisation of this procedure using trial and error and expert knowledge, can provide new information on the habitat characteristics of the organism. Furthermore, this can result in a model that gives insights in the impacts of land use change.

The approach here described is similar to the one adopted by Harms & Opdam (1990) who used size and isolation as discriminating landscape characteristics. The partial information input from satellite images can however greatly facilitate such investigation. Another useful comparison is with field and expert based models, such as the model Meles (Heijnen, 1990) which describes the carrying capacity of the home range of the Badger, from which impacts of land use changes can be derived.

3. CONNECTIVITY ANALYSIS

In landscape ecology, increasingly attention is given to flows of different kind (materials, energy, water, organisms, information).
In the case of organisms, this finds its expression in the research on landscape conditions and structures that facilitate or guide the movement and migration of plants, animals and diaspores between landscape parts. This concept is also referred to as connectivity (Baudry and Merriam, 1988), not to be confused with the pixel-neigborhood relations in image analysis, cf. section 1.

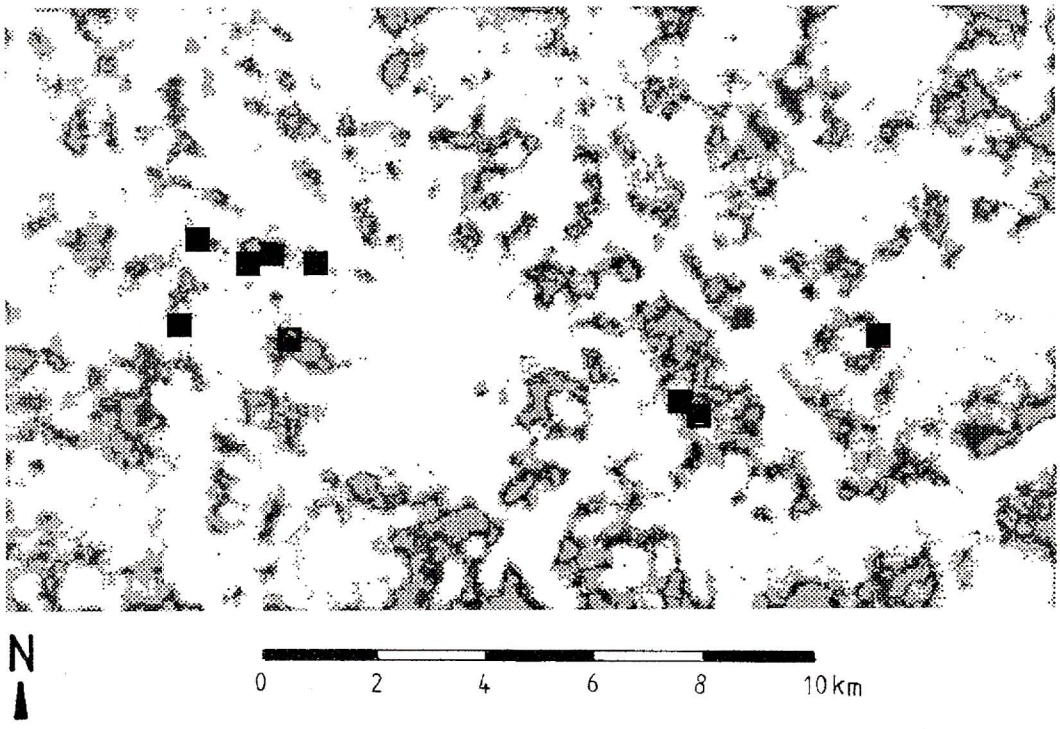

Fig. 2 - Habitat model for the badger: black quadrants: known sites; dark gray: very high habitat probability; gray: high habitat probability; white: low habitat probability.

The landscape-ecological concept of connectivity is closely linked to that of corridor (Soule and Gilpin, 1991).

In an earlier paper (Gulinck et al, 1991) we discussed the possibilities of SPOT imagery in mapping hypothetical corridors in the landscape, corridors being material structures such as hedgerows, valley bottoms etc. along which organism preferentially move or migrate (Baudry & Merriam, 1988). In that paper, the higher described heuristic operands (distance, connectivity etc.) were used for the generation of hypothetical corridor-like patterns, based on criteria such as distance and intervisibility between source and destiny ecotopes.

Early concepts of ecological corridors were based on vectorial approaches whereby links are established between nodes (ecotopes) along vertices that correspond to prelocated units such as hedgerows or channels. The grid format of the classified satellite images however, allows to consider the total space as potential link between ecological patches. In this case, woodland patches were considered as general source or destiny units. Each source unit "radiates" into the surrounding landscape, whereby the organisms face resistances dependent on the kind of land cover encountered on their trekking. Hence, following connectivity factors were considered:

- source factors: - size of each source patch
  - kind of each source patch (to differentiate intrinsic niche 'quality' differences
- path factors: - resistance per kind of land cover - the negative influence of certain landscape units, such as urban or industrial areas.
  - distance limit related to the maximum radius that a species can migrate per time unit.

This, of course, is a deductive approach that is still general, coarse and speculative. It should be refined in parallel with landscape ecological insights, in more specific applications, the different factors should be species and landscape specific. For the time being, however, the influence of certain factors can already be tested, such as grid resolution and the omission of landscape detail. Preliminar investigation was performed on SPOT(1987) and TM(1990) data over a test area in Normandy, France, a typical hedgerow/grassland landscape. The satellite data were first classified in a more or less exhaustive way, in order to preserve the maximum possible information on the hedgerows. For comparison, datasets were prepared in the same resolution, based on aerial photographs of 1955 and 1991, topographic maps, and a field survey.

In fig. 3 the land cover classification is given for the three datasets (SPOT-TM, Reference-55 and Reference-91). According to the aerial photographs and field survey, there has been a substitution of grassland for cropland of 8.3%, and a decrease in total length of hedgerows with 8.47%, during the last four decades.

Pixelwise comparison of the SPOT-TM classification with the 1991 reference map yielded an apparently poor overall accuracy of 43.5%, due to a confusion between meadow and orchard classes (34.5%). This can be explained by the difference between a strict per field approach in the reference map, versus the pixel approach in the classification procedure. Clearly, the real landscape shows up all gradations and mixtures between pure meadow landcover and crown closed orchard. Hence the value and at the same time relativity of ground truth data. As one can expect, these approach-related confusions should neutralise each other over a relatively large dataset in a non-spatial comparison, which is confirmed by the global 82.5% accuracy level.

An additional feature in the same dataset might show the importance of a clear definition of the parameters in observation: The pixelwise comparison of hedgerows shows a commission error of 14%. Obviously, optimizing a classification procedure in terms of detection of small landscape elements can partly explain this commission factor. Yet a detailed analysis of both maps and knowledge from the field survey shows that cartographic symbology, in casu: small lines for any type of hedgerow, does not always match the real landscape structure: in the Nor-

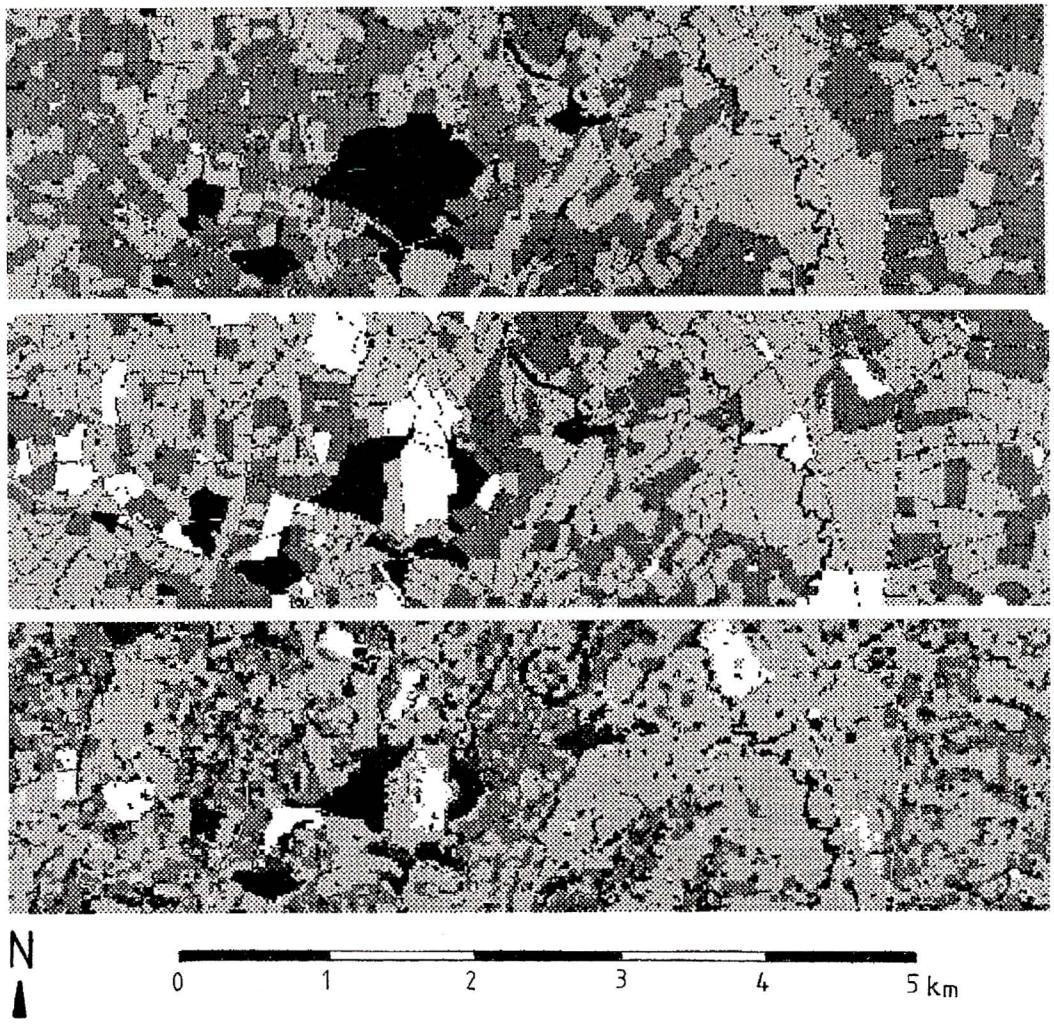

Fig. 3 - Landuse maps north east of Livarot (Normandy, France); black: forest stands; dark gray: orchards; pale gray: arable land; white: roads and builtup areas.
a: 1955 (based on aerial photographs and topomaps)
b: 1991 (based on aerial photographs, topomaps and field survey)
c: 1990 (classification result based on SPOT panchromatic and Landsat TM imagery).

mandy case, hedgerows at either side of roads and ditches may be in total more than ten meters wide such that relative surface figures from a grid-tranformed reference map underestimate the share of hedgerows.

In this general exercise on functional connectivity, hedgerows are assumed to have the least resistance, next to woodland patches. Negative influence was introduced in the model from builtup areas and roads, whereas in the residual background matrix growing resistance factors were assigned from orchards over meadow to arable land. Any woodland or hedgerow 'object' larger than 100 pixels of 10x10 m was considered as a source node with maximum internal connectivity value. From the edge of these nodes, the connectivity degrades gradually in all directions. Fig. 4 gives the result of the connectivity analysis.

Keeping in mind the spatial arrangement of landuse types from fig. 3c, one immediately recognises its effect on the connectivity dispersal.

Repeating the same procedure based on the reference map yields some interesting differences between satellite based analyses, and traditional map based analyses. Here again the difference in ground coverage of the hedgerows as previously discussed, results in a more differentiated spatial connectivity pattern for the satellite based approach, corresponding better with the real landscape structure. Still, the satellite based approach fails through the non-continuous detection of the local road pattern, thus reducing their negative influence radius.

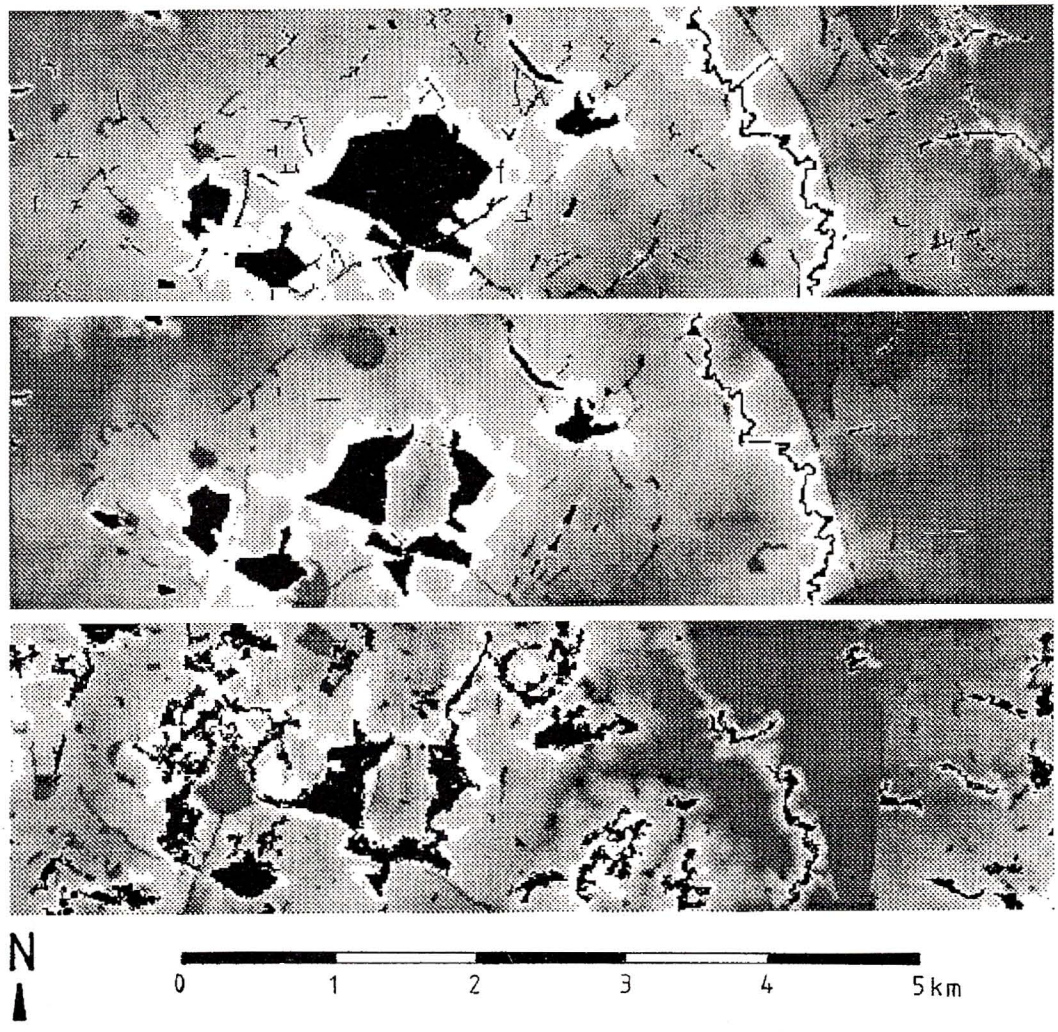

Fig. 4 - Connectivity analysis: black: forest stands and large hedgerows, used as source nodes for the analysis; white to dark gray gradation corresponds with degrading connectivity values.
a: 1955 (derived from landuse map based on aerial photointerpretation)
b: 1991 (derived from landuse map based on aerial photointerpretation)
c: 1990 (derived from landuse classification based on satellite imagery).

DISCUSSION AND CONCLUSION

Success of application of remote sensing should not only be sought through trials of fitting of its information into our current concepts of environmental organisation, but also by the attitude that these concepts themselves can be profitably enhanced by using the specific content and format of this information.

This argument is especially valid since landscape ecology is still itself an immature science, but both its own development and its applications can be enhanced by a parallel development of remote sensing and GIS techniques. The deductive approach used here shows that it is possible to deduce landscape ecological qualities based on general structural parameters of the landscape. It seems promising to combine this approach with field and expert based, rather inductive approaches, which may substantially improve the linkage of landscape ecological relations across geographical scales. The satellite image based models can be considered as neutral with respect to landscape characteristics that are difficult to extract by remote sensing, such as road traffic intensity (often a major barrier factor), soil characterics or management practices.

Furthermore, the methodology is promising in practical issues of landscape planning. Especially the planning of major ecological structures in the frame of nature development may be helped with spatial landscape models derived from satellite images, since the models are easily applied over large geographical areas.

Compared with "classical" remote sensing applications such as land cover classification, landscape oriented applications are still in an early stage of development. Considerable gains may be expected through careful research strategies in which the combination of landscape models, image analysis and G.I.S. is further investigated.

ACKNOWLEDGEMENT

This paper presents research results of the Belgian scientific research program in the field of space-borne remote sensing. We are grateful to the Services of the Prime Minister - Science Policy Office, for the financial and coordinating support. The scientific responsibility of this paper is assumed by its authors.

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