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Satellite image interpretation (SPOT) for the survey of the ecological infrastructure in a small scaled landscape (Kempenland, Belgium)

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Abstract

This paper deals with the problem of the detectability of the field pattern and the associated linear elements in the Kempenland (Belgium) using SPOT multispectral imagery. The SPOT images are edge-enhanced in order to put the ecological infrastructure in a clearer image display. The detectability is investigated in relation to the size and the shape of the land blocks. The influence on the detectability on SPOT images of the kinds of linear elements, bordering the land blocks, is investigated as well. The use of edge-enhanced SPOT images for (ecological) network analysis (connectivity and circuitry) is also discussed.

Introduction

This study deals with the potentialities and constraints of satellite image interpretation for the detection of ecological structures and patterns. The latter topics are only treated briefly, in a general way. The maps resulting from the study are intended as a basis for further detailed research by ecologists. The study area was chosen specifically for evaluation of the suitability of remote sensing techniques for a detailed analysis of corridor-networks and landscape patches.

The test sites are located in the Kempenland, in the NE of Belgium. This is a rather flat area with some NE-SW oriented ridges, and is characterized by sandy soils where dune formation has taken place during the glacial periods. These ridges are nowadays covered by pinewoods. Generally, the valleys are parallel to the ridges. The valleys are built up of young sediments and, therefore, are characterized by Entisols, which are poorly to very poorly drained. The dominant land use on the valley floors is pasture land. Recently, maize (as a fodder crop) has become more abundant on the poorly-drained soils. The traditional agricultural area is situated between the ridges and the valleys at an intermediate topographical position. Here the land use consists of crop and pasture land. The area of parcels ranges between 0.2 and 10 ha. The landscape concepts and definitions of patch and corridor used in this study are based on Forman and Godron (1988).

Techniques and methods

Topographical maps of the N.G.I. (National Geographical Institute) at a scale of 1/10,000, 1/25,000 and 1/50,000 and topographical maps (1/5,000) offered by the 'Provinciale Directie van de Nationale Landmaatschappij' in Herentals were used for this study. The satellite imagery was SPOT XS 1B sensor data for The Kempenland, June 28, 1986 (scene 043/246) at a spatial resolution of 20 x 20 m.

To detect linear landscape features in the image some 'edge enhancement' techniques, known as 'filters,' are applied. This technique puts a three by three matrix (kernel) over the image. The reflectance values, or digital numbers (DNS), in this kernel are multiplied by a factor depending on the filter used, and the summation of the new values is put in the centre of the kernel. Then the kernel will shift one position and the procedure starts again. In this way contrast between light and dark pixels is heightened and edges are sharpened.

From a bird's-eye view, one seems to recognize parcels (defined as a property owner unit) in the landscape on the satellite images. **A** closer look at the SPOT images, however, shows that some parcels cannot be distinguished from each other. For example, parcels with the same land use, separated by barbed wire or furrows, appear as one unit. The ability to recognize parcels is a matter of contrast between them. It is possible to detect parcels with the same land use when they are separated by a row of poplar trees due to the effect of the shadows on the imagery. Therefore, the term 'parcel' detection in the context of satellite image interpretation should not be used, and the new term 'land blocks' is introduced. **A** land block is defined as a surface area with the same land use, surrounded by at least three linear elements. A land block can consist of several parcels.

Land blocks can be detected by passive satellite sensors for two reasons:

- the contrast on the image between different land blocks can be caused by differences in land use.
- linear features can result in linear structures due to alignments of mixed pixels which are caused by a slight difference in contrast. The detection of these small linear features is possible when using the modern, passive sensors, such as SPOT, characterized by their high spatial resolution (20 x 20 m).

It is necessary to enhance the linear features in order to detect land blocks and corridors on the SPOT images. The enhancement is done using a hard filter, the so-called line detectors. Three different line detectors (kernels) are used.

These line-enhanced images are used for further study and are compared, by visual means, with topographical maps at a scale of 1/10,000 (National Geographical Institute, Brussels). All maps data from 1970 to 1975, while the satellite imagery was recorded in June 1986. This difference in time necessitates the updating of the maps during field surveys, where special attention is paid to changes in parcel shape.

Different types of linear elements are present in the study area:

- hedgerows are in general too small to be detected on the SPOT multispectral images as pure pixels. Differences in their reflection and their shadows, however, can generate mixed pixels.
- 'parcel'-edges are visible on SPOT images due to differences in the phenological stages or in land use.
- drainage ditches can sometimes be detected due to the effect of the groundwater table close to the surface.
- roads and paths can cause the occurrence of some mixed pixels by their strong contrast with the vegetation.

In general, the corridors or the linear landscape elements can be detected due to their effects on spectral signature. In most cases, however, they occur as mixed pixels.

Factors influencing the detectability of corridors

Linear structures visible on the satellite images can be caused by differences in land use (Fig. 1). Adjacent parcels with different crops, or the same crop in a different phenological stage, will cause differences in spectral reflectance.

It is common in the study area to surround the parcels by hedgerows and rows of trees. This pattern changed in the sixties, and the structures have disappeared gradually due to the modernization of agriculture. Nevertheless, some hedgerows are still present. Their width (approximately one meter) is too small to influence the spectral characteristics of complete pixels. However, the hedgerows may influence the DNS, resulting in an alignment of mixed

BARE SOIL						GRASSLAND						WATER							PINEWOOD				
50	49	51	50	52	75	102	100	99	101	102	100	9	10	11	9	10	11	45	80	79	81	78	80
49	51	50	52	50	73	100	99	101	102	100	99	10	11	9	10	12	9	43	79	81	78	80	80
51	50	52	50	49	77	99	101	102	100	99	101	11	9	10	12	9	10	47	81	78	80	80	79
50	52	50	49	51	74	101	102	100	99	101	102	9	10	12	9	10	10	44	78	80	80	79	81
52	50	49	51	50	76	102	100	99	101	102	100	10	12	9	10	11	9	46	80	80	79	81	78

Fig. 1. Theoretical example of the DNS for some land use classes in the infrared part of the spectrum, including columns of mixed picels.

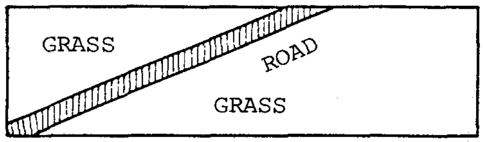
pixels, which can be detected by the so-called line detectors. The shadows of the trees and hedgerows also play an important role in the spectral signature and consequently the DNS. The effect of the shadows on the DNS is influenced principally by three factors:

1) the height of the object: the higher the object, the longer its shadow.
2) the sun angle: the lower the sun angle, the longer the shadow.
3) the orientation of the trees and hedgerows: this influences the detectability due to the direction of the shadows. A row of poplar trees perpendicular to the incident sun rays can be detected easier than a row parallel to the incident sun rays.

Most roads are too small to influence the DNS completely; they appear as an elongation of mixed pixels. Figure 2 illustrates the appearance of a road in band 3 of the SPOT images. The application of a hard filter makes it possible to enhance the roads.

The reallotment area of Lichtaart is characterized by large, rectangular and convex parcels. Pasture land is the dominant land use. The soils are poorly drained. During reallotment of land the whole area was dissected with open drains which led to convex parcels. This means that the high groundwater table is at shallower depth near to the ditches than towards the center of the parcels (Fig. 3).

This phenomenon locally results in very poorly-drained soils along the open drains. The rectangular pattern caused by the artificial drainage system is clearly visible on the SPOT images. The open drains have a width of approximately 0.5 m and are, in many cases, covered by grasses or other vegetation types. It is unlikely that the strong difference in reflection, which is mainly in the infrared part of the spectrum, is caused by the open drains only because these phenomena are visible over more than 4 pixels along the ditches. The absorption of the incident light can be explained by the underlaying soil groundwater table and the physiology of grasses in relation to the presence of water. Grasses growing on very poorly-drained soils (oxido-reduction at 0 to 20 cm) dispose of more water during a longer period than those on poorly-drained soils (oxido-reduction at 20 to 40 cm). The pheophitine/chlorophyll ratio will be higher for plants with less available water than is the case for plants with more available water. Spectral differences, mainly in the infrared part of the spectrum, will occur in relation to the pheophitine and chlorophyll content (Fig. 4). The grasses with more available water will absorb more infrared light than those which have less available water. This phenomenon causes the lower reflection of the incident light on the SPOT images



102	103	100	101	102	100	78	75	99	101	103
100	101	102	100	87	77	79	100	102	104	102
103	100	101	85	73	80	99	101	103	105	103
101	102	87	74	82	100	102	104	102	100	102
100	81	79	87	99	101	103	105	103	101	99
75	72	100	102	104	101	100	102	103	101	100

Fig. **2.** Example of the influence of roads on DNS (band **3**).

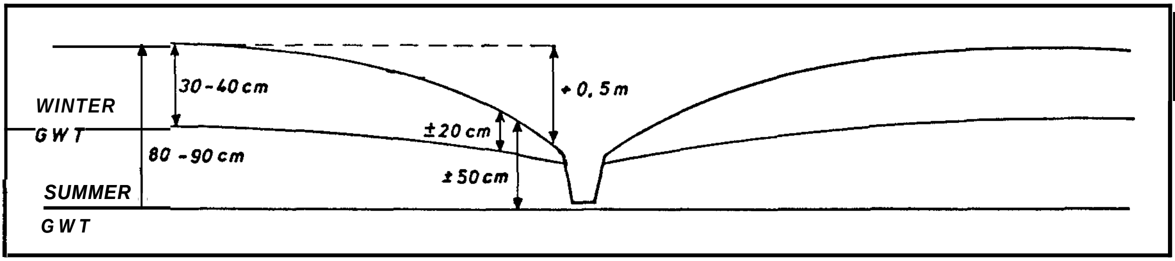


Fig. 3. Depth of the groundwater table in relation to the distance to the open drains in winter and summer (test site Lichtaart).

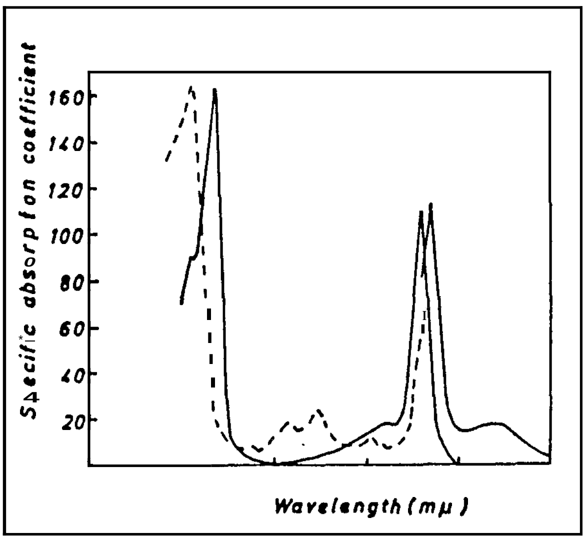


Fig. 4. Absorption curves of the pheophitine (dotted line) and chlorophyll (solid line) (after Goedheer **1976).**

by the grasses near to open drains. These reflection differences are large enough to be detected by the line detectors (Kidwai, A., 1989).

Statistical and graphical processing of the data is done using REFLEX, an integrated software package which combines the facilities of a database, a spreadsheet, and graphics. REFLEX, (the analytical database system), 1985, is obtained from BORLAND/ANALYTICA Inc., Scotts Valley, California, 95066.

Results and discussion

The updated topographical maps, (used as ground truth), and the edge-enhanced SPOT multispectral image are compared in order to evaluate the utility of satellite data for the detection of corridors and patches, in relation to their size and shape.

The results can be summarized as follows:

1) Land blocks with an area of more than 3 ha are unmistakably detectable on SPOT imagery; those with an area smaller than 1.2 ha cannot be detected. A transition zone occurs between 1.2 and 3 ha (Fig. 5). The size of detectable land blocks seems large when considering pixel sizes of 20 x 20 m (=0.04 ha). The individual pixels are not able to be visually interpreted – they need to be grouped. Accurate detection depends on preprocessing and image contrast, and can also be influenced by season (*e.g.* harvest, sowing time, changes of land use). This is also true for the limitations of the length and the width of the land blocks.

When the length exceeds 300 m, all land blocks can be detected. When the length is smaller than 130 m, it is not possible to detect the land blocks. A transition zone occurs between 130 and 300 m (Fig. 7). Concerning the width, the smallest size must be 120 m. Land blocks cannot be detected when the width is smaller than 80 m. **A** transition zone occurs between 80 and 120 m (Fig. 7). In terms of SPOT-XS images, one can say that a block must be built up of thirty pixels. The edges of blocks will normally consist of some mixed pixels. This means that only ten of those thirty pixels are pure pixels.

Figure 8 gives an overview of the detectability of land blocks in relation to their area and their length/width ratio. Two major groups can be distinguished: land blocks larger than 3 ha (group 1), and those with an area smaller than 3 ha (group ***2).*** All land blocks of more than **3** ha can be detected (class 1B) except those with a length/width ratio exceeding 7 (class 1A). The lack of contrast due to

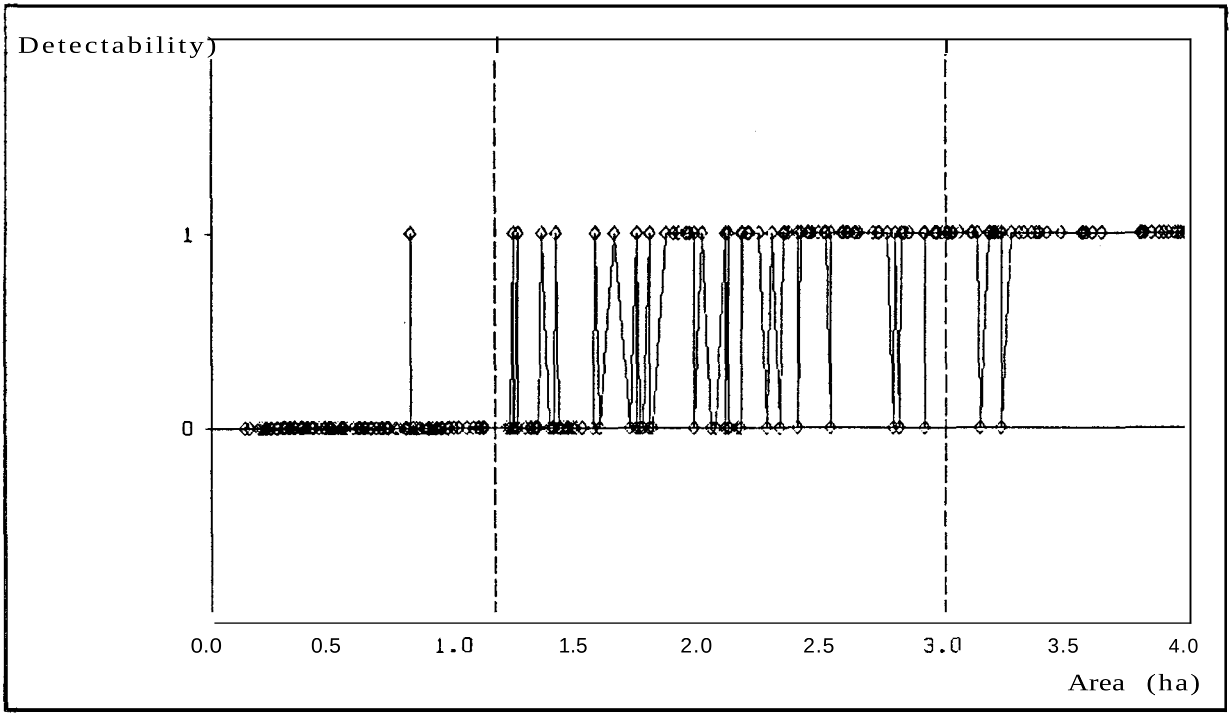


Fig. **5.** Detectability of land blocks in relation to their area (0: not detectable; 1: detectable).

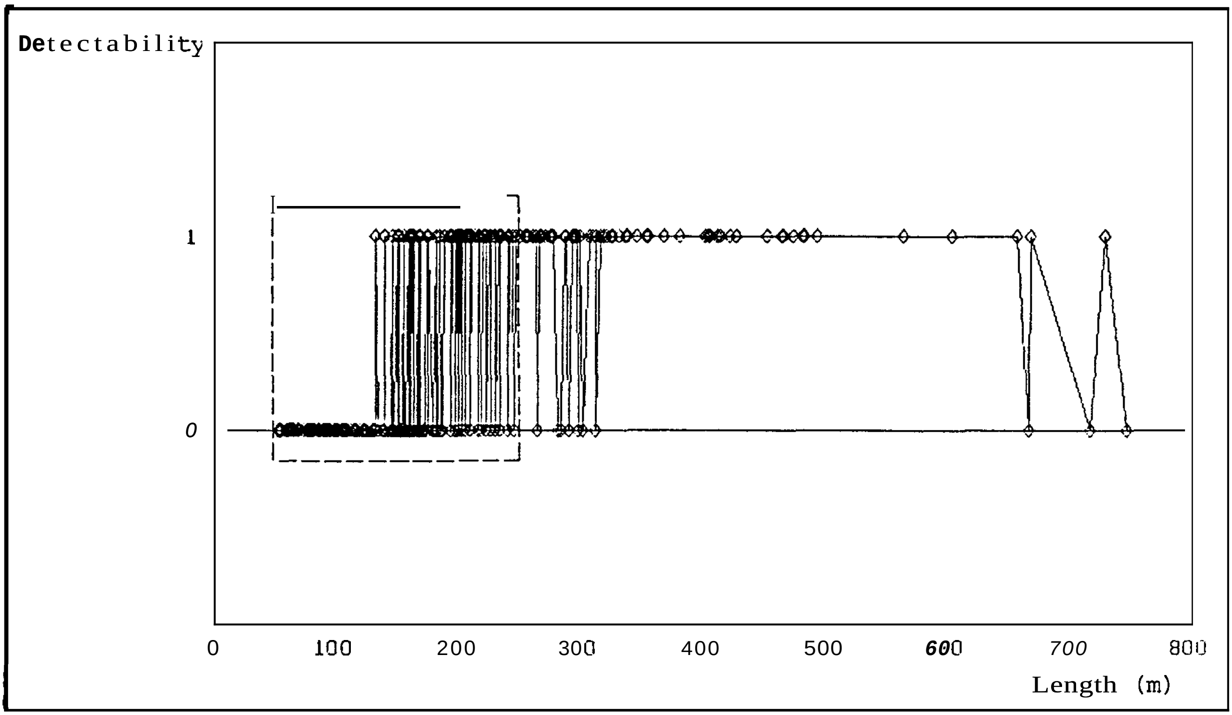


Fig. 6. Detectability of land blocks in relation to their length (0: not detectable; 1: detectable).

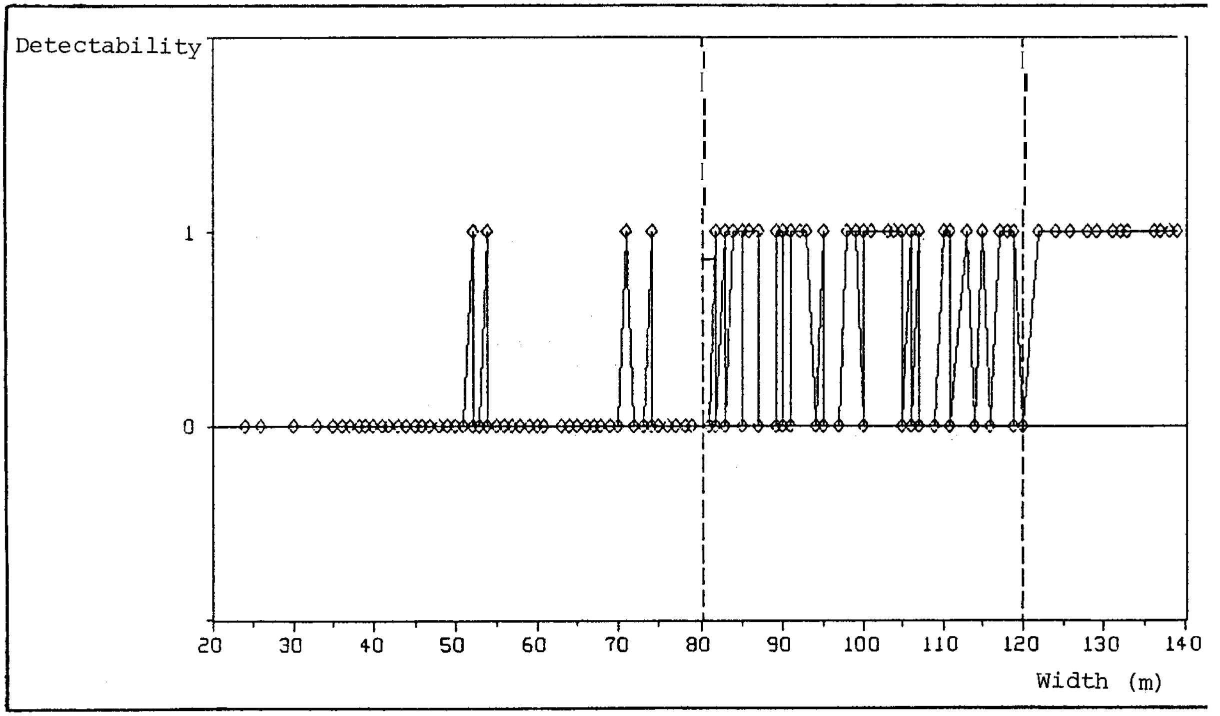


Fig. 7. Detectability of land blocks in relation to their width (0: not detectable; 1: detectable).

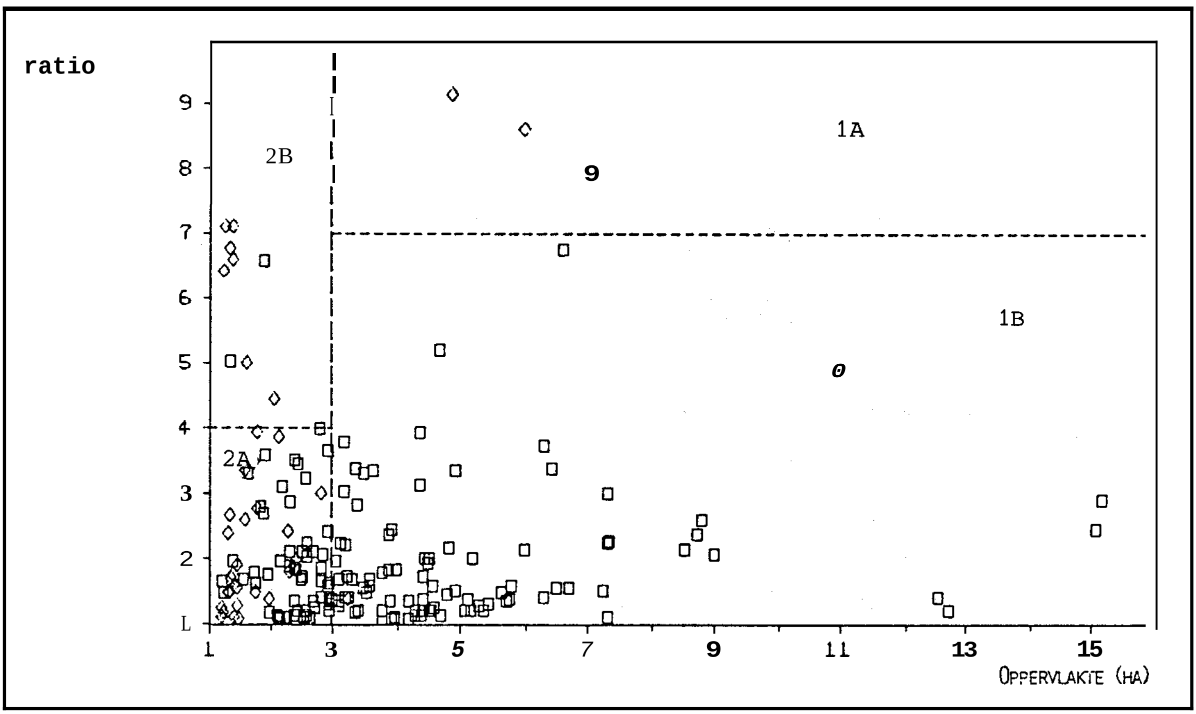


Fig. 8. Detectability of land blocks in relation to their area and length/width ratio (◇ : not detectable; □ : detectable).

Table 1. Comparison of the results of network analysis, applied on topographical maps and SPOT edge enhanced images.

	TOPOMAP (scale 1/25,000)	SPOT general	SPOT very hard filter
connectivity (gamma-index)	0.98	0.98	0.69
circuitry (alpha-index)	0.93	0.97	0.10

a uniform land use also plays an important role in the undetectability of the land blocks in the last-mentioned class. Two trends can be seen in group 2 (< **3** ha): land blocks with a length/width ratio larger than 4 are generally not detectable (class 2B); those with a length/width ratio smaller than 4 form a transition zone (class **2A)** – two-thirds are visible, one-third cannot be detected. Classes 1A and 2B do not count enough elements to be statistically relevant – they only give an idea about possible relationships and correlations. Further investigation is necessary to accept or to reject the stated hypotheses.

2) All visible linear features are studied around land blocks of more than **3** ha. The aim is to examine the influence of the composition on detectability:

- drainage ditches are clearly visible due to their influence on the groundwater table.
- roads are detectable because of their high contrast with the surrounding vegetation.
- combined linear features (such as roads and ditches bordered by trees) can easily be detected due to the presence of the trees. When trees are replaced by hedges, some difficulties may occur. Summarizing, three linear features are important: roads, ditches and trees. Hedges give some difficulties.

On one test-site, with clearly detectable land blocks, a network analysis was performed. Network connectivity can be defined as the degree to which all nodes in a system are linked by corridors. The gamma index of network connectivity is the ratio of the number of links in a network to the maximum possible number of links in that network. Circuitry is the degree to which circuits (loops that provide alternative routes for flow) that connect nodes in a network are present. It can be measured using the alpha index. For more details one can refer to Forman and Godron (1988, p. 417–420). **A** comparison between the results based on maps and those based on edge-enhanced SPOT imagery was made (Table 1). Two different 'edge' filters were used: a general filter and a very hard filter. The topographical map was considered as ground truth. Compared with the topographical map (scale 1/25,000), the general filter gives good results: analogous values of the indices were obtained. On the contrary the very hard filter gives disappointing results.

Conclusions

The use of SPOT imagery for the mapping of the ecological infrastructure can provide maps, which can be basic documents (even when topographical maps of the study area are available) for further detailed research by ecologists. **A** great advantage is the currency (since 1986) of the data: so, perhaps the main advantage of satellite images over maps is the timely and repetitive acquisition for determining landscape changes and trends. Nevertheless, it is important to emphasize that the parcel size must be rather large so that they can be unmistakably detected by the new generation of sensors (SPOT-**XS:** ground resolution 20 × 20 m). The shape of the land blocks is also an important factor for their detectability.

Acknowledgements

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