Landsat TM images in mapping of semi-natural grasslands and analysing of habitat pattern in an agricultural landscape in south-west Finland

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Toivonen, Tuuli and Miska Luoto (2003). Landsat TM images in mapping of semi-natural grasslands and analysing of habitat pattern in an agricultural landscape in south-west Finland. *Fennia* 181: 1, pp. 49–67. Helsinki. ISSN 0015-0010.

Decision-making in land-use and conservation planning requires relevant and good quality information over wide areas, collected in a cost-efficient manner. This study focuses on the use of medium-resolution satellite imagery in landscape level studies of habitat pattern, particularly in fragmented agricultural landscapes. We analysed the suitability of multi-temporal Landsat TM images in habitat mapping, in particular for the discrimination of semi-natural grasslands. The results showed that even patchy agricultural mosaics can be coarsely mapped with Landsat TM and that the use of multi-temporal imagery notably improves the classification results. The best classification result (total accuracy 89%) was achieved with early spring, midsummer and late summer images combined. The classification accuracy for semi-natural grasslands was relatively low overall (63%), but over 90% of large (> 1 ha) patches were discriminated. Furthermore, we compared a set of landscape composition and structure indices calculated from 1) a Landsat TM -based habitat classification (25 m resolution) and 2) a habitat map derived from aerial photographs (2 m resolution). The compositional indices, diversity index and patch sizes gave similar results on both scales. Finally, the habitat pattern of the study area was described using the calculated compositional, structural and environmental indices, and three main landscape types were identified.

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Introduction

European and national environmental regulations frequently necessitate the nation-wide assessment of land cover changes and biodiversity, and monitoring of the effects of political decisions on landscape level. Good decision-making from the biodiversity viewpoint inevitably requires reliable environmental, habitat and species data and a rigorous understanding of species-habitat relationships for their interpretation (Margules & Austin 1991; Scott et al. 1993). Owing to this, there is an increasing need for novel broad-scale mapping methodologies of diversity at the habitat to the species level, and the related environmental conditions (Nagendra & Gadgil 1999; Gould 2000; Griffiths & Mather 2000; Stoms 2001).

The overall landscape pattern influences biotic diversity and the flow of species and energy (Turner 1989; Turner & Gardner 1991; Forman 1995). Based on this idea, and on the continuous development of computing systems, landscape quantification has become an increasingly popular means of collecting habitat information over wide areas (O'Neill et al. 1988; MacGarigal & Marks 1995; Cain et al. 1997; Gustafson 1998; Tischendorf 2001). The measures of landscape structure and habitat composition have, in addition to abiotic conditions, been shown to be related to species diversity and the occurrence of rare species in a certain area as different landscape types support different amounts and differently specialised species (see e.g., Hill & Keddy 1992; Petit & Usher 1998; Natuhara & Imai 1999; Luoto 2000a). Good examples are available of the use of such surrogate measures in directing research efforts, making conservation plans and modelling species diversity or the occurrence of certain species (Mladenoff et al. 1995, Duelli & Obrist 1998; Luoto et al. 2002a, 2002b).

The quantification of landscapes for analysis or modelling purposes requires a relevant habitat map as a basis. Ready-made land cover products are, however, often either unavailable or do not have a suitable nomenclature or temporal or spatial scale for ecological monitoring. Therefore, remote sensing is commonly used to obtain habitat information (see e.g., Mladenoff et al. 1997; Debinski et al. 1999). In comparison to the use of traditional aerial photographs or new high-resolution satellite imagery, medium-resolution sensors currently provide the most cost-effective data for habitat classifications over wide areas. Biodiversity studies put, however, a particular pressure on the land cover classifications: habitats important from the biodiversity viewpoint generally occur as small and complex-shaped patches and are thus difficult to map using medium-resolution sensors. Several authors have discussed the use of medium-resolution imagery in biodiversity studies from the habitat to the species level (Stoms & Estes 1993; Debinski et al. 1999; Nagendra 2001). Examples are available on analysing landscape heterogeneity (Riera et al. 1998; Pan et al. 2001), species occurrence and richness (De Merode et al. 2000; Griffiths et al. 2000) and conservation status (Scott et al. 1993; Gonzales-Rebeles et al. 1998), mainly using Landsat TM. Most of these examples operate, however, at the regional scale, while fewer studies utilise medium-resolution habitat maps in a meso-scale approach (Luoto et al. 2002a, 2002b).

In the Finnish agricultural landscapes, semi-natural grassland is one of the most threatened habitat types but at the same time it is the most essential for maintaining biodiversity (Rossi & Kuitunen 1996; Pykälä 2000; Rassi et al. 2001). Therefore, reliable spatial information on this habitat type is crucial for attempts to quantify or describe Finnish agricultural landscapes from ecological, conservation and land use planning perspectives (see e.g., Luoto 2000a; Luoto et al. 2002b). Although most of the valuable semi-natural grasslands in Finland have been mapped for conservation purposes (Pykälä et al. 1994; Lehtomaa 2000), studies on the distribution of this habitat type as such, and on its occurrence within a habitat mosaic have concentrated on limited study sites only (Jutila 1997; Kontula et al. 2000), and no methodology have been presented for the collection of landscape level information of this rare habitat type that often occurs in small patches.

Generally, multi-temporal images, vegetation indices and image transformations are used to improve classification of habitats based on medium-resolution imagery (Riera et al. 1998; Hardy & Burgan 1999; De Merode et al. 2000). In the literature, few examples on mapping patchy semi-natural grassland habitats using space-borne remote sensing exist (e.g., Basham et al. 1997; Debinski et al. 1999), and none are available on the use of multi-temporal, medium-resolution imagery for mapping the small semi-natural grasslands of Northern Europe.

This study aims to test whether Landsat TM images can be used for mapping fragmented agricultural landscapes of Finland. In addition, we aim to provide information on the significance of multi-temporality of images in the classification of habitats and, in particular, semi-natural grasslands. Furthermore, the usability of a Landsat TM -based habitat map in the quantification of landscape characteristics at the meso-scale (500 by 500 m analysis units) is evaluated by comparison with quantifications of the same characteristics based on more detailed data. Additionally, the study aims to provide a characterisation of an agricultural landscape in SW Finland using landscape indices and to analyse the distribution pattern of semi-natural grasslands within the study area. More specifically, the study focuses on the following four questions:

1) Can the semi-natural grasslands of SW Finland be mapped using Landsat TM satellite imagery?

2) Does the use of multi-temporal imagery notably improve habitat discrimination?

3) How well can the landscape be quantified using landscape indices when a Landsat TM -based habitat map is used in comparison to a habitat map based on aerial photographs?

4) How are semi-natural grasslands distributed and what is the overall habitat pattern like?

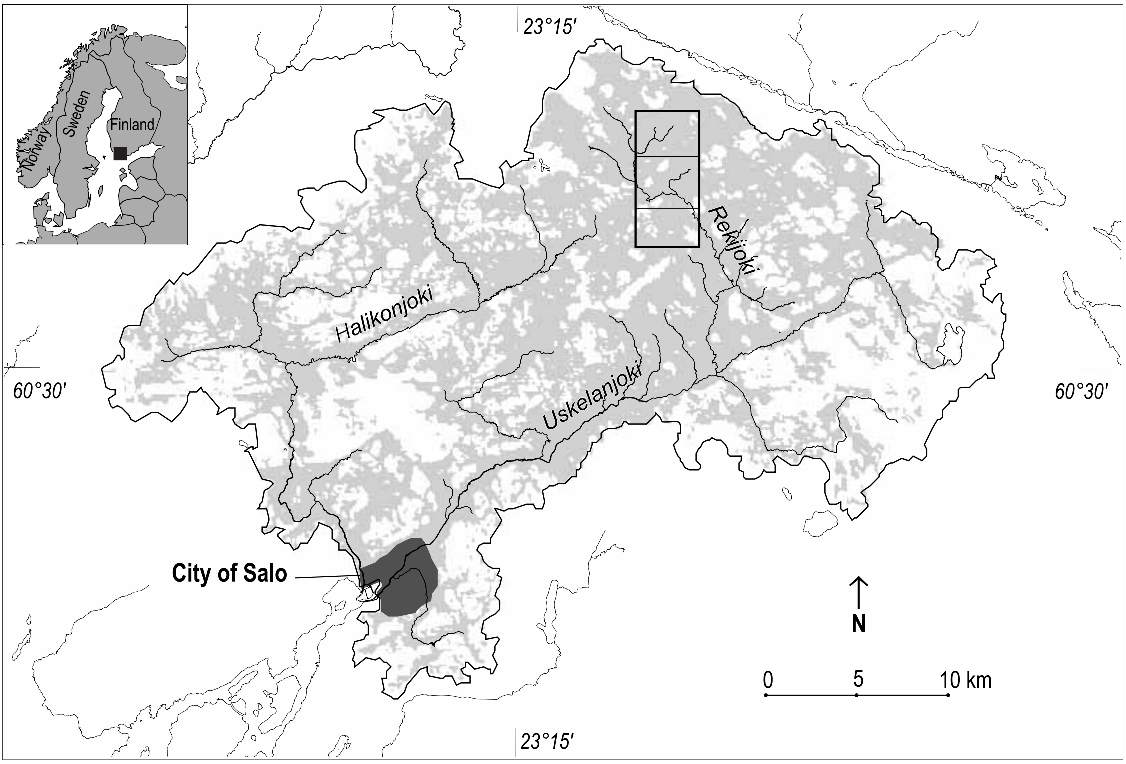

Fig. 1. Location of the study area in SW Finland. The light grey on the main map indicates the area covered by clay deposits. Rectangular areas in the northern part of the study area indicate the borders of the Rekijoki habitat map used in the study. The northern and southern parts of the maps were used for training the classifier while the middle part was reserved for accuracy assessment of the result.

Study area

The study area covers catchment areas of the rivers Uskelanjoki and Halikonjoki between the towns of Salo and Somero in SW Finland. The total area is approximately 900 km^2 and lies at 60°19'–60°39'N and 22°50'–23°4'E (Fig. 1). The mean monthly temperature in January is –6.5 °C and in July, 16.7 °C. The mean annual temperature and the mean annual precipitation are 4.8 °C and 645 mm, respectively (Climatological Statistics… 1991).

The landscape is characterised by flat clay plains occupied by agriculture and scattered woodland-covered hills. The bedrock in the area is predominantly granite (Simonen 1987) with pronounced NE–SW and NNW–SSE orientated fractures. The thickness of superficial deposits reaches 30 m in places and is generally at least 20 m (Aartolahti 1975). The rivers have eroded channels into the deposits forming steep-sided (5°–30°) river valleys up to 25 m deep. As the walls of the river valleys are mostly composed of clay, landslides occur frequently along the river.

The hydrological system of the area consists of two main rivers, the rivers Halikonjoki and Uskelanjoki, their catchment areas accounting for 306 km^2 and 566 km^2 of the study area, respectively (Hydrological Yearbook 1992). The main courses of the rivers follow the bedrock fracture lines. Few lakes of the area are small (ca. 2 km^2 in size).

According to the division of vegetation zones in Finland, the study area is situated on the border between the hemiboreal and southern boreal zones (Kalliola 1973). Many demanding southern herb and tree species are found only in these regions in Finland. Generally, south-western Finland is agriculturally the most favourable part of the

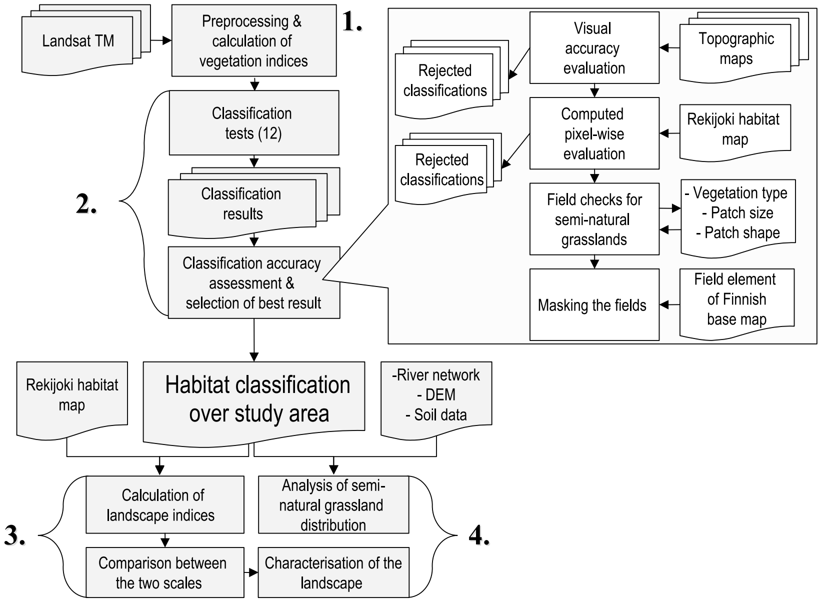

Fig. 2. The main processing steps ( ) of the study plus the source and result data sets ( ). Numbers 1–4 refer to the processing steps presented in the text.

country due to its relatively mild climate and fertile soil conditions. Therefore, the cultivated areas dominate the landscape.

Methods

The study included four main steps (Fig. 2): 1) data pre-processing and calculation of vegetation indices, 2) classification of satellite imagery and testing the effect of using multi-temporal data and vegetation indices, 3) calculation of landscape indices and assessment of their usability, 4) analysis of the geographical location of semi-natural grasslands, characteristics of the study area and structural and compositional habitat diversity.

Step 1: Data pre-processing

Three Landsat TM mini scenes from different dates during the growing season of 1999 were obtained. The scenes were acquired on 18 April, 28 June and 30 July, with the effective temperature sums of 0, 600 and 1000, respectively (Finnish meteorological institute 1999a, 1999b, 1999c). The area of the mini scenes (50 km by 50 km) was selected to cover the entire basin of the rivers Uskelanjoki and Halikonjoki, the centre of the area being at 60°30'N and 23°17'E. The images were obtained from paths 189 and 190 and row 18 in the Landsat world reference system. National and local GIS data sets were used to support the pre-processing and classification of images (Table 1). The most important of these was a detailed habitat map produced over the Rekijoki area (see the map limits in Fig 1.) Digitising of the habitat boundaries in the Rekijoki map was made using aerial low altitude photographs at the scale 1:4000 (for more details, see Luoto 2000b).

The Landsat TM images were rectified to each other using a 25 metre pixel size. The June image was used as a reference and after rectification all images were stacked to form an 18 layer image (all Landsat TM bands from the three dates excluding the thermal band 6). Thereafter, the image stack was georefenced to a Universal Transverse Mercator map projection and to the Finnish coordinate system (YKJ). The centroids of small lakes and ponds visible in the digital base map were used as ground control points. In both cases the rectification was performed using a first order polynomial transformation and the nearest neighbour resampling method in order to retain the original pixel values. The root mean square error of the first rectification was 0.47 pixels, corresponding to ca. 10–15 metres on the ground. Comparison

Table 1. National and local GIS data sets used for the image processing.

Data set	Format	Resolution/scale	Coverage	Source*
Base maps	Vector / raster	1:20 000, 2m	Entire country	NLS
Digital elevation model (DEM)	Raster	25m	Entire country	NLS
Catchment area divisions	Vector	N/A	Entire country	FEI
Soil map	Raster	25m	Entire country	GSF
Rekijoki habitat map	Vector / raster	1:4000, 2m	Rekijoki, 26.25 km^2	Luoto 2000b

* NLS = National Land Survey, FEI = Finnish Environment Institute, GSF = Geological Survey of Finland

Table 2. Vegetation indices calculated for each image with reference information.

Index name	Abbrev	Formula	Source
Simple ratio vegetation index	SRI/SVI	TM4/TM3	Jordan (1969)
Normalised differential vegetation index	NDVI	(TM4-TM3)/(TM4+TM3)	Rouse *et al.* (1973)
Optimised soil adjusted vegetation index	OSAVI	(TM4-R)/(NIR+R+0.16), with the constant 0.16 adjusted for clay soils	Rondeaux *et al.* (1996)

Table 3. Classification tests performed with different Landsat TM image and band combinations, and vegetation indices. The thermal band 6 was not included in any of the data sets.

Test	Data set	Number of Bands in data set
Test 1	June image, all bands	6
Test 2	April and June images, all bands	12
Test 3	June and July images, all bands	12
Test 4	April and July images, all bands	12
Test 5	April, June and July images, all bands	18
Test 6	The 3 bands for each image that offer the best separability: April image, bands *TM3, TM4, TM5* June image, bands *TM2, TM4, TM7* July image, bands *TM3, TM5, TM7*	9
Test 7	The 3 best bands for all images: April (TM3), June (TM4) and July(TM3)	3
Test 8	NDVI of all images	3
Test 9	NDVI and April (TM3), June (TM4) and July (TM3)	6
Test 10	NDVI + test 5 data set	21
Test 11	SVI + test 5 data set	21
Test 12	OSAVI + test 5 data set	21

with the digital base map and the Rekijoki map proved the quality of the rectification to be satisfactory.

Three widely recognised vegetation indices were calculated for each image (Table 2). Furthermore, waters were masked away from the images using the normalised differential vegetation index NDVI for the June image and supervised parallelepiped classifier.

Step 2: Classification tests

Twelve different classification tests were performed with the Landsat TM data (Table 3). The tested combinations were chosen to evaluate the importance of multi-temporal satellite imagery and vegetation indices for classification of semi-natural grasslands and main habitat types. In order to focus testing to the source data rather than the classification method, the actual classification was always carried out in a standard way: using supervised classification and applying the maximum likelihood classifier (Swain & Davis 1978).

Identified habitat classes

Semi-natural grasslands were the primary targets of the classification tests. However, we also wanted the classification results to be of use in the evaluation of landscape structure and composi-

Table 4. The final habitat classification with 6 classes (middle column), and the groupings in the Rekijoki habitat map (left column) and the 10-classes initially identified in the satellite image classifications (right column).

Original classes of Rekijoki map	6-class system used in this study	Subclasses used temporarily in classification
Cultivated field Fallow Field Stock yard	**Arable land**	Crop cultivation Hay / Fodder Set-aside
Meadow Moist river meadow Extensive pasture	**Semi-natural grassland**	Semi-natural grassland
Deciduous forest Tree or bush groups	**Deciduous woods**	Deciduous woods
Coniferous forests Mixed forests Plantation Felling Mire Stone blocks Rock outcrops	**Other woodlands**	Felled area/plantation Mixed/coniferous forest Mire
Farmyard Barn Local road Farm road Electric line	**Built-up area**	Built-up area
Water	**Water**	Water

tion in the area. In other words, the classes needed to be ecologically meaningful in order to allow the distribution and structure of habitats to be evaluated. After consideration, the following 6 habitat classes were selected:

1) *Arable land,* including managed cereal and fodder fields and pastures mostly treated with fertilisers, pesticides or herbicides, as well as fallow fields.

2) *Semi-natural grasslands,* including areas dominated by herbaceous sedge (*Carex* spp.) and grass (Poaceae) species. In the Finnish classification of traditional biotopes (Vainio et al. 2001), these habitats are defined as being natural pastures and meadows maintained by mowing. In this study, we have also included abandoned grasslands to this group on the basis of their similar species composition.

3) *Deciduous woods,* comprising closed woodlands dominated by broad-leaved deciduous tree species, mainly birches (*Betula pendula* and *B. pubescens*), grey alder (*Alnus incana*) and aspen (*Populus tremula*).

4) *Other woodlands,* comprising several forest types, mainly coniferous forests, where the predominant species are generally Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*), as well as mixed forests. Felled areas, plantations and mires were also included in this class.

5) *Water class,* comprising of aquatic habitats, i.e. sea bays and lakes.

6) *Built-up area,* covering areas with man-made surface materials present, like buildings, roads, etc.

Training the classifier

The ground truth for the classification training and testing was derived from the Rekijoki habitat map. To avoid mixed pixels in the training and testing stage caused by the different scales of the training data and Landsat TM, only the central areas of habitat patches were used. To separate the patch core areas, a negative buffer of 15 metres was created around each habitat patch. Thereafter, the patch core areas of Rekijoki map were converted to a raster grid with a pixel size of 2 metres to be used in the training and testing. The 22 original habitat classes were reclassified into the six habitat types used in this study, as presented in Table 4.

The area covered by the Rekijoki map was divided into three parts (Fig. 1). The northern and southern parts were used for ground truthing the satellite image classification, while the central part provided quality control data. Some classes of the selected nomenclature, namely arable land and other forests, contained substantial internal variation in satellite imagery. Therefore, these two habitat classes were first each divided into three sub-classes for which ancillary field data was available. The sub-classes were used in the training process and later re-grouped according to the main classification as presented in Table 4. Additionally, as the Rekijoki map contained only small amounts of water surfaces and built-up areas, training areas for these two classes were delineated also outside the map area, using topographical maps for ground truthing (NLS 1992, 1998, 1999a, 1999b).

Before the classification, the separability of the spectral signatures was assessed using Jeffries-Matusita distances (Erdas 1995; Richards 1996) and the contingency using a contingency matrix (Erdas 1995). Rather than effecting the delineation of training areas, this information was used to define data sets to be used in tests 6 and 7.

Accuracy assessment

The evaluation process used for the classification results is presented in Fig. 2. The first evaluation of the classification result was done visually using topographic maps at the scale 1:50 000 scale as a reference (NLS 1992, 1998, 1999a, 1999b). Since some of the maps were several years old and mapping intentions had been different from ours, more attention was paid to the accuracy of the patterns of the dominant land cover types, agriculture and woodland, than to the minor types, such as grasslands and deciduous woods. Most test results were rejected at this stage. Accepted results were further evaluated by a pixelwise comparison with the central area of the Rekijoki map. Error matrices were used to evaluate the omission and commission of different classes. The total classification accuracy, or map accuracy, was determined by dividing the number of correctly classified pixels by the total number of all classified pixels (Richards 1996). The classification result to be used in further analyses was selected based on this measure.

Finally, all semi-natural grassland patches over one hectare in area that were present in the final classified map were checked in the field in order to verify that they had been correctly identified, as well as to compare their extents and shape with the classification result. Even the best classification result had individual falsely classified semi-natural grassland pixels in the middle of agricultural fields. We used the digital field element of the Finnish base maps in scale 1:20,000 to mask these speckles of semi-natural grassland away before further use of the habitat classification.

Step 3: Quantification of the landscape

To evaluate the usefulness of the Landsat TM -based habitat map for quantifying agricultural landscapes in SW Finland, 6 compositional and 5 structural indices were used (Table 5). As noted by e.g., Cain et al. (1997), no simple set of statistical indicators can fully capture the complexity of ecosystems and characterise the landscape. In the selection of structural indices we followed the suggestions of Luoto (2000a), while composition was defined as being the amount of each habitat type present in the analysis grid (see e.g., Gustafson 1998). As noted by Turner (1989), the indices describing spatial pattern are dependent on the extent of the area in which the measurements are made. Thus, analysis units of equal size were chosen in order to eliminate error caused by the scale dependence of the spatial variables (see also Luoto 2000a, 2000b).

The study area was divided into 500 m by 500 m grid squares. A total of 3481 grid squares covered the catchment areas of the rivers Uskelanjoki and Halikonjoki. 105 of these squares overlapped with the Rekijoki habitat map. Using these 105 squares we tested how dependent the selected landscape indices were on the source material. All indices were calculated first for all 3481 squares using the Landsat TM -based habitat map and then, again, for the 105 overlapping grid squares also using the Rekijoki habitat map.

The six compositional indices, each representing the total area of a certain habitat type in the classified image, were calculated using ArcInfo software. For calculation of the selected structural indices we used FRAGSTATS software (MacGarigal & Marks 1995). Similar settings to those used by Luoto (2000a) were applied in calculation. The edge area width was set to 0 and the cell size was the same as in the data used (25 m).

Table 5. Indices calculated from classified satellite image and the Rekijoki habitat map, together with additional environmental variables.

Index name	Description
Habitat composition	
Arable land	The total area of arable land within analysis grid.
Semi-natural grassland	The total area of semi-natural grassland within analysis grid.
Deciduous woods	The total area of deciduous woods within analysis grid.
Other woodland	The total area of other woodland within analysis grid.
Water	The total area of water within analysis grid.
Built-up area	The total area of built-up area within analysis grid.
Habitat structure	
Mean patch size, MPS	Measures the average patch size within the analysis grid*
Mean shape index, MSI	Measures the average perimeter-to-area ratio of patches*
Area weighted MSI, AWMSI	Measures the average MSI of patches, but weights more large than small patches*
Nearest-neighbour standard deviation, NNSD	Measure of patch dispersion. The magnitude is function of the mean nearest-neighbour distance and variation in nearest-neighbour distance among patches*
Shannon's diversity index, SHDI	Measures the composition of habitats by combining richness and evenness of habitat types within the analysis grid*
Environmental variables	
Mean slope	Maximum slope within the analysis grid.
Relative altitude	The difference between the highest and the lowest altitude.
Maximum slope	Maximum slope within the analysis grid.
Soil type	The predominant soil type within the analysis grid

* MacGarigal & Marks (1995).

Comparison of indices calculated from different source data sets

The usefulness and quality of the indices calculated from the Landsat TM -based data with a 25 metre pixel size was evaluated by correlating them with indices calculated from the Rekijoki habitat map with 2 metre pixels. The correlations were calculated using the 105 grid squares for which both kinds of source data were available using Spearman's rank correlation coefficient, R_s. A bivariate correlation coefficient, which compared ordered lists of grid squares, was considered superior to other measures, such as the Pearson correlation coefficient, R_p, because the aim was to measure the similarity of the high and low values, and not the absolute magnitude of the indices. R_s was calculated for the 5 structural indices and 4 of the habitat compositional indices. Water and built-up areas were left out from the analyses due to their low occurrence in the Rekijoki area.

Step 4: Characterisation of habitat pattern and location of semi-natural grasslands using measures of structure and composition

In order to evaluate the relation between the habitat distribution patterns and topographic and soil variation, we derived two topographic and one soil variable (Table 5). The topographic variables were calculated for each grid square from the national digital elevation model (NLS 1995) using Arc/Info software. Slope was calculated in degrees from the digital elevation model. Relative altitude was defined by subtracting the minimum from the maximum elevation within each grid square. The predominant soil type was derived from soil data of the Geological Survey of Finland (GSF 1996).

Spatial variation in the habitat composition and structure of the landscape was analysed visually using thematic maps. Furthermore, in order to evaluate the spatial pattern, including possible corridor-like structures formed by semi-natural grasslands, an additional variable was calculated

Table 6. A comparison of the results of classification tests employing different combinations of Landsat TM data. The best classification result is indicated in bold.

Test	Data set	Arable	Semi-natur.	Dec.woods	Other woods	Built-up	Total
Test 1	June image	76%	54%	42%	82%	23%	*74%*
Test 2	April and June images	86%	57%	50%	87%	24%	*85%*
Test 3	June and July images	87%	59%	34%	77%	26%	*81%*
Test 4	April and July images	84%	60%	50%	75%	22%	*79%*
Test 5	**April, June and July img.**	**91%**	**63%**	**47%**	**87%**	**27%**	***89%***
Test 10	Test 5 images +NDVI	93%	60%	44%	86%	27%	*88%*

by summing the area of semi-natural grasslands in an 8-neighbourhood around each grid square (see also Riitters et al. 1997). This calculation produced a very simple index of the concentration of semi-natural grasslands. Ecologically, this kind of measure of concentration reflects the amount of certain important habitat within a certain distance of any grid square (see e.g., Verboom et al. 1991; Hanski 1999).

The proximity of semi-natural grasslands to the river network, as well as their occurrence in relation to topography and soils was analysed using overlay analysis and buffering in GIS. For each patch of semi-natural grassland, mean slope angle and dominant soil type were defined using a digital elevation model (NLS 1995) and soil data (GSF 1996). Furthermore, a buffer zone of 200 metres was built around the rivers to see how commonly patches were found close to the river network. The area of semi-natural grasslands within this zone was compared to its total coverage throughout the study area.

Results

Habitat map accuracy

Most of the classification test results were abandoned after the visual evaluation of quality. The results of tests 2, 5 and 10 were considered good enough for further evaluation rounds. Additionally, despite their obviously poorer quality, the results of tests 1, 3, and 4 were selected for quantitative testing to gain insight into the advantages of using multitemporal data for image classification. Table 6 shows the classification accuracy for each habitat type using different temporal data combinations.

The advantages of multitemporal data are seen when the classification results of tests 1, 2 and 5 are compared. The total accuracy and the discrimination of habitat types were highest in test 5 where all bands of all three images were used. Classification accuracy declined when only two images were used (tests 2 to 4). A comparison of these tests indicated that if only two images can be used, the best overall classification accuracy is obtained by using spring and midsummer images. However, the discrimination of semi-natural grasslands is best with combination of midsummer and late summer images. With the latter combination, however, the classification accuracy of deciduous woodland is rather poor (34%). The decline in total accuracy is clear (from 89% to 74%) when only one image is used. The addition of indices calculated from pixel values (NDVI, SVI or OSAVI) did not improve the classification result, and in some cases even impaired it.

The overall classification accuracy of the best classification (test 5) was 89 %, as compared with the test areas in the Rekijoki habitat map. The results show that the predominant habitat types, arable land and other woodland, are over-represented, while small, and in this case ecologically important habitats, namely semi-natural grasslands and deciduous woodlands, are under-represented (Table 7). Deciduous forests were mixed up in the classification with other woodlands and also, in places, with semi-natural grasslands. Semi-natural grasslands were mixed up to some extent with all other classes, particularly with other woodlands. The accuracy of the built-up area class was poor (27%) and of natural habitats, large rock outcrops, ditched mires and sandpits had been classified as built-up area.

Field checks based on the results of the classification test 5 showed that the overall classifica-

Table 7. Pixel level classification accuracy of natural and semi-natural habitat types in the classification result of test 5. The central part of the Rekijoki habitat map was used as reference data.

		Rererence data				
		Arable land	Semi-nat. gr.	Deciduous forests	Other forests	Total
Classification	Arable land	**91%**	8%	5%	2%	106%
	Semi-natural grassland	5%	**63%**	10%	2%	80%
	Deciduous woods	1%	14%	**47%**	7%	69%
	Other woodland	2%	16%	38%	**87%**	143%

tion accuracy of large (> 1 ha) patches of semi-natural grassland was satisfactory: of 150 field-checked patches of semi-natural grassland, 140 were classified as semi-natural grassland also in situ. Within these, however, habitat quality varied from poor fallow-like patches to dry and mesic meadows. In most cases the patch shape and elongation in the classified image corresponded to reality.

Equivalence of landscape metrics

The comparison of landscape metrics calculated from the classified satellite image and the Rekijoki map showed significant correlation (Fig 3). The correlation coefficients of habitat compositions were significant in all classes, and were particularly high for indices of the dominant classes, arable land and other woodland, and less so for indices of smaller habitat types deciduous forests and semi-natural grassland. The structural indices, however, showed a larger variation in correlations: mean patch size (MPS) and the diversity index (SHDI) showed significant and high correlations between the two resolution, while the mean shape index (MSI) and the neighbourhood index (NNSD) correlated more weakly, the correlation of NNSD being 0.125. Since this measure was not statistically significant, it was left out of the characterisation of the habitat pattern within the study area.

Habitat pattern within the study area

The most predominant habitat types in the area were arable land and other woodlands. Combined, these classes occupy almost 90% of the study area. The rest, ca. 10%, is divided between the other habitat types. Arable lands are concentrated on the flat clay plains, particularly in the central part of the study area along the river Uskelanjoki, while forests occupy the topographically higher areas in the east and west (Fig. 4). The entire landscape is, however, a mosaic of these land cover types, although areas with agricultural or forest dominance can be identified. Deciduous forests have a fragmented distribution across the entire study area and no clear concentrations are found. Built-up areas are mostly found in association with the city of Salo and villages along the rivers Halikonjoki and Uskelanjoki.

The habitat structure of the study area is presented in Fig 5. Mean patch size (MSP) is largest in the arable areas and near the eastern and western edges of the study area where continuous woods are present. Thus, the low values coincide with river valleys and areas where woods and agriculture are evenly distributed. The mean shape indices (MSI and AWMSI) have their highest values along the river valleys where elongated habitat patches are present. The diversity index, SHDI, reflects the richness and evenness of habitat types within the analysis grids. The highest values are concentrated along the rivers, where patches of semi-natural grassland and deciduous woods are present. Additionally, the index gives high values in places where other rare habitat types like built-up areas or waters occur. Selection of just the 5% of grids with the highest SHDI values showed even more clearly that these "hotspots" of habitat diversity are found near the rivers. A particularly high concentration of these high diversity grid squares is found in the region of Rekijoki in the northern part of the study area.

Location of semi-natural grasslands

Semi-natural grasslands have a corridor-like distribution in the study area (Fig. 4). Over 40 % of the semi-natural grasslands are located within 200-metres of the main rivers, although these

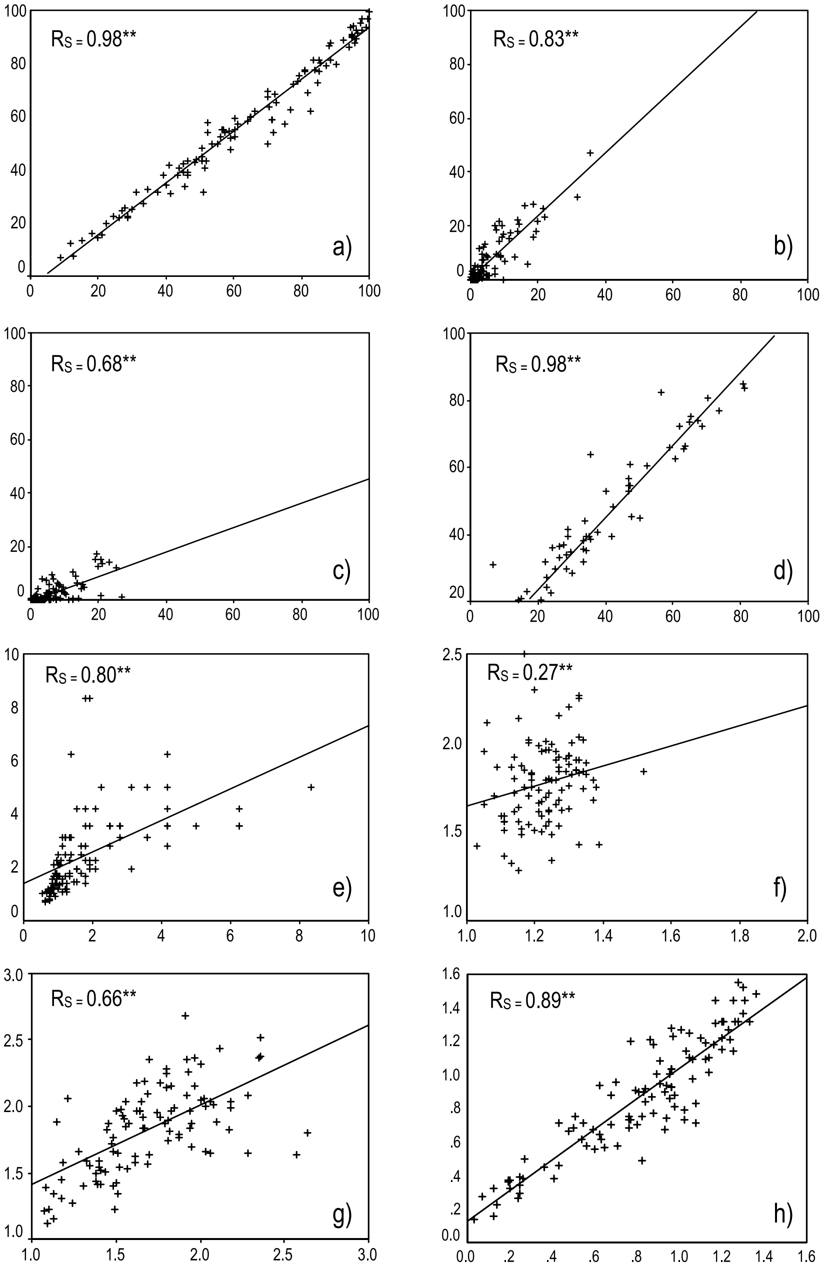

Fig 3. Spearman's rank correlation (R_s) of the structural and compositional indices calculated from 105 grid squares of classified Landsat TM imagery (x-axis) and the Rekijoki habitat map (y-axis): a) Arable land, b) Semi-natural grassland, c) Deciduous woodland and d) Other woods, e) mean patch size in hectares (MPS), f) mean shape index (MSI), g) area weighted mean shape index (AWMSI) and h) Shannon's diversity index (SHDI). $^{**}p < 0.01$.

buffer zones cover only 17 percent of the entire study area. The patch level examination showed that there were, altogether, 150 separate patches of semi-natural grassland one hectare or more in size. The largest single patch found was 19 ha in size, and the second largest was 13 ha. In all, only 6 patches were more than 10 ha in size. Most of the largest patches are located along the river Uskelanjoki or its tributaries, and particularly along the river Rekijoki. An overlay of semi-natural grasslands and soil data showed that all large patches (≥ 1 ha) are located in clay areas surrounded by arable lands. In general, semi-natural grasslands are often found on relatively steep

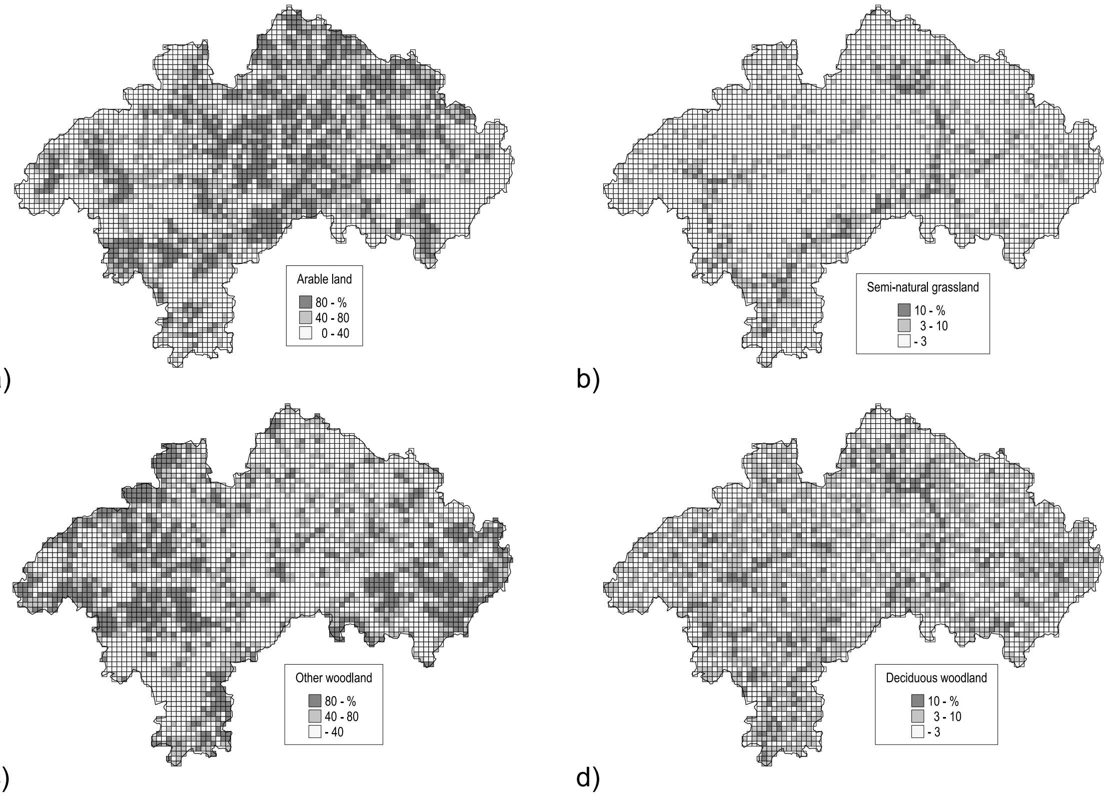

Fig. 4. Distribution of the main habitat types in the study area based on the satellite image classification. a) Arable land, b) Semi-natural grassland, c) Other woodland and d) Deciduous woods. Note that the range divisions are not equal in all maps.

slopes: 32 percent of the patches are located on slopes with an inclination of 5° or more. This varies, however, between different river valleys: in the upper branches of the river Halikonjoki nearly all semi-natural grasslands are situated on flat surfaces, while near the river mouth of Uskelanjoki and Halikonjoki, steep slope patches are more common. Also the neighbourhood analysis revealed that there are more continuous stretches of semi-natural grassland along the length of the river Uskelanjoki and the southern part of the river Halikonjoki (Fig. 6).

Discussion

Multitemporal imagery in habitat mapping

Medium-resolution satellite images have been widely used to obtain habitat maps for landscape ecological and biogeographical research (Riera et al. 1998; Debinski et al. 1999; De Merode et al. 2000; Griffiths et al. 2000; Pan et al. 2001). The properties of any habitat map used as the basis for landscape studies strongly affect the landscape quantifications or modelling exercises. Generally, the acquisition and processing of remotely sensed material is a significant investment for research projects and thus, the data and acquisition dates need to be carefully considered. The results of this study support the assumption that multitemporal data greatly improve the discrimination of habitat types at least in areas where seasonal changes are apparent. Different data combinations seemed, however, to be optimal for the discrimination of different habitat types, depending on the phenological characteristics of vegetation type in question. As can be expected, coniferous and deciduous forests had a higher separability when a spring image from the time before leafing

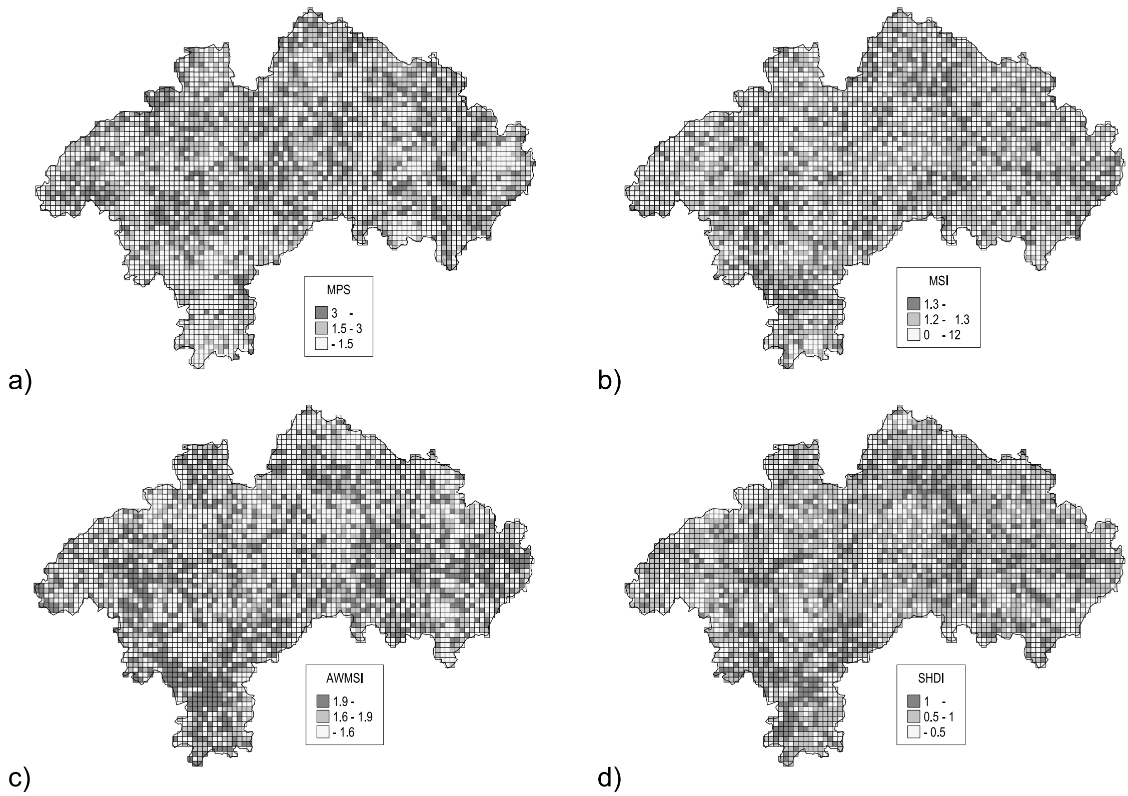

Fig. 5. Structural patterns of the study area presented by mean patch size in hectares (MPS), mean shape index (MSI), area weighted mean shape index (AWMSI) and Shannon's diversity index (SHDI).

was introduced. Discrimination of arable lands and semi-natural grasslands was largely based on their reflectance differences in the near-infrared area and was facilitated by the inclusion of the late summer image. This seems to be due to the ripening of the cereals, which changes the reflectances more pronouncedly than the coincident drying of semi-natural grasslands.

Contrary to our expectations, the calculation of the ratio or vegetation indices from the source data did not improve the classification result, although their benefits have widely been acknowledged (Jensen 1986; Eldvidge & Chen 1995; Rondeaux et al. 1996). NDVI has been widely criticised for being strongly affected by the background soil properties, especially when the vegetation is low and relatively sparse, as in arable areas and semi-natural grasslands (Eldvidge & Chen 1995). However, the index designed for low vegetation, namely OSAVI, yielded poorer results in this study. In our classification tests, vegetation indices were used together with band-wise reflectance values, which resulted in a high number of variables. If fewer variables, i.e. images or bands, were available, vegetation indices might result in the expected improvement of the classification accuracy.

Although the summer of 1999 was generally sunny, our analysis was restricted to just three cloud-free images from the same growing season. Ideally, in order to collect unambiguous information on the phenological development of the spectral signatures of different habitat types and on the optimal time to acquire remotely sensed images during the growing season, a systematic analysis using a spectrometer should be conducted (see e.g., Price 1994).

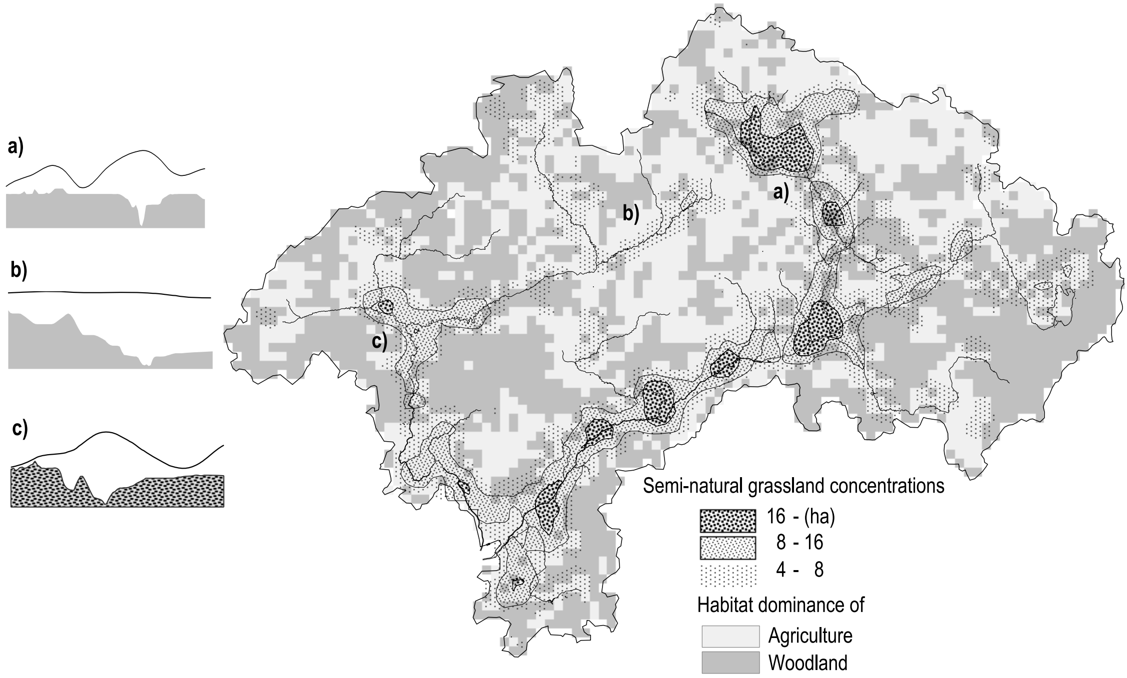

Fig 6. The amount of semi-natural grassland within an 8-neighbourhood presented as smoothed contours. The base map shading indicates the dominance of the main habitat types. The cross-section images sketch the variation of SHDI (line) and topography in three river valleys marked with a), b) and c). The grey shading indicates clay soil, while the dotted cross-section symbolises higher variation in soil types.

Accuracy of the produced habitat map

When using satellite images as the source data for habitat maps, some uncertainties are to be expected. In our results the misclassification of habitat types was common among habitat types with similar reflectance, as well as those with high internal variation (see e.g., Mladenoff et al. 1997). This explains the relatively low classification accuracies for internally highly variable small habitat types, in particular deciduous woods. We had expected from the outset that only patches larger than one pixel (900 m^2) in size would be discriminated from the image. However, even larger patches may have been left out of the classification owing to the patch shape, elongation, location in relation to pixel boundaries, or to the sensor properties (Stoms 1992; Fisher 1997; Cracknell 1998).

Rectangular spatial units seldom match the true shape or size of natural objects (Fisher 1997; Cracknell 1998). The shape and elongation issue is particularly relevant when mapping corridor-like habitats (Kalliola & Syrjänen 1991; Cracknell 1998), such as the semi-natural grasslands in our study area. If the patch width is constantly smaller than pixel width, the patch may be missing from the classification, or it may appear more fragmented than it is in reality. Varying topography of the river valleys even accentuates the problem: When viewed from above, a patch located on a steep slope appears smaller than it really is and may, therefore, be too small to be distinguished. In addition, owing to the movement of the sensor, the reflectances recorded for a certain pixel are influenced by the reflectance of its neighbourhood (Fisher 1997), which can be a considerable factor, particularly in the case of small habitat patches. Moreover, when using multispectral and multi-temporal data, the blending between adjacent pixels is pronounced because pixels in different bands of an image or several images seldom overlap completely (Cracknell 1998).

Despite the problems related to sensor and pixel properties, almost all large patches of semi-natural grassland in the study area could be correctly classified. From an ecological and conservation viewpoint, large patches of rare habitats are the most valuable (MacArthur & Wilson 1967; Verboom et al. 1991) and thus, the result is encouraging. The introduction of object-orientated classification methods, like segmentation, instead of pixel-based ones, could lead to more reliable classification results of even smaller habitat patches in a fragmented landscape (see e.g., Cortijo & Perez de la Blanca 1998; Kilpeläinen & Tokola 1999; Stuckens et al. 2000; Mäkelä & Pekkarinen 2001).

Landscape indices

Luoto (2000a, 2000b) and Hietala-Koivu (1999) have used habitat maps based on aerial photos to describe the habitat pattern and diversity of agricultural areas in Finland. Although recent examples of the use of coarser data exist as well (see e.g., Luoto et al. 2002a, Luoto 2002b), the scale dependency and the effect of different source data on landscape indices has been unclear. Several authors have investigated the effect of scale on landscape structural and compositional metrics by changing the resolution of the same original source data (see e.g., Wickham & Riitters 1995; Cain et al.1997; Riitters et al. 1997). In this study, however, data sets were acquired from different sources at different scales and thus represent a more normal situation.

As supposed on the basis of other studies (see e.g., Wickham & Riitters 1995), compositional indices were less sensitive to changes in pixel size than structural indices. They are dependent not only on scale but even more clearly on the classification accuracy, as is demonstrated by the poor correlation of deciduous woods. The results suggest that landscape compositional indices calculated from relatively coarse source data could be used at the mesoscale with analysis units of 500 by 500 metres as well as indices measured from spatially more detailed data.

Of all the structural indices tested the most general and widely used landscape structure indices (SHDI and MPS) had the highest bivariate correlation, whereas the correlation between the more specific ones (NNSD, AWMSI, MSI) was much weaker. Shape indices suffered from the inevitable replacement of curvy edges with stepped ones when coarser data were used. Shapes and patch lengths are not biased equally, but they vary depending on the patch orientation in relation to that of pixels. In diagonal directions, straight lines are represented as stepped boundaries, whereas in vertical and horizontal directions boundaries remain straight. On the other hand, the poor correlation between NNSD values was expected as patch dispersion changes dramatically when the smallest patches are left out. No such problems are present with compositional indices, MPS or SHDI, which simply measure the size of areas (MacGarigal & Marks 1995; Wickham & Riitters 1995; Cain et al. 1997).

Our results show that the Landsat TM data can well capture landscape characteristics on a mesoscale and thus, provide a very useful and cost-efficient data source for analyses. Landscape index values are highly dependent on the habitat classes used in the source data (MacGarigal & Marks 1995; Cain et al. 1997), but they seem to tolerate rather well the changing resolution of the source data.

Semi-natural grasslands and general habitat pattern

In the entire study area the distribution of the predominant habitat types seems to be related to soil types while the habitat diversity is related both to topography and soil conditions. If the results of the landscape pattern analysis are viewed holistically, the study area seems to have three main landscape types.

There is a vertical belt of *intensive agricultural areas with high habitat diversity* following the course of the rivers Uskelanjoki and Rekijoki (the example area *a* in Fig. 6). The valleys of these rivers are steep and landslides occurring frequently in the clay soils provide new ground for succession (Kontula et al. 2000; Luoto 2000a). As shown by mean patch size (MPS), habitat patches are smaller than on average and their diversity (SHDI) is higher. Semi-natural grasslands still exist as a remnant of traditional agricultural practices and have been spared mainly because they have been difficult to utilise for present-day cultivation practises. River valley slopes with steep angles, in particular, have been left uncultivated due to the risk of erosion and the inconvenience involved in their management. Although the amount of semi-natural grasslands is exceptionally high compared to an average agricultural landscape in Finland, they are nevertheless fragmented and the distances between the larger patches may be several kilometres. Thus, rather than creating a continuous ribbon of "stepping stones", semi-natural grasslands form several spatially separated concentrations along the rivers. This could eventually lead to isolation and an increasing extinction risk for populations of species specialised to this habitat type (Verboom et al. 1991; Hanski 1994; Hanski 1999). Traditional management in the form of grazing and clearing of tall vegetation is needed to maintain the habitat diversity. Additionally, with a relatively small management effort it may be possible to restore some recently forested grasslands, and consequently increase the habitat level diversity.

Landscapes of *intensive agriculture with low habitat diversity* (the example area *b* in Fig 6) are mainly found in the upper reaches of the river Halikonjoki, where on average less steep slopes have made it possible to plough the fields right up to the rivers, as well as in the middle of the agricultural plains further away from the main rivers. Owing to the gentle topography, the less steep river valleys and the flat clay plains probably lack the micro-climatological variation and extremes occurring in topographically more heterogeneous landscapes. Patches are simple and geometric in shape and large in size. Thus, the landscapes are characterised by modern agricultural land uses of high productivity but low ecological value. In these areas, widespread restoration of a more heterogeneous habitat pattern would probably be a time-consuming task.

Agriculture-woodland mosaics are present near the mouths of the rivers Uskelanjoki and Halikonjoki (the example area *c* in Fig. 6), as well as in the watershed areas further from the river valleys. In these mosaics woodlands form the predominant habitat type although arable land is well represented. These areas contain most of the settlements of the study area but also considerable areas of semi-natural grassland. The high compositional habitat diversity reflects the mosaic of small patches and the presence of all six habitat types. Topography varies strongly, mainly due to the bedrock and moraine formations near watersheds but also because river valleys are steep sloped. The habitat types are more equally represented than in other landscape types. Additionally, several soil types are present, which probably contribute to the diversity of these areas.

Conclusions

The study aimed to analyse the usefulness of multi-temporal Landsat TM Images in the mapping of semi-natural grasslands and habitat patterns in an agricultural landscape in SW Finland. Our results showed that the general habitat patterns of a fragmented landscape can be mapped using Landsat TM imagery. Additionally, at least large patches of semi-natural grasslands can be reliably mapped using Landsat TM images. Multi-temporal images, where available, can significantly improve the classification results. Furthermore, the results showed that a Landsat TM -based habitat map can be used as a reliable source of landscape quantifications at meso-scale, particularly for habitat composition and general measures of structure that operate with patch sizes rather than with their shape. To conclude, a similar approach using medium-resolution imagery and landscape indices to characterise landscape pattern and identify main landscape types might be useful for planning of more detailed research, in directing of conservation or management efforts, or in monitoring changes in the landscape.

ACKNOWLEDGEMENTS

We would like to thank Risto Kalliola for his critical comments concerning the manuscript and Mirkka Jones for correcting our English. The GIS and remote sensing unit of the Finnish Environment Institute provided support and facilities at the analyses stage and during the preparation of the first versions of the manuscript. The Finnish Biodiversity Research Programme, FIBRE, financially supported the study.

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