5 The influence of thematic and spatial resolution on metrics of landscape diversity, structure and naturalness – an analysis of Land Use and Land Cover data from Vendsyssel, Denmark

5.1 Introduction

In this study, the objective was to compare different land use and land cover (LUC) data from a public service provider, the Danish Ministry of the Environment, and assess their usefulness for calculation of spatial metrics at different spatial and thematic levels, for use in a specific study area. The results were also compared with metrics derived from the Corine Land Cover (CLC) database. Information on terrain and geomorphology was used to relate metric values to the physical environment and an integrated spatial index for characterisation of landscape naturalness and impact of human activity was evaluated.

A similar suite of spatial metrics as in the previous chapter was used, with values calculated for three different data sources, and three thematic levels. The extension of scope from forest to landscape called for minor changes and additions. The concept of Hemeroby, which was introduced earlier as a measure of disturbance or land use impact was implemented in the present study, under the assumption that this can be quantified and assessed through interpretations of land use data. The moving-window application was used as an integrated tool for the analyses, this time with a specific application in mind, namely characterisation of forest and landscape structure for an Internet based atlas of cultural environments, with the northernmost part of Denmark as the test area. The forests were placed in a landscape context and metrics of forest structure related to metrics of landscape structure. So the current work was also intended as an investigation of whether spatial metrics calculated from land use data can serve as indicators of valuable cultural environments. A minor range of possible sizes of the moving windows (corresponding to the ecological term extent) was tested, and the relation between the metrics values from different sources for different window sizes was evaluated, in order to see *where* agreements between different data sources could be found.

5.1.1 Background – a cultural environment project

The cultural environment is in general seen as a third dimension of the environment, along with protection of animals and plants and prevention of pollution (Schou and Handberg 2000, Møller 2001). The concept of *the* cultural environment is related to the cultural and historical aspects of the physical surroundings, while the individual cultural environments are geographically delimited areas that reflect important features of societal development (Schou and Handberg 2000). A 'cultural environment' can thus mean an area where monuments and objects form *part of an integrated whole*. In Denmark and the other Nordic countries, new proposals for protection orders give much more priority than only a few years ago to how single objects can be preserved as part of a functional landscape context, and how this context can be maintained for posterity (Møller 2001, Møller et al 2002, Fry et al 2003). Cultural environments may be in towns and urban areas, in the agricultural landscape or in forested and other uncultivated areas. Thus, cultural environments have become a theme in landscape research and planning during the last few years. Building of basic knowledge and development of methods that must lie behind the cultural environments have however only taken place to a small degree (von Haaren 2002, Fry et al 2003). In Denmark, the Forest and Nature Agency has been working on providing guidelines for selection of valuable cultural environments (Bach et al 2001, chapter 4.2: Land use in Denmark), following a decision by the Danish parliament in January 1996, to increase the protection of the cultural environment.

The current project, hosted by the University of Southern Denmark (SDU), aims at providing Internet based and cartographically illustrated access to knowledge about cultural environments, so it has also been termed 'creation of a Digital Atlas of Cultural Environments' (DACE). The project will primarily establish this for the central parts of

Vendsyssel in northern Denmark, which has been chosen as test area. Acquisition of historical map information will focus on the two shires Børglum and Dronninglund, see Figure 5.1, while more general efforts will focus on development of methods for data handling and selection and for regionalisation in the landscape. The projects will form the basis of continued research, for selection of cultural environments and for issues of general cultural and historical interest[23].

Amongst the objectives of the DACE project is to evaluate whether individual cultural environments also have special environmental and/or recreational qualities, and it has been proposed that these could be measured in terms of diversity and landscape structure. Also modelling of forest cover in historic and pre-historic time is included, to facilitate models of settlement and former land use – and to aid planning of afforestation[24]. A need has been identified for indicators of landscape structure and means of transferring these between different map types (Ejstrud 2003). This is in line with the objectives of this thesis, so it has been obvious to apply the methods and software already developed here to the data and problems of the DACE.

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[23] A description (in Danish) of the project, application text, methods etc. is found at http://www.humaniora.sdu.dk/kulturmiljoe (accessed 3/3 2004).

[24] Official Danish policy is to increase the forest cover from around 11% in 1989 to about the double area within a 'tree generation' i.e. 80-100 years. Ref. http://www.sns.dk/internat/dnf-eng.pdf (accessed 12/12 2003), see also Jensen (1999).

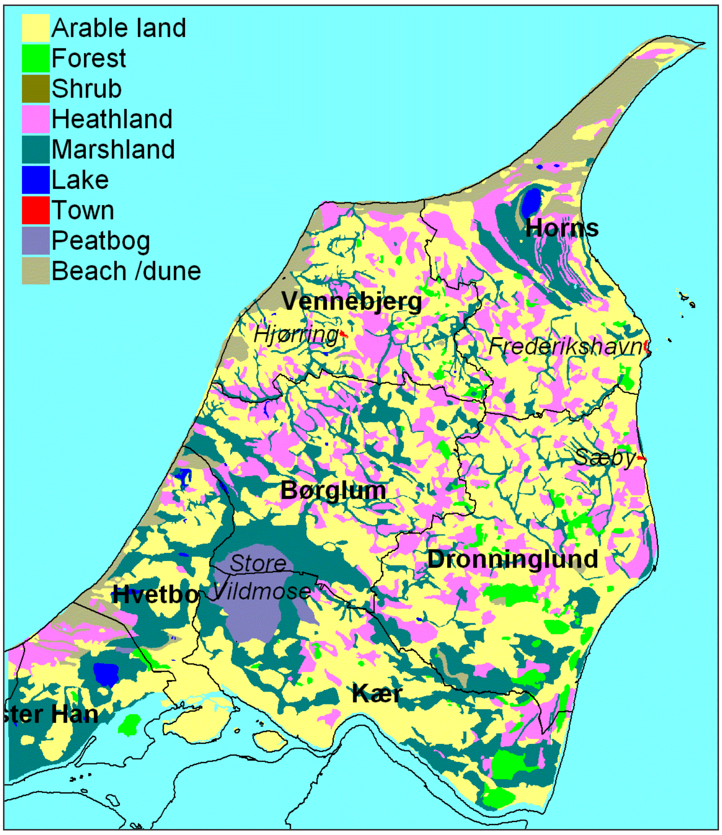

Figure 5.1 Land use in Vendsyssel around the year 1800 from Videnskabernes Selskab's (Asssociation of the Sciences) map of Denmark with shire borders. Shown are also market towns and Store Vildmose. The disagreements between the raster map and the vector with the current coastline are due to subsequent erosion, land uplift and land reclamation. The extent of this map is 78*90 km, corresponding to the box in Figure 5.2.

5.1.2 Background – the study area

Vendsyssel was chosen as test area for the DACE project because of the richness of different landscape types with very different land use history within a limited area, and thus it is also the study area of this chapter. An example of historical land use data is shown in Figure 5.1. The text in this section, which provides some background for the landscape analysis done here, is based mostly on the 'Book about Denmark' (Sehested and Wulff 2003), which is compiled by the editors of the Danish National Encyclopaedia and published by the Danish Ministry of Foreign Affairs[25].

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[25] The section about Northern Jutland, which is written by the geographers K. M. Jensen and H. Kuhlman, is available in edited form at www.denmark.dk; select THE DANISH STATE > Nature & Environment > The Cultural Landscape (accessed 23/6 2004).

Vendsyssel is the northernmost landscape in Denmark, consisting of the north-eastern, main part of the Vendsyssel-Thy island, which again is normally seen as the northern part of Jutland, the rest of it being a peninsula which forms an extension of the North German Plain that is geomorphologically similar to that region. Between the two parts of Jutland runs a long, narrow strait, the Limfjord. Vendsyssel's position is shown in Figure 5.2.

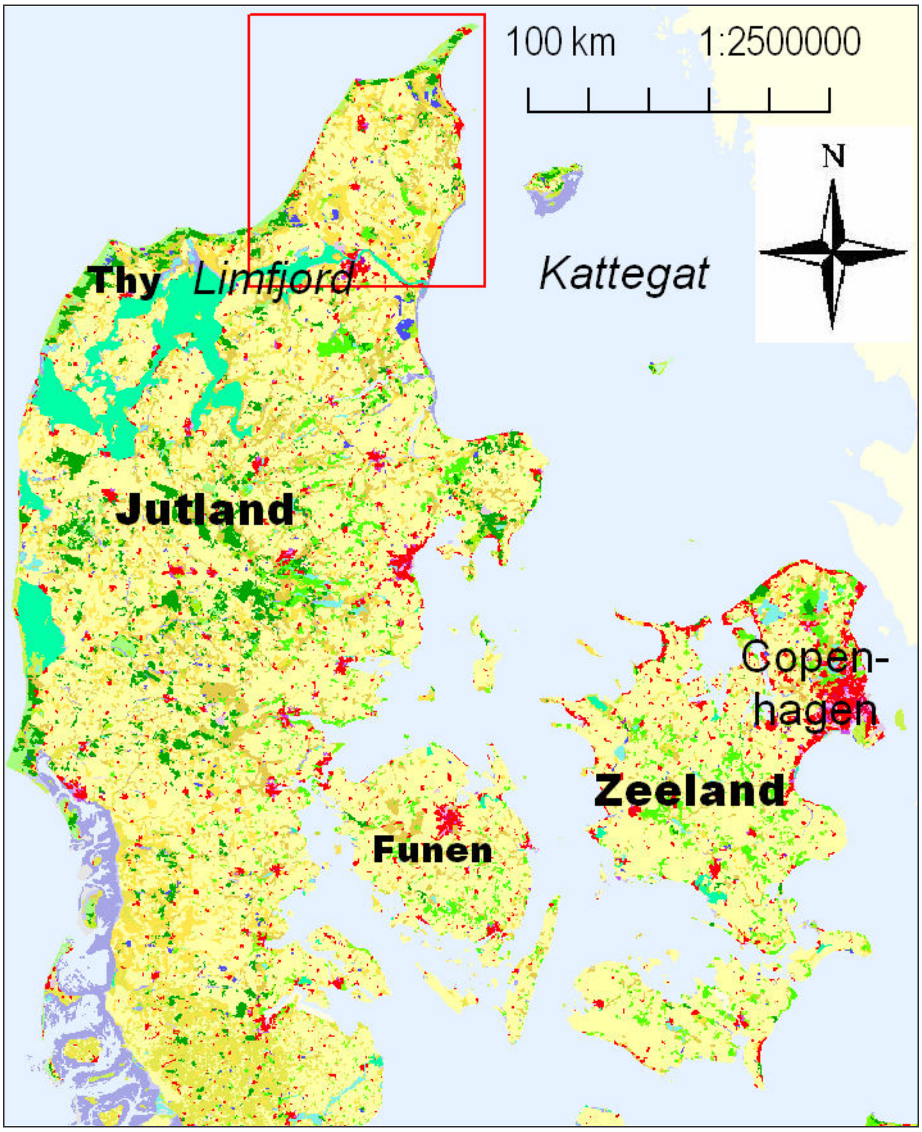

Figure 5.2 Subset with Denmark from the EU-wide CLC map, following the standard CLC legend/palette. The base-map for studies of Vendsyssel is marked by the red box (size 78*90 km).

Geologically Vendsyssel consists of glacial and marine deposits, with moraines, two distinct levels of plains (*Yoldia*[26] from the 'Baltic Ice lake' ca. 14000 BP and *Littorina*[27] from the post-glacial transgression 6-7000 BP) with marine sediment and recent coastal formations as

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[26] After the lead fossil, the bivalve Portlandia (formerly Yoldia) Arctica.

[27] After the lead fossil, the snail Littorina littorea.

the dominating landforms, see Figure 5.3 below. The coast mainly consists of sandy beaches with small sandy cliffs behind them. In places, however, promontories formed by ice age sediments and limestone jut out onto the coast as can be seen at Lodbjerg, Hanstholm, Rubjerg, Hirtshals and Frederikshavn. Huge dunes, some stretching up to 7 kilometres inland, have been formed by sand blown up from the coast. The dune belts are dominated by large, dark conifer plantations, intermixed here and there with white dunes, heaths and heather bogs. The dune zone is generally sparsely developed, and has some of the largest undisturbed natural areas in Denmark, but large holiday housing developments have sprung up since 1930 wherever nature conservation regulations and shifting sands have allowed. The Skagens Odde spit, with Denmarks northernmost point at the end, is one of the most remarkable dune regions in the area, not only because of its extent (it stretches 30 kilometres out into the sea), but also because of its huge migrating dunes. A prime example of this type of dune is the sparsely vegetated Råbjerg Mile which is still very active, moving eastward at a speed of app. 20 m/year. More fertile cultivated areas are however found in the strictly controlled "dune desert", particularly towards the Kattegat and in the reclaimed lake Gårdbo Sø.

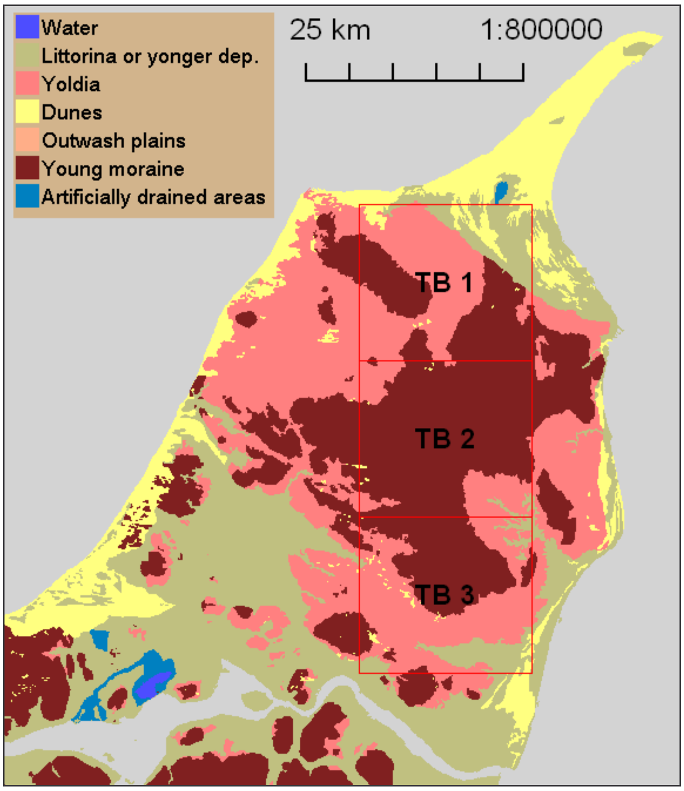

Figure 5.3 Geomorphological map of Vendsyssel, extracted from national dataset copyright Danish Institute of Agricultural Sciences. The boxes show the three test areas for test of metrics values and scaling behaviour (see below and methods section).

There are other unusual terrains and culture landscapes in Vendsyssel. The extensive, low-lying marine plains created by the Littorina Sea stretch from the dune belts of the Jammerbugten, along the Limfjord to the Kattegat coast. Since the Iron Age, several bogs have appeared on the plains north of Aalborg. The most important example is the approximately 100 square kilometres raised bogs known as Store Vildmose. The peat layer in this bog is up to 5 m thick. At the beginning of the 1900s, Store Vildmose was bought up and redeveloped by the State. It was then partly drained and marled after peat-cutting. Grass fields were sown for the rearing of disease-free cattle; the area was later divided into plots and sold off and long rows of farms were built. Other areas of the moor have been set aside as a nature reserve.

Central Vendsyssel is higher than the Littorina plains and is equally divided between high terminal moraine formations, together termed Jyske Ås (Jutland's ridge) and Yoldia flats consisting of sea deposits, mainly sandy. The highest point, 'Knøsen' at the southern end of the ridge is at 136 m above sea level. In both areas the soil is sandy and farming is hindered by drifting soil, despite the use of winter crop cover and the many windbreaks that have been constructed. Large streams such as Uggerby Å and Voers Å have worn away deep trenches in the terrain during the isostatic uplift, which has taken place since the ice age. Since the Stone Age, the sandy Littorina plains have risen between 4 and 10 m, and the area has a number of littoral cliffs formed during different geological periods by the action of the sea. These are generally found in the west and only to a lesser extent in the east. The old farm buildings are seldom grouped in villages, but are instead scattered round the area on both types of terrain. Ever since the 17th century, single farms have been much more common in Vendsyssel than elsewhere in Denmark (Hansen 1964). This is reflected in the isolated locations of the churches built during the Middle Ages. Numerous small towns, known as 'rural towns' have appeared during the 20th century to serve the scattered countryside population. These are generally found by cross-roads and near the railway stations, most of which have since been closed down.

5.2 Objectives

When spatial metrics are used for mapping and selection of cultural landscapes, it is inevitable that specific questions arise over their implementation. The overall question of special relevance to the current project is "can spatial metrics yield a significant contribution to descriptions of areas of interest?" Furthermore, following the needs of the DACE project and the availability of a comprehensive data set of land use, land cover and supplementary data, providing information on a number of forest and other land use/land cover types in the open land, it has been possible to formulate some specific research objectives and questions:

1) Examine 'thematic scaling properties' of the current data.
    a) How does level of detail (thematic resolution) affect the values of spatial metrics?
    b) How does the inclusion/exclusion of internal background (matrix class) affect the metrics values?
2) Examine spatial resolution properties of current data set.

    a) How does changing grain size influence metrics values?
    b) Is there an optimal spatial resolution (grain size) or interval of useful resolutions, for characterising the elements of landscape structure that are relevant to the cultural environment? If yes, can a method be described that is reproducible for similar data sets?
3) Examine comparability of data sources for landscape characterisation.
    a) What causes the differences in average metric values between the different data types?
    b) Why do some data types and some metrics agree better than others, and differently at different thematic resolutions?
    c) Can metrics values from one data source be used to predict metrics values from another (e.g. is there a link between forest diversity in vectorised land use maps and in remote sensing based land cover maps)?
4) Describe possible agreements and disagreements between metrics values from different levels of thematic resolutions and relate the values to the nature and appearance of the data of the different resolutions.
    a) Is the relation between the different thematic levels the same for different data types, or should these levels (and the metrics extracted from them) be interpreted differently?
    b) Can metrics values at one thematic level be used to predict metrics values at another, e.g. do these thematic maps provide a link between for instance landscape diversity and forest diversity?
5) Describe the influence of terrain features on spatial metrics values within moving windows.
    a) Does spatial metrics values depend on the terrain features elevation and slope?
    b) Are significant differences found in metrics values when the test area is stratified according to geomorphological types?

6) Develop methods and/or guidelines for description of landscapes using land use/land cover data.
    a) When moving-windows are used to create maps of landscape properties, what (combinations of) metrics and window size(s) are most useful for characterising cultural environments?
    b) Do the emerging patterns of spatial metrics show any agreement with the location of exicting appointed cultural environments or protected natural areas?
7) Development of an ‘Integrated Hemeroby Index’ and creation of comparable maps of Hemeroby based on averaging disturbance/degradation factors assigned to each grain of the maps based on land use categories.
    a) What is the agreement between Hemeroby index values from high- (the Danish AAK) and low-resolution (Corine) land use data respectively?
    b) How should the Hemeorby index images be processed in order to give the best overview of human influence on the landscapes and/or be used ?

Expected results and outputs from the spatial metrics calculations and subsequent image processing and statistical analysis included:

* Statistics on proportion of class types – for description of the input data sets.

* Values of spatial metrics for each test block at different resolutions/grain sizes; derived from those results response curves for each test area, which will allow comparison of values across scales.

* Results from MW-methods applied to maps of the entire test area, including regressions between data sources, average, minimum and maximum values for different data types, leading to choices of suitable window size(s).

5.3 Data

As already stated, data of various origins were used for the studies described in this chapter. Early in the cultural environment atlas project, it was decided to use a standard ‘base map’ for all raster data covering Vendsyssel. The grain size should be 25m or a multiple hereof, the projection UTM 32N and the datum WGS84. The size of the base map is 78*90 km (east-west and north-south) and the upper left corner in the UTM coordinates are 522,000E and 6,405,000N. The outline of this base-map area is shown in Figure 5.2, and it is also this geographic subset that is used in Figure 5.1 and Figure 5.3.

The Corine land cover (CLC) data are described elsewhere in this thesis (section 4.3.2.2) so here only the different AIS data are described in some detail.

5.3.1 The AIS data

The Danish Area Information System (AIS) was developed during the last half of the 1990's, on initiative from the ministry of the Environment, partly by integrating existing geo-referenced information from various public services, and partly by mapping from satellite images and aerial photography (Mielby 1999, Groom and Stjernholm 2001). The AIS represents an effort to bring together geo-referenced, environmental data that were formerly stored with different public administrative instances (state and counties, with themes such as property, agriculture, environment etc.). One of the reasons for creating the AIS was the growing interest in monitoring terrestrial environments, with management applications such as nature conservation and protection in mind (Groom and Stjernholm 2001, Weiers et al 2002). The sources of data for the AIS are thus vector maps as well as raster imagery. In particular, images from the Landsat satellite have been used, as they have recently become cheaper, and thus land-cover data can be updated with relatively low expenses (Reichhardt 1999). The intended reference year for EO data in the AIS is 1996 (Mielby 1999), although in practice images from a period around that have been used. Denmark is covered by seven Landsat scenes of 183*170 km each. A total of 20 images from the period 1992 to 1997 have been acquired, and combined to form an image archive, with all parts of the country covered by at least two images (Weiers et al 2002, table 1). During image acquisition it was ensured that the images were from two different times of the year, in order to use vegetation dynamics for the purpose of mapping natural and agricultural land cover.

A land cover map (LCM) has been derived from the satellite image archive, through an iterative ‘supervised image classification’, with assignment of pixel to land cover classes through the maximum likelihood algorithm (Nielsen et al 2000a, pp. 31-39, the method is also explained in Weiers et al 2002, figure 1). The LCM covers the entire Danish territory and is delivered as a raster image with pixel size 25m, in the UTM projection (zone 32N). In addition to the LCM, a product termed Land Cover Plus (LCP) is produced and made available. LCP is based on the same image data and subclasses that were used for deriving the final LCM classes. The thematic resolution of the LCM is 12 classes: “unvegetated” and different cultural and natural vegetation types. The LCP however is the result of an interpretation of as many subclasses as possible. This LCP interpretation has been done separately for seven different sections, roughly corresponding to different Danish nature/land use regions (see map in Nielsen et al 2000a p. 32). For each of seven zones, a different selection of spectral classes are assigned to land cover classes with a satisfying statistical agreement. Therefore the LCP have a varying number of classes for these regions, for Northern Jutland amounting to nineteen. The LCM and LCP classes are listed in Table 5.3. For the region including Northern Jutland, the LCP approach made it possible to distinguish five additional forest classes, including spruce plantations and thin evergreen forests, which are significant landscape elements in this region (see also Table 5.1).

At the centre of the AIS is the land use map, known as AAK[28]. It is based on topographic maps at 1:10,000 and 1:25,000 and exists in vector format, as blocks of 25*25 km; altogether Denmark is covered by 118 of these blocks[29]. The land use classes in the AAK product are

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[28] From Danish: Areal Anvendelses Kortet (The Land Use Map)

[29] The blocks are available for download in MapInfo table or Arc/Info shape format at http://www.dmu.dk/1_viden/2_miljoe-tilstand/3_samfund/ais/4_Download/download.htm (accessed 7/10 2003).

partly derived using the satellite images, through (manual) use of LCM and LCP for labelling for nature and forest classes. The forest areas in the AAK are outlined from topographical maps, with the forest type defined from the satellite based LCM. Actually, the older, printed maps have two categories of forest: broad-leaf or coniferous, while newer vector-based maps have just a single forest category, a fact that underlined the need for satellite based land cover mapping (Groom and Stjernholm 2001). Thus, the satellite data has been used to determine nature LC classes in the AAK, not the other way around. The AAK data are well suited for display as maps at the scale 1:10,000, and are as such useful in detailed planning applications. For raster data this corresponds to pixel sizes of 5 to 10 meters. A direct comparison of the two data sources above reveal that the AIS vector based maps show classes that cannot be distinguished by satellite RS – compare Table 5.3 and Table 5.4 - while the LCM and LCP maps show (nature) classes that are very hard and time consuming to map in the field (thus using RS as a monitoring tool). More detailed information of the data sets of the AIS can be found in the meta-data catalogue (Nielsen et al 2000b).

The CLC spatial database is described elsewhere in this thesis, the data used here is from the 250m image data, for a further description of the data see EU – DG AGRI and others (2000, chapter 1.2), Büttner et al (2002). Neither the CLC nor AAK are land use maps in the strict sense that they show only the human use of the land surface along land register borders, they are to a large extent based on interpretation of satellite images, partly through classification of surface and vegetation types, thus the analyses here are not directly confronting land use with land cover maps, rather comparing two different approaches to creation of LUC maps for environmental management. The four available map types are compared in Figure 5.5, along with the appearance of the different thematic resolutions to which they have been re-classified (see section 5.4.2).

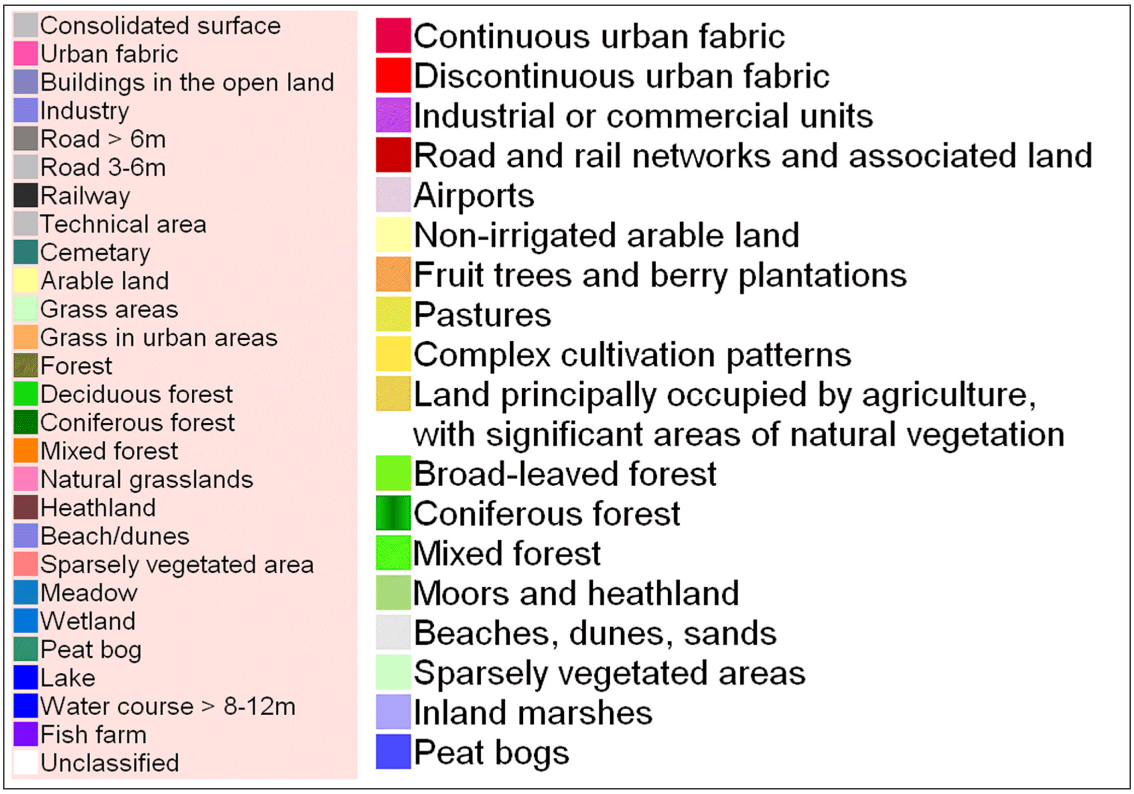

Figure 5.4 Legends for land use – land cover data used in this study, AAK (left) and CLC (right). Only the relevant classes are included, i.e. those observed within the study area.

These data sets of land use/land cover data will be used as background and context data for the DACE described in section 5.1.1. For delineation of protected areas and areas of special cultural and historical interest, data from the regional administration, Nordjyllands Amt (county[30]), has been used. Interactive maps from the region are made available to the public at the web site: http://www.nja.dk/Serviceomraader/Regionplan/KortOgLuftfoto/Kort.htm (accessed 13/10 2003, in Danish). The maps can be viewed and printed, but not (yet) downloaded as data layers in GIS-formats. Some of the county's data have however been supplied to the AIS and form part of nation-wide coverages.

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[30] Denmark currently has three administrative levels: national (state), regional (counties) and local (municipalities).

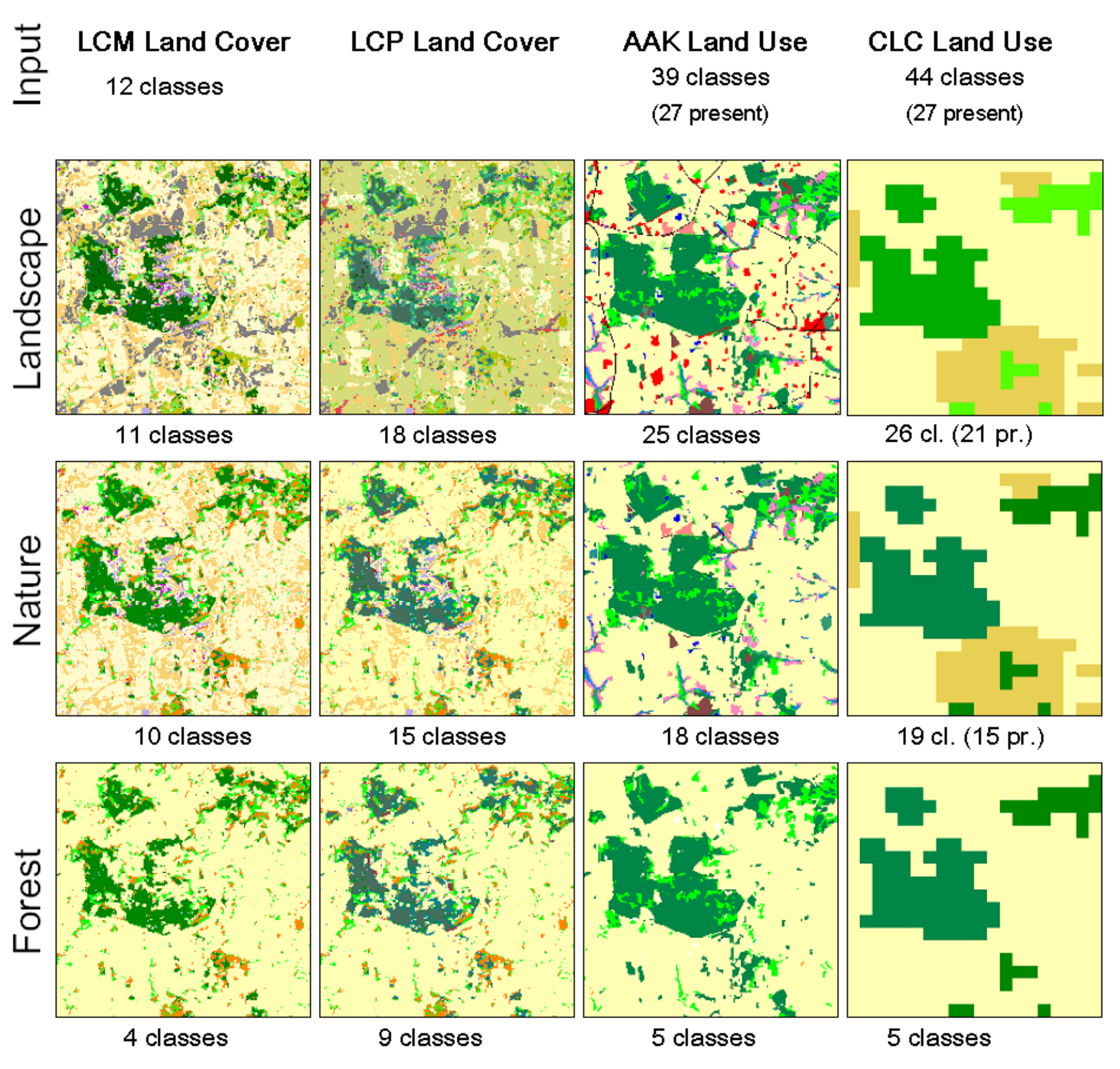

Figure 5.5 Subset of 5*5 km from the different image data sets used in this chapter. Note that for the land use data sets, not all classes are present in the study area; for the CLC-Corine data due to the location of the area, for the AAK data because some classes are very rarely used. The number of classes stated above the images is actual land use/land cover classes, excluding the "background/sea class". Upper left corner in UTM32N: E 570,000m, N 6,353,000m. The large object is Pajhede skov (forest) with strongly sloping terrain and a highest point of 112m, to the right is the small village Brønden.

5.3.2 Elevation model and supplementary data

A digital elevation model (DEM) has been acquired from Kort og Matrikel Styrelsen (KMS), the national Danish provider of geodetic services, maps and cadastral information, where it is named the DHM (Digtal Højde Model). The DHM was derived from contour lines from 1:50,000 maps, at 5m intervals. The information was delivered as point data in vector format, with points placed at the intersections of a 50m grid. For this study, the data was transformed (interpolated) to a raster grid with 25m grain size. The precision as stated by the supplier is better than 2m, however for strongly sloping terrain up to 10-20m. Other supplementary data layers include:

- Land use approx. 1800, digitised from Videnskabernes Selskab's map of Denmark (1:120,000), see Figure 5.1.
- Geomorphology, from Danish Institute of Agricultural Sciences (1:200,000), see Figure 5.3.
- Subsoil (underground/base) map from GEUS, Geological Survey of Denmark and Greenland (1:200,000).
- Danmarks Digitale Kortværk (digital map collection of Denmark). Digital versions of topographic maps, from KMS, used for illustration (see for instance Figure 5.7).

The above data have been transferred to raster format and transformed or re-sampled to UTM-32N projection with the WGS-84 datum.

5.4 Methods

The methods described and applied in this chapter include data extraction and aggregation, calculation of spatial metrics on image subsets and using moving windows, as well as analysis of the sensitivity of this particular data set to scaling of the map data in raster image form. In contrast to chapter 3 where a binary forest-non forest map was used, and chapter 4 where two forest maps with 5 and 6 forest classes were compared, LUC data with between 5 and 27 classes were used here. Concerning the image processing, the IDL-scripts used for the moving-windows application in chapter 4 could be used with only slight modifications, along with some routines in the GIS software packages Idrisi and MapInfo. The output tables and images are used for display and comparison of their relation to other landscape, terrain and cultural features. Fragstats for Windows was used for extraction of patch count metrics for the test blocks. The spatial metrics are calculated for each test block, and used for creation of grain-scalograms for the different areas, and for comparison of 'base values' for the different data sources. Finally, Idrisi MapWalker (Hovey 1998) was used for fast creation of 'average maps'.

The set of images for metrics calculations, that was compiled from the input data, was of a quite manageable size: 24 images ranging from 4000*3600 to 180*200 pixels for the scaling analysis (3 'test blocks' * grain sizes), 9 images of 3120*3600 pixels (3 thematic levels*3 data types) and 3 images of 312*360 pixels (3 thematic levels for the CLC data), in sum 36 images for the M-W analyses and two images of 3120*3600 pixels for the Hemeroby assessment. The different processing steps however spawned a large amount of text files and images that could be combined in numerous ways, and all sorts of relations investigated, resulting in more text-files and spreadsheets. A central task in this study has thus been to select among possible analyses, judging which combination of input data would yield the most relevant and interesting results.

5.4.1 Creating base-maps and geo-referencing the data

The first task for compiling a coherent data set like this is making the layers fit, i.e. match spatially. All vector and raster data have been re-projected to UTM zone 32 N with the WGS84 datum, because this datum is implicit for the UTM projection in Idrisi (Eastman 1997, Appendix 2), and thus the conversion was necessary in order to make the raster data compatible with different (additional, ancillary) vector data. The AAK vector data were thus re-projected and then converted to raster format, through gridding by use of the Vertical Mapper module of MapInfo. The CLC, LCM and LCP maps were rectified using the rectification functions of WinChips (Hansen 2000). This step was necessary because these maps could not be re-projected in MapInfo, as this system does not allow nearest-neighbour re-sampling of raster images, but insists on using a built-in interpolation algorithm (which does not make sense with categorical data). The result of these processing steps was subsets of the above mentioned maps corresponding to the previously defined base map.

5.4.2 Thematic levels and re-classifications

As stated in the objectives (in particular points 1 and 4), a set of images at different thematic resolutions, covering the study area, were to serve as input to the spatial analyses. Three possible thematic levels were identified, which could be derived from all types of original data: these are “landscape”, “nature” and “forest”. For the AAK and CLC images, the thematic level “landscape” is the closest to simulating a land cover map from the land use data. The reason that more classes are assigned to ‘background’ for the forest maps is that the land class here should represent areas that can potentially be forested[31]. This is in line with GAP analysis approaches, where the amount existing vegetation types are compared with their potential distribution, as was done for the entire European area by Smith and Gillet (2000), using CLC data and maps of potential vegetation in Europe.

The extraction of ‘nature type’ relevant information (layers) means that it is possible to calculate contextual metrics describing the ‘nature context’ of potential cultural environments in agricultural areas. Before re-classification, and in order to get a first impression of the comparability of the data types, the amounts of forest types were calculated from each data type, the results are shown in Table 5.1. From there it appears that the CLC map generally underestimates the forest area and overestimates the extent of agricultural activities, which illustrates that this kind of LUC data should be interpreted with care. This over-representation is due to the effect of aggregation that makes small forest patches disappear in open land as do background patches in forest areas, an effect shown already by Turner et al (1989), and discussed in more detail in the following section. The effect is actually *not* observed in the subset used for Figure 5.5, because a subset with an above-average proportion of forest was deliberately chosen – in order to make a clearer illustration. Note that with higher resolution of the input (image) data becomes, the lower the proportion of the ‘mixed forest’ class, as the need for mixed classes decreases with increasing resolution (Goffredo 1998, chapter 2, Brown

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[31] Which is basically all land surfaces in Denmark, except bogs, dunes, cliffs and other special landforms.

and Duh 2003). Visual inspection of the satellite derived images reveal a problem of confusion of the urban/infrastructure and unvegetated classes in the LCM and LCP, due to their similar spectral behaviour.

Class no.	Class description	LCM	LCP	AAK	CLC
0	water/unknown				
1	non-forest land	89.12	88.39	90.55	92.26
2	bush/forest	2.84	2.84	0.01	0.97
3	Deciduous forest	2.73	2.73	2.03	0.46
4	Coniferous forest	5.31	0.32	7.39	4.46
5	mixed forest		0.47	0.02	1.85
6	Spruce plantation		1.51		
7	thin needle-leaved forest		3.02		
8	Overgrown heath		0.64		
9	Recently cut forest		0.09		
	Total forest and similar	**10.88**	**11.61**	**9.45**	**7.74**

Table 5.1 Proportion of forest land cover types from different mapping sources. The classes correspond to the ones shown for the row of forest images in Figure 5.5. Data from entire base map area, background excluded, pixel size 25m.

It was not obvious whether the ‘heterogeneous’ agricultural classes of CLC, type 2.4 at level 2, should count as nature (as such area can contain some natural elements) or as clean agricultural blocks which would closer resemble the AAK. In this study however, it was decided to assign the class ‘complex cultivation patterns’ to the landscape matrix in the nature thematic image while ‘land principally occupied by agriculture, with significant areas of natural vegetation’ was assigned to a class of its own at ‘nature’ and ‘landscape’ thematic levels. Table 5.2 summarises the proportions of the land area of the base maps that contain the respective thematic layers, and Figure 5.6 illustrates the visual appearance of some results of the tentative re-classifications.

Percentage of total area	LCM	LCP	AAK	CLC
Forest	10.88	11.61	9.45	7.77
Nature	36.73	28.40	24.55	25.30
Landscape level 1	36.73	40.26	34.94	48.50
Landscape level 2	81.13	85.70	89.61	93.59

Table 5.2 Proportion of non-matrix and non-background (including all objects/classes of interest) for the different thematic resolutions and different data sources used here. Landscape level 1 denotes areas that are not strict agricultural classes (for CLC including the category of complex cultivation patterns (2.4.2), while Landscape level 2 denotes areas that are not urban, infrastructure or unvegetated classes, representing all permanently or seasonally vegetated surfaces. The reason that L2 fractions are relatively low for LCM and LCP is the relatively (unrealistically) large areas classified as unvegetated, for instance seen as the grey patches in Figure 5.5. Level 1 and 2 is only used here for landscape description, not as reclassified layers.

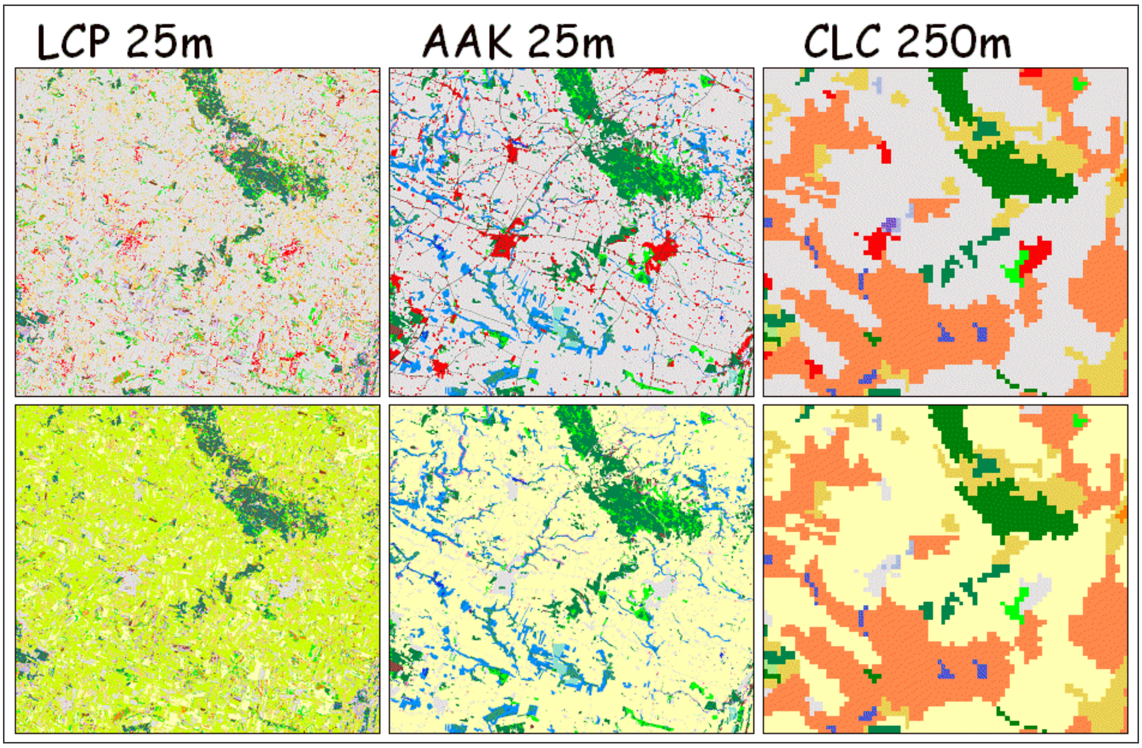

Figure 5.6 Tentative re-classifications into thematic levels, Test block 3, size 20*18 km, with the towns Hjallerup (left) and Dronninglund (right) and Dronninglund Storskov as prominent features (compare Figure 5.7). Although these images are based on the same data sets, extracted from AAK, the structure of the landscape is reflected in different ways when the selections "landscape" with agriculture as matrix – shown in light grey, top row and "nature" with arable and urban/artificial excluded – pale yellow, bottom row, are used.

It was chosen not to use the thematic level "Landscape 1" for further image processing and analysis in this study, as it would not be clear how this level differs functionally from the nature level. The names of the classes used in Table 5.2 constitute a very simple legend, but this is necessary in order to allow direct comparison of different image data sources. Still, this approach was found to allow display and evaluation of basic landscape structure.

The details of the nomenclature and re-classifications strategy chosen are listed in Table 5.3 to Table 5.5, and the visual appearance of the resulting images is seen in Figure 5.5 on page 201.

class/pixel no.	LCP/LCM classes	LCP_landscape	LCP_nature	LCP_forest	LCM_landscape	LCM_nature	LCM_forest
0	Unknown	**Background**	**Background**	**Background**	**Background**	**Background**	**Background**
1	Water	**Background**	**Background**	**Background**	**Background**	**Background**	**Background**
3	Unvegetated	Unvegetated	**Land**	**Land**	Unvegetated	**Land**	**Land**
5	Grass heath	Grass heath	Grass heath	**Land**	Grass heath	Grass heath	**Land**
7	Cropped/grazed	Cropped/grazed	Cropped/grazed	**Land**	Cropped/grazed	Cropped/grazed	**Land**
8	Meadow	Meadow	Meadow	**Land**	Meadow	Meadow	**Land**
10	Bush/grass heath	Bush/grass heath	Bush/grass heath	**Land**	Bush/grass heath	Bush/grass heath	**Land**
11	Bush/heather heath	Bush/heather heath	Bush/heather heath	**Land**	Bush/heather heath	Bush/heather heath	**Land**
14	Shrub/forest	Shrub/forest	Shrub/forest	Shrub/forest	Shrub/forest	Shrub/forest	Shrub/forest
15	Deciduous forest	Deciduous forest	Deciduous forest	Deciduous forest	Deciduous forest	Deciduous forest	Deciduous forest
16	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest
18	Arable/rotational	Arable/rotational	**Land**	**Land**	Arable/rotational	**Land**	**Land**
21	Densely built	Densely built	**Land**	**Land**	-	-	-
28	Spruce plantation	Spruce plantation	Spruce plantation	Spruce plantation	-	-	-
29	Mixed forest	Mixed forest	Mixed forest	Mixed forest	-	-	-
33	Recently cut forest	Recently cut forest	Recently cut forest	Recently cut forest	-	-	-
34	Thin needle-leaved Forest	Thin needle-leaved Forest	Thin needle-leaved Forest	Thin needle-leaved Forest	-	-	-
35	Overgrown heath	Overgrown heath	Overgrown heath	Overgrown heath	-	-	-
37	Exposed	Exposed	**Land**	**Land**	-	-	-
40	Undifferentiated Grass or arable	Undifferentiated Grass or arable	**Land**	**Land**	-	-	-
Number of classes	20	19	15	10	11	10	5

Table 5.3 Aggregation of Land Cover Map (LCM) and Land Cover Plus (LCP) image data for landscape analysis at varying thematic resolutions.

Class no.	**AAK_ID**	**AIS_landuse (AAK)**	**AIS_landscape**	**AIS_nature**	**AIS_forest**
0		Unclassified	**background**	**background**	**background**
1	1100	Consolidated surface	*Unvegetated/ exposed*	**Land**	**Land**
2	1110	Continuous urban fabric	*Built*	**Land**	**Land**
3	1120	Discontinuous urban fabric	*Built*	**Land**	**Land**
4	1121	Multistoreyed houses	*Built*	**Land**	**Land**
6	1123	Buildings in the open land	*Built*	**Land**	**Land**
7	1210	Industry	*Built*	**Land**	**Land**
8	1221	Motorway	*Traffic infrastructure*	**Land**	**Land**
9	1222	Expressway	*Traffic infrastructure*	**Land**	**Land**
10	1223	Road>6m	*Traffic infrastructure*	**Land**	**Land**
11	1224	Road 3-6m	*Traffic infrastructure*	**Land**	**Land**
12	1226	Railway	*Traffic infrastructure*	**Land**	**Land**
13	1228	Bridge	*Traffic infrastructure*	**Land**	**Land**
14	1229	Embankment	*Vegetated infrastructure*	**Land**	**Land**
15	1240	Airport	*Vegetated infrastructure*	**Land**	**Land**
16	1242	Runway	*Traffic infrastructure*	**Land**	**Land**
17	1310	Mineral extraction area	*Unvegetated/ exposed*	**Land**	**Land**
18	1340	Technical area	*Other surface sparse veg.*	**Land**	**Land**
19	1341	Cemetery	*Parks and similar*	**Land**	**Land**
23	2112	Arable land	Arable land	**Land**	**Land**
25	2300	Pastures	Pastures	**Land**	**Land**
26	2310	Grass in urban areas	*Parks and similar*	**Land**	**Land**
28	3100	Forest	Forest	Forest	Forest
29	3110	Deciduous forest	Deciduous forest	Deciduous forest	Deciduous forest
30	3120	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest
31	3130	Mixed forest	Mixed forest	Mixed forest	Mixed forest
32	3210	Natural grasslands	Natural grasslands	Natural grasslands	**Land**
33	3220	Heathland	Heathland	Heathland	**Land**
34	3250	Mixed nature	Mixed nature	Mixed nature	**Land**
35	3310	Beach/dune	Beach/dune	Beach/dune	**Land**
36	3330	Sparsely vegetated area	*Other surface sparse veg.*	Sparsely vegetated area	**Land**
37	4110	Inland marsh	Inland marsh	Inland marsh	**Land**
38	4112	Wetland	Wetland	Wetland	**Land**
39	4120	Peatbog	Peatbog	Peatbog	**Land**
40	4130	Salt marsh	Salt marsh	Salt marsh	**Land**
41	5120	Lake	Lake	Lake	**Background**
42	5121	Water course >8-12m	Water course >8-12m	Water course >8-12m	**Background**
43	5123	Lake - reed forest	Lake – reed forest	Lake - reed forest	**Background**
44	5126	Fish farm	fish farm	**Background**	**Background**
45	5230	Open sea	**Background**	**Background**	**Background**
46	6000	Unclassified	**Background**	**Background**	**Background**
Number of classes (incl. Background)		41	25	18	6

Table 5.4 Step-wise re-classification of land use data from the AAK. Classes at the Landscape level roughly correspond to Corine level 2 for the urban/agricultural parts, though the nomenclature is not the same.

Hierarchical class number	Image class number	CLC_LEVEL3	CLC_Landscape	CLC_Nature	CLC_Forest
1.1.1	1	Continuous urban fabric	*urban fabric*	**Land**	**Land**
1.1.2	2	Discontinuous urban fabric	*urban fabric*	**Land**	**Land**
1.2.1	3	Industrial or commercial units	*Industrial, commercial and transport units*	**Land**	**Land**
1.2.2	4	Road and rail networks and associated land	*Industrial, commercial and transport units*	**Land**	**Land**
1.2.3	5	Port areas	*Industrial, commercial and transport units*	**Land**	**Land**
1.2.4	6	Airports	*Industrial, commercial and transport units*	**Land**	**Land**
1.3.1	7	Mineral extraction sites	*Mine, dump and construction sites*	**Land**	**Land**
1.3.2	8	Dump sites	*Mine, dump and construction sites*	**Land**	**Land**
1.3.3	9	Construction sites	*Mine, dump and construction sites*	**Land**	**Land**
1.4.1	10	Green urban areas	*Artificial, non-agricultural vegetated areas*	**Land**	**Land**
1.4.2	11	Sport and leisure facilities	*Artificial, non-agricultural vegetated areas*	**Land**	**Land**
2.1.1	12	Non-irrigated arable land	*Arable land*	**Land**	**Land**
2.1.2	13	Permanently irrigated land	*Arable land*	**Land**	**Land**
2.1.3	14	Rice fields	*Arable land*	**Land**	**Land**
2.2.1	15	Vineyards	*Permanent crops*	**Land**	**Land**
2.2.2	16	Fruit trees and berry plantations	*Permanent crops*	**Land**	**Land**
2.2.3	17	Olive groves	*Permanent crops*	**Land**	**Land**
2.3.1	18	Pastures	*Pastures*	**Land**	**Land**
2.4.1	19	Annual crops associated with permanent crops	*Heterogeneous agricultural areas*	**Land**	**Land**
2.4.2	20	Complex cultivation patterns	*Heterogeneous agricultural areas*	**Land**	**Land**
2.4.3	21	Land principally occupied by agriculture, with significant areas of natural vegetation	Principally agriculture, significant nature	Land principally occupied by agriculture, with significant areas of natural vegetation	**Land**
2.4.4	22	Agro-forestry areas	Agro-forestry areas	Agro-forestry areas	**Land**
3.1.1	23	Broad-leaved forest	Broad-leaved forest	Broad-leaved forest	Broad-leaved forest
3.1.2	24	Coniferous forest	Coniferous forest	Coniferous forest	Coniferous forest
3.1.3	25	Mixed forest	Mixed forest	Mixed forest	Mixed forest
3.2.1	26	Natural grasslands	Natural grasslands	Natural grasslands	**Land**
3.2.2.	27	Moors and heathland	Moors and heathland	Moors and heathland	**Land**

3.2.3	28	Sclerophyllous vegetation	*other forest*	other forest	other forest
3.2.4	29	Transitional woodland-shrub	*other forest*	other forest	other forest
3.3.1	30	Beaches, dunes, sands	Beaches, dunes, sands	Beaches, dunes, sands	**Land**
3.3.2	31	Bare rocks	Bare rocks	Bare rocks	**Land**
3.3.3	32	Sparsely vegetated areas	Sparsely vegetated areas	Sparsely vegetated areas	**Land**
3.3.4	33	Burnt areas	**Background**	**Land**	**Land**
3.3.5	34	Glaciers and perpetual snow	Glaciers and perpetual snow	Glaciers and perpetual snow	**Land**
4.1.1	35	Inland marshes	Inland marshes	Inland marshes	**Land**
4.1.2	36	Peat bogs	Peat bogs	Peat bogs	**Land**
4.2.1	37	Salt marshes	Salt marshes	Salt marshes	**Background**
4.2.2	38	Salines	Salines	Salines	**Background**
4.2.3	39	Intertidal flats	Intertidal flats	Intertidal flats	**Background**
5.1.1	40	Water courses	Water courses	Water courses	**Background**
5.1.2	41	Water bodies	Water bodies	Water bodies	**Background**
5.2.1	42	Coastal lagoons	**Background**	**Background**	**Background**
5.2.2	43	Estuaries	**Background**	**Background**	**Background**
5.2.3	44	Sea and ocean	**Background**	**Background**	**Background**
	49	NODATA	**Background**	**Background**	**Background**
	50	Sea and ocean	**Background**	**Background**	**Background**
Number of classes		44+2	27	19	6

Table 5.5 Step-wise re-classification of land use classes from the CLC.

Note that the CLC landscape categories *almost* correspond to the Corine Level 2 nomenclature for the non-nature parts of the land surface. The difference lies in the splitting of group 2.4 where the class “Principally agriculture, significant nature” is kept apart from other agricultural land use, due to the assumption that it has a different functionality in terms of providing habitats and “landscape quality”. The Agro-forestry class is not found in Denmark. This approach is similar to the one used by Gallego et al (2000, table 4.1), where a 23 class and 9 class legend are made for the CLC data, in a comparison of diversity metrics between sites at the European level.

The agreement between similar thematic layers from different data sources were assessed with the Kappa index of agreement (KIA), where pixel-to-pixel cross tabulation is performed. In the absence of common legends, only binary images were used. As Table 5.6 below shows, the coefficient of agreement between the AAK data of vector origin and the satellite derived LCM and LCP forest maps are similar to the value for the agreement between the CLC and FMERS forest maps in the previous chapter, where KIA was 0.522.

Forest	LCM	LCP
AAK	0.5851	0.5783
LCM		0.9656
LCP		

Nature	LCM	LCP
AAK	0.3805	0.4321
LCM		0.8441
LCP		

Table 5.6 Kappa index of agreement for forest-non forest and nature-non nature images derived from the datasets at 25m grain size.

It appears from Table 5.6 that the agreement between the nature theme maps is rather poor, and visual inspection of the AAK and LCM maps show that this is mostly due to the status of the cropped/grazed class, which is included as one of the 'nature' classes when aggregating from the landscape thematic level. In the LCP map with more classes, the cropped/grazed class has been split between cropped/grazed and 'Undifferentiated Grass or arable', which it was chosen not to consider nature.

5.4.2.1 Definitions of landscape and background classes

When dealing with spatial metrics and landscapes through the optics of landscape ecology, a central question is how to handle the parts of the images that are classified as "background". In practice, as in the current data set, that means whether one should distinguish water/unknown from non-forest (or non-nature) land. It is important to decide carefully what should be considered background and what is 'outside' the landscape, because the choices made will strongly affect the resulting metrics values (McGarigal and Marks 1995, Coulson et al 1999, Willems et al 2000). In the user guidelines for the latest version of Fragstats for Windows (McGarigal and Holmes 2000), a distinction is made between *interior* background, which is included in area calculation and *exterior* background, which is assumed to be outside the landscape of interest and completely ignored in the metrics calculations[32]. Ideally, the re-classification strategy should follow implicitly from an understanding of the model that lies behind the metric(s) used. For instance, since metrics of *forest fragmentation* describe the forest-non-forest interface, it makes sense to include a non-forest class in their calculation. On the other hand, for metrics of forest- or nature-diversity at the landscape level, the inclusion of non-forest and non-nature (i.e. mostly agricultural) areas will provide information on the over-

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[32] The guidelines are available at the Fragstats project web site: http://www.umass.edu/landeco/research/fragstats/documents/User%20guidelines/User%20guidelines%20content.htm (accessed 8/12 2003)

all structure and state of the landscape (window) rather than on the objects(s) in question (such as the forest patches/classes). This effect was illustrated in the previous chapter, in comparisons of diversity metrics values for administrative regions **[insert reference to table 4.26, when combining chapters]**.

The choice of definitions for the analysis also determines the re-classification strategy, through which the images are prepared for calculation of spatial metrics. The definition of a landscape or 'matrix' class is a rather rough approach, as it defines and uses the classes non-forest and non-nature, which are not necessarily functionally homogeneous, but it is a practical approach for raster image processing. The 'matrix' class type corresponds to the 'interior background' in the Fragstats guidelines. In practice, two kinds of background are used in the implementation of metrics calculation: Cover (proportion) calculations are based on all pixels that are non-water and non-unknown. Diversity calculations on the other hand should only be performed on the pixels belonging to 'natural' or 'forest' land cover classes, and thus the landscape/matrix class is excluded or ignored. As a standard approach, the re-classified images for these analyses have been assigned a value of 0 (zero) for non-landscape pixels, i.e. sea/ocean and unclassified and a value of 1 for landscape pixels which are not in any of the classes of interest (as here "nature" and forest). Examples of the visual appearance of these re-classifications are seen in Figure 5.5 on page 201. In contrast to the 'matrix', the classes of interest (forest etc.) are here called 'patch' or 'the patch level', in order to be in line with standard terminology of Landscape Ecology.

Once the distribution of classes at different thematic resolutions has been decided, the strategy for re-classification is quite straightforward, using the RECLASS function of the Idrisi raster-GIS (Eastman 1997). Input is the land cover or land use product along with a text file that defines the reclassification, in this case an Idrisi reclass- (.rcl) file, which contains a 'look-up' table with (the numbers of the) input and output classes. Reclass-files have been made for each type of transformation from the existing maps (highest thematic resolution) to maps with the selected and merged classes (thematic subsets).

5.4.3 Selection and extraction of test areas for assessment of AAK data

The test blocks, shown in Figure 5.7 below, are situated in the central parts of Vendsyssel. Together they include almost completely the moraine ridge Jyske Ås. The blocks were chosen in order to include a certain amount of forest, and preferably contain older forests rather than the conifer plantations found in the dune areas to the north and the west, as visual inspection showed these ‘original’ forests to have a more diverse composition. Also the complex landscape patterns in hilly terrain were preferred to the more homogeneous agricultural areas on the Yoldia plains, as this was observed to create more complex and diverse land use patterns. Still, agriculture is the dominating type of land use in all three blocks. Test blocks 2 and 3 represent typical rural Danish landscapes with agriculture dominating the land use, while test block 1 represent a rural landscape with a significant amount of nature.

Block 1, the northernmost area, includes some marine and aeolian deposits in the north-western corner, adding a landscape that is complex in terms of nature types, particularly heaths and moors. The rest of the block is dominated by the scenic hills Tolne Bakker and Yoldia plains with the stream Uggerby Å which flows through a gap in the ridge east of the rural town Sindal. This block largely coincides with Sindal commune, which in Danish context is a large and thinly populated municipality with just 39 inhabitants per km^2.

Block 2 contains the central part of the moraine landscapes of central Vendsyssel, with the Yoldia plain in the northwest. Uggerby Å has its source near Søhedens bakke (hill, 112m) in Pajhede skov on the ridge. To the east flows Sæby Å and to the southwest Voers Å, which forms a significant valley in the Yoldia plain, filled with younger marine deposits. This block holds the interior parts of Hjørring, Sæby and Brønderslev municipalities. Hjørring is the largest town in Vendsyssel, with 35,500 inhabitants, of which 24,700 in the centre town, but there are no suburban part in the area of this block, so like for the other municipalities the parts included here are of rural character.

Block 3 includes the highest are steepest parts of central Vendsyssel, the southern end of Jyske Ås with large continuous forest areas, especially Dronninglund Storskov with an area of approx. 850 ha. In the south is Yoldia plain and the valley of the Gerå stream. The block coincides well with Dronniglund commune, which also is a large and thinly populated municipality with 48 inhabitants per km^2. Two relatively large towns are Dronninglund (2900 inhabitants) and Hjallerup (3200 inhabitants). Recently a motorway has been constructed through the area, it was inaugurated in October 2000. It runs from the village Flauenskjold in the northeast to near Hammer Bakker (hills) in the southwest, and has only a few crossings, thus forming a significant barrier to movement and flows across the landscape.

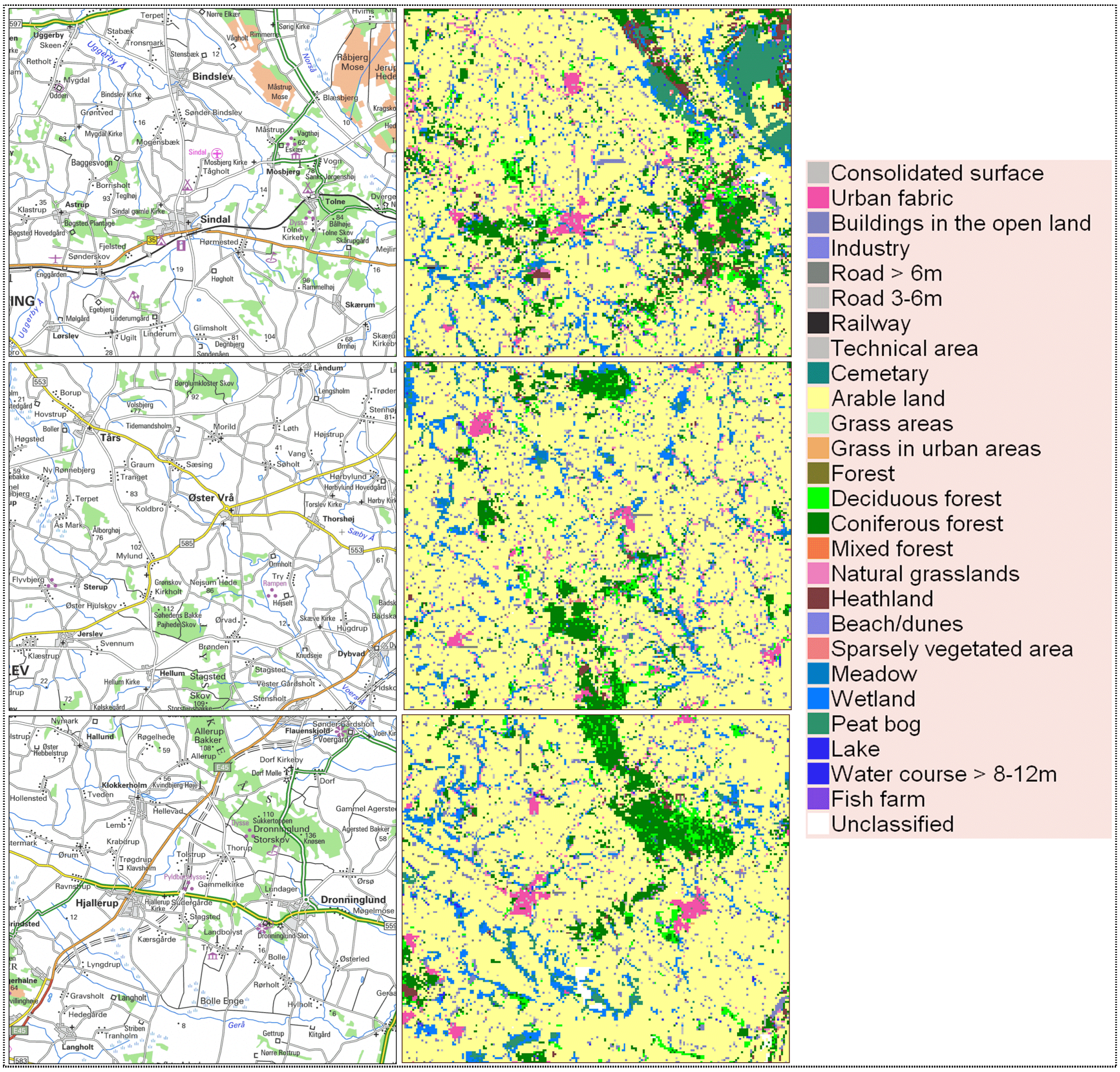

Figure 5.7 Test block 1 to 3 as KMS traffic maps. Left column from top to bottom shows the blocks as KMS traffic map 1:200.000, middle column shows AAK LULC maps of the same blocks sampled to 100m grain size, right column AAK legend with selected classes, present in the area. The extent of the test blocks is 20*18 km, an area of 360 km^2.

For these three subsets, the AAK map was converted to grids with grain sizes ranging from 5 to 100 meters, and exported as ASCII-grids for subsequent import to WinChips and/or Idrisi formats. The resulting image files have sizes from 3600*4000 pixels to 180*200 pixels. This covers a range of resolutions where linear elements such as roads, railways and streams are visible at the small grain sizes but tend to dissolve and then disappear at larger grain sizes (>20-30m). Thus, at high resolution these elements will appear as barriers or corridors in the landscape, while at lower resolutions, the landscape will seem to have lost these functions – a phenomenon that should be reflected in the spatial metrics values.

Table 5.7 shows the distribution of the AAK classes at the "landscape" thematic level in the three test blocks. Here the 5m resolution rasterised images are taken to represent the ground truth. The proportions found confirm that agriculture is the dominant land use class and constitute the landscape matrix.

Land Use, AAK aggregated		TB1	TB2	TB3
2	Bush-forest	0.03	0.02	0.01
3	Deciduous forest	2.37	2.02	2.59
4	Coniferous forest	9.12	5.91	7.41
5	Mixed forest	0.03	0.02	0.01
6	Commons	2.42	2.29	0.76
7	Heath	1.91	0.47	0.53
10	Other sparsely vegetated	0.07	0.10	0.08
11	Meadow	1.76	1.93	1.56
12	Wetland	3.49	3.63	4.17
13	Bogs	4.78	1.65	1.75
14	Tidal meadow	0.003	0.000	0.004
15	Lake	0.40	0.42	0.34
16	Water course	0.08	0.00	0.05
19	Built	4.79	4.97	5.15
20	Traffic	1.89	1.91	1.63
22	Parks and similar	0.010	0.003	0.008
23	Agriculture	66.44	74.46	73.42
24	Grass areas	0.11	0.08	0.09
	Patches (non-external)	**99.71**	**99.88**	**99.55**
	Forest theme	11.51	7.97	10.01
	Nature theme	26.48	18.46	19.24
	Landscape theme excl.	33.27	25.42	26.13

Table 5.7 Percentage of land use types in the three test blocks, collected from 5m grain images with the "landscape" thematic resolution as described above. The bottom three lines summarise the area proportions of the thematic levels. The difference between the area of the nature themes and landscape excl. agriculture correspond to a possible urban or poly- to metahemerobic theme.

The test block images have been created independently at each resolution (grain size). Since they are based on data in vector format, thus there has been no need to consider which strategy to use for aggregating the raster land cover maps, otherwise a common problem in scaling analyses, as discussed by Goffredo (1998, chapter 3) and Wu (2003). Still the metrics values will be affected by the use of this method, which is similar to sampling the land use/land cover type at a specific geographical position (the centre of the grid cell), as shown in section 5.5.1. Different approaches for aggregation would result in different metrics values (Bian and Butler 1999, Bian 1997), but an investigation of that phenomenon was considered outside the scope of this study.

5.4.4 Selection and mathematical implementation of metrics

The NP_Backgrond metric introduced in previous chapter is here called NP_matrix, since 'matrix' is now considered to have properties different from the external background, i.e. outside the patches or landscape of interest. The *total edge length* (EL) metric is included here for the MW-analysis. This is in order to have a structural metric for the landscape thematic level, as the Matheron and SqP metrics, which use edge as well as area information, will yield spurious results when most windows have 'landscape' cover fractions that approach unity. *Edge Density* (ED) is calculated by dividing EL with the 'landscape' i.e. patch + matrix area, the unit of this metric becomes metres per hectare, corresponding to m^{-1}.

It is possible to calculate values of structural metrics such as NP and EL and of fragmentation metrics as M and SqP for separate classes (which are then 'seen' by the script as a binary landscape theme). This was used for the detailed analysis of scaling effects, reported in section 5.5.1. Table 5.8 below is intended to summarise the discussion above and the choices made for the implementation of the metrics.

Terrain slope was calculated using the SURFACE module of Idrisi (Eastman 1997). Averages of these slope values as well as of elevation within the output cells were derived using an IDL-script that allow background pixels to be ignored (Appendix 1.5).

Spatial Metric	Measures	Landscape/matrix class (internal background)	(external) Background
Cover Percentage	Coverage, proportion	Included (defines total area)	Excluded
Number of Patches (NP)	Complexity and coherence/fragmentation	Included	Excluded
NP_matrix	Perforation of patches	Included, is the object of interest	Excluded – not counted as patches even when present
Class Richness	Diversity	Included	Excluded
Shannon's Diversity Index (SHDI)	Diversity, richness	Excluded	Excluded
Shannon's Diversity Index (SIDI)	Diversity, evenness	Excluded	Excluded
Edge length (EL)	Complexity and fragmentation	Included, edges patches-matrix are counted	Excluded – edges to background are not counted
Edge Density (ED)	Complexity and fragmentation	Included, edges patches-matrix are counted. Used for normalisation.	Excluded
Matheron index (M)	Fragmentation	Included for total area	Excluded
Square Patch Index (SqP)	Fragmentation, complexity of patch shapes	Included for total area	Excluded

Table 5.8 Metrics used in this chapter, categorised according to type, with description of the handling of landscape/matrix and background pixels.

5.4.4.1 Influence on metrics potential range and maximum values

The decision to exclude external background and/or exclude matrix or internal background will influence the ranges of possible values for some of the metrics, and as a consequence the actual derived values. A summary of the consequences is given here, with each metric as a separate point.

- Cover proportions will increase when total area is based on patch area divided by (patch+matrix area), and external background excluded. The maximum value is still

100%, and the largest differences will be seen for output cells with large proportions of external background, such as coastal areas or islands.

- Patch count metrics will decrease, when background patches are not counted in.
- Changes in diversity metrics will depend on the relative proportions of the areas that are included or excluded, thus if the matrix is included and constitutes a large part of the land area, especially the Simpson's 'evenness' index will be smaller than if only the patches were used for calculations.
- Edge Length values will remain the same, but Edge Density values will increase.
- For the Matheron index, the maximum value will rise from $20\sqrt{2} = 28.284$ to 40.

For both the ED and M metrics, maximum values will occur for landscapes having a checkerboard pattern, where all pixel edges are forest-non forest borders, as illustrated in Figure 5.8 below. Excluding the external background corresponds to seeing it as having no landscape functionality at all, making the patches more isolated (as if they were separated by sea rather than land), as indicated by the higher values of the fragmentation metrics.

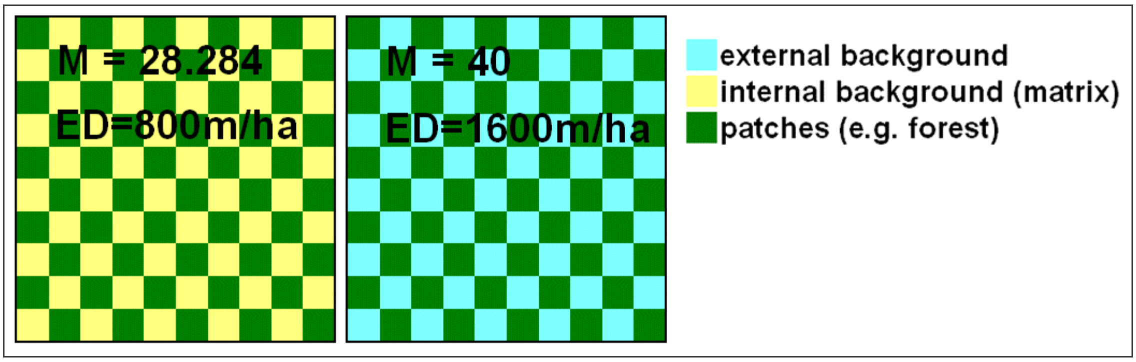

Figure 5.8 Matheron index and Edge Density maximum values with alternative status of pixels around patches.

- SqP, by definition, only depends on the patch(es) area and perimeter, and is thus not affected by the amount of internal background or matrix area.

5.4.5 Metrics calculation and statistical analysis

For the scaling exercise performed on the test block subsets, a combination of modified IDL-scripts (Appendix 1.1) and Fragstats for Windows software was used. For these calculations, the Moving-Windows loops in the scripts were deactivated so the test blocks could be treated as one large window, and the script was then run once for each thematic resolution (3 or 4 possible), each block (3 different) and each grain size (8 different). Fragstats was used for the patch count operations, as the IDL scripts turned out to be very slow for the large images (with grain sizes of 5 and 10m, of 4000*3600 and 2000*1800 pixels, and for some classes patches of very large extent). The output text files were then imported to Excel-spreadsheets for further calculations and illustration.

For the Moving-Windows calculations, a set of spatial metric-images were produced, on which comparisons could be made, and the relations evaluated here are only some of those possible, since the multiple dimensions of spatial structure gives numerous possible combinations of metrics-images. More grids and images could be produced from the output files by simple arithmetic operations, such as EL or NP *per class*, diversity metrics for landscape including matrix class etc. Window sizes used here range from 1 to 5 km corresponding to 40 to 200 pixels. In terms of geographic size, this is the interval where the largest variation of metrics values is found (compare Figure 4.11). The outputs include a large number of tables and graphs/plots, of which only representative examples and summary tables and images can be displayed here. The issue of masking or rather of, what part of the images to include in calculations was also found to be highly relevant here. For comparisons of diversity values, only output cells with richness of more than two classes present were used, this is because besides the matrix class, at least one forest class should be present. Windows with just one forest class will yield a zero value for the diversity of that theme, but this must be considered a valid result, showing that forest is present, but forest diversity is absent. Thus, when different themes from the same data source were to be compared, the criterion for inclusion has been the presence of at least one of the classes of interest (the background class does not suffice).

WinChips was used for extracting

a) Correlations between data sources (section 5.5.2.1),

b) Correlations between different thematic levels (section 5.5.2.2),

c) Correlations between metrics and terrain parameters (section 5.5.2.3);

since these calculations involved up to 24 different metrics 'maps', which would amount to very large spreadsheet files if the calculations were to be done in Excel. The selected metrics maps were then at the same time available for quality check by visual inspection, further image processing and use as illustrations.

The preparation of the data sets for these analyses has led to the observation that such large amount of images that can be combined in an almost endless number of ways, and all sorts of relations investigated – so a central task here has actually been to select among possible analyses, judging which combination of input data would yield the most relevant and interesting results.

5.4.5.1 Scaling and scalograms

When applicable, the metrics values response to changing pixels size are displayed using scalograms for the area of interest. The type of scalogram used in the previous chapter can be termed 'window-' or 'extent-scalogram', here they are supplemented by 'grain (size) scalograms'. It is important to distinguish between these two methods of scaling analysis, also from a third type: the MMU-scalogram (Saura 2002), which describes the influence of the minimum mapping unit on metrics values – an issue of strong relevance for the application to land use data as some metrics have been found to be extremely sensitive to MMU[33]. A fourth type of scalogram is the metric value-proportion/abundance plot, as shown by Gardner and O'Neill (1990) and Gustafson and Parker (1992), in both cases on data from neutral models). Using this type of graph can also be seen as an investigation of the relation between the metric 'cover proportion' and other (more complex) metrics, as was done in the previous chapter, see for instance and Figures 4.14 and 4.23.

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[33] Especially since both the Corine classification and the AAK methodology has specific minimum polygon areas.

At the moment, only limited research has been carried out in the field of scaling behaviour of spatial metrics relating to window size in moving window applications for landscape analysis – but see O'Neill et al (1996) and Häusler et al (2000) for practical approaches and Saura and Martínez-Millán (2001) for a theoretical assessment of metrics sensitivity. The findings of Riitters et al (2000) also point out some effects of changing window sizes, but only for their methods for assessment of fragmentation. Only recently, and following theoretical advances and availability of computational power, simulations of metrics behaviour are being carried out, see Wu et al (2002), Wu (2003). The form used here is the one set out by Wu (2003), in which the metric values are plotted against either grain size or window/landscape extent.

5.4.5.2 Terrain features

Geomorphological features have been found to strongly influence plant species diversity (Burnett et al 1998, Nichols et al 1998) and a similar relation with animal diversity has been supposed (Hunter et al 1988, Forman 1995). In this study geomorphology was characterised by elevation and slope from the DEM and by geomorphological landscape types. Slope was calculated from the terrain model, using Idrisi, and measured as percentage. Average values of elevation and slope was calculated for cells corresponding to the output cells from the M-W application. The geomorphology map was aggregated to 250m, 1km and 2km grain sizes in order to allow comparisons with the CLC data and the smallest window sizes from the M-W application (using IDL-script, see Appendix 1.4).

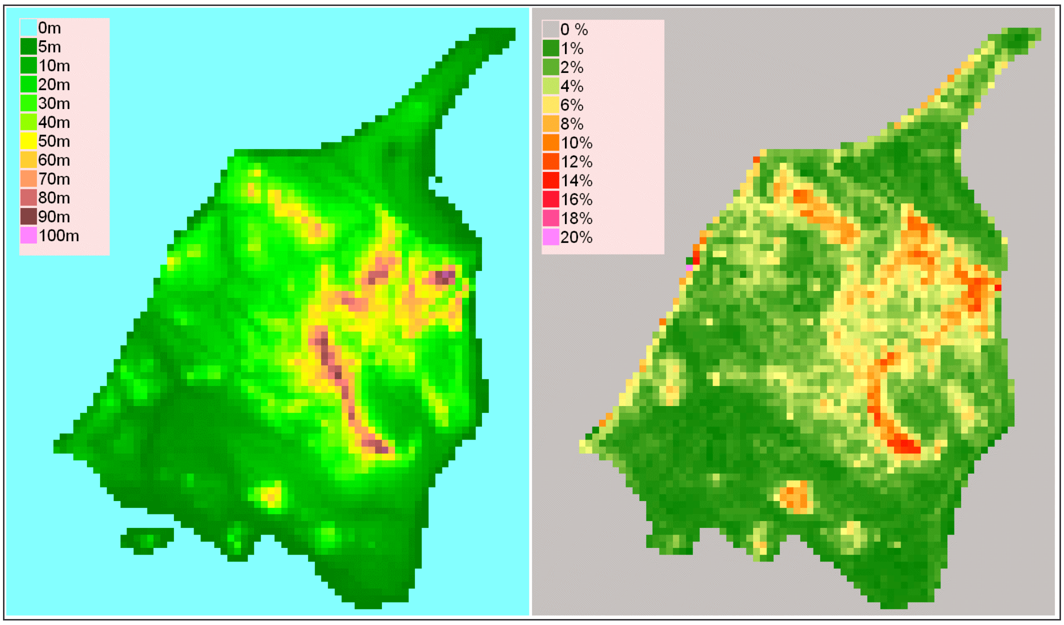

Figure 5.9 Average elevation and slope based on values in 25m cells, averaged to 1km cells for comparison and correlation with spatial metrics values in identical geographic windows.

5.4.6 Hemeroby – definition and calculation

In this chapter the previously defined and used metrics of land cover class *amount* (relative area), *diversity* and *fragmentation* will be supplemented by a quantitative measure of *Hemeroby* which expresses the human impact on and disturbance of landscapes. The concept and some previous applications is described in section 2.2.5. The implementation here follows the methods outlined by Steinhardt et al (1999) and Brentrup et al (2002). Calculation of metrics of human impact on landscapes was made possible by the availability of complete land cover maps with sufficient thematic resolution. After a critical review and interpretation of LUC map legends, an *impact factor* could be assigned to each land cover class, based on its deviance from the natural, undisturbed state. In this project these factors assumed the values of the Nature Degradation Potential (NDP), which are defined and assigned to CLC classes by Brentrup et al (2002, table 2 and Annex), with values ranging from 0: no human influence, completely natural, to 1: completely disturbed, unnatural. What is new here, relative to the above-mentioned approach, is the application of moving-windows methodology for the creation of a ‘Hemeroby-map’ of the area of interest and for providing context information about sites of cultural historical interest. The Hemeroby values are intended to be used for characterising areas of variable geographical extent, and they ought to be comparable, since they are ‘simple’ average values. Hemeroby maps have been made in other contexts, such as the project mentioned by Grabherr et al (1995), which resulted in a map of Hemeroby of Austrian forest ecosystems[34]. Such maps are however the result of a bottom-up process, i.e. based on (costly) field surveys, possibly supplemented with aerial photo interpretation.

The Hemeroby index values were calculated using images with NDP values, assigned on pixel/grain-basis to the land use maps, with values derived from re-classifications of the original CLC and AAK images. This is admittedly a crude way of assessing naturalness and disturbance of landscapes. On the other hand it is a fast, transparent and well suited methods for categorical maps in raster format. The Hemeroby types and their properties are described in section 2.2.5, Table 2.3. For practical reasons (Idrisi re-classification working only on integer values) NDP is set to values between 0 and 100. The completely undisturbed, ahemerobic class with values between 0 and 10 is not found in Denmark, owing to the relatively large population density and a long history of settlement and use of the available natural resources. A potential source of bias in the Hemeroby maps is the NDP values assigned to open sea, coastal lagoons and other water bodies, which provide the context for terrestrial landscapes. Experimentally, different values were assigned to this background class, but in all cases the result was a blurring of the coastal zones. Therefore, it was decided to completely exclude sea areas from the calculation, even if it means assigning Hemeroby values to output cells holding some coastline, that are based only on parts of the cells. Table 5.9 and Table 5.10 together show that the CLC and AAK typologies are so similar, that it is possible to make Hemeroby maps that are comparable between the two data sets. Also visual comparisons of the re-classified maps and Hemeroby-maps for the test areas showed good agreement.

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[34] Available at http://www.pph.univie.ac.at/forest/hem_forest.htm (accessed 20/12 2003).

hemeroby type	NDP value	AAK surface types
oligohemerobic	15	Sparsely vegetated surfaces, wetlands, bogs, tidal meadows
	25	sand/dunes
mesohemerobic	30	broad-leaved forest, heath, reed forest,
	35	Mixed forest, meadows
	40	coniferous forest
	50	lakes, water courses, sea
euhemerobic	55	Commons
	60	Grass areas
	70	graveyards, grass in urban areas
	80	agriculture, fish farms, buildings in open land
polyhemerobic	85	low buildings
	90	high buildings, roads and railways, dams, airports, technical areas
metahemerobic	95	town centres, consolidated surfaces, industry

Table 5.9 Hemeroby types with estimated NDP values and corresponding AAK classes for re-classification to disturbance maps which are used for derivation of landscape naturalness/disturbance maps.

hemeroby type	NDP value	CLC surface types
	10	Bare rocks, glaciers and perpetual snow
oligohemerobic	15	Sparsely vegetated areas, marshes, peat bogs, intertidal flats
	25	Sclerophyllous vegetation, beaches, dunes, sand, lagoons, estuaries
mesohemerobic	30	Broad-leaved forest, moors and heathland, woodland-shrub
	35	Mixed forest
	40	Agro-forestry areas, coniferous forest
	50	Agriculture with natural vegetation, burnt areas, water
euhemerobic	55	Pastures
	60	Annual crops associated with permanent crops, complex vegetation patterns
	70	Green urban areas, sport and leisure, vineyards, fruit and berry plantations, olive groves, salines
	80	Arable land
polyhemerobic	85	Discontinuous urban fabric
	90	Roads, rail, airports, mineral extraction and dump sites
metahemerobic	95	Continuous urban fabric, industrial and commercial units, port areas, construction sites

Table 5.10 Hemeroby types with estimated NDP values and corresponding CLC level 3 classes for re-classification to disturbance.

Since the calculation of the integrated Hemeroby values is done by simple averaging of the values within the moving windows, this is (also) a spatial degradation process, similar to the derivation of the other spatial metrics implemented here – and different from the normal filtering routines implemented in GIS/image processing software (see script, Appendix 1.5). The visual impression of the outputs can be rather grainy, but it was chosen to continue with this method, in order to have comparable results and to avoid over- sampling for the statistical analyses. During calculation of the averages, an image layer with information on the proportion of non-background is created, which is used as inclusion mask during subsequent extraction of statistical properties. For the comparison of AAK and CLC results, the criterion for a cell to be included was that at least 10% of both maps should be non-background. In practice this image layer functions as a land-mask. For comparison with the traditional filtering approach, regarding the appearance of the resulting maps, a simple and fast program was used for calculations of average values (Hovey 1998), as seen in the top line of Figure 5.10 below. A simple legend was defined, for the possible creation of thematic maps to be used for planning and illustration purposes; intervals and descriptions are listed in Table 5.11. This legend also serves as guideline for re-classification of the real-value average images into byte-value 'maps' with these four themes plus background as the classes – an approach illustrated in Figure 5.10.

Hemeroby index value	**Hemeroby type**	**Description**
< 40	Mesohemerobic	Moderate human influence
40 - (just below) 60	β-euhemerobic	Strong human influence
60 - (just below) 80	α-euhemerobic	Very strong human influence
>= 80	Polyhemerobic	Mainly artificial surfaces

Table 5.11 Proposed assignment of rough Hemeroby classes to output cells from averaging operations.

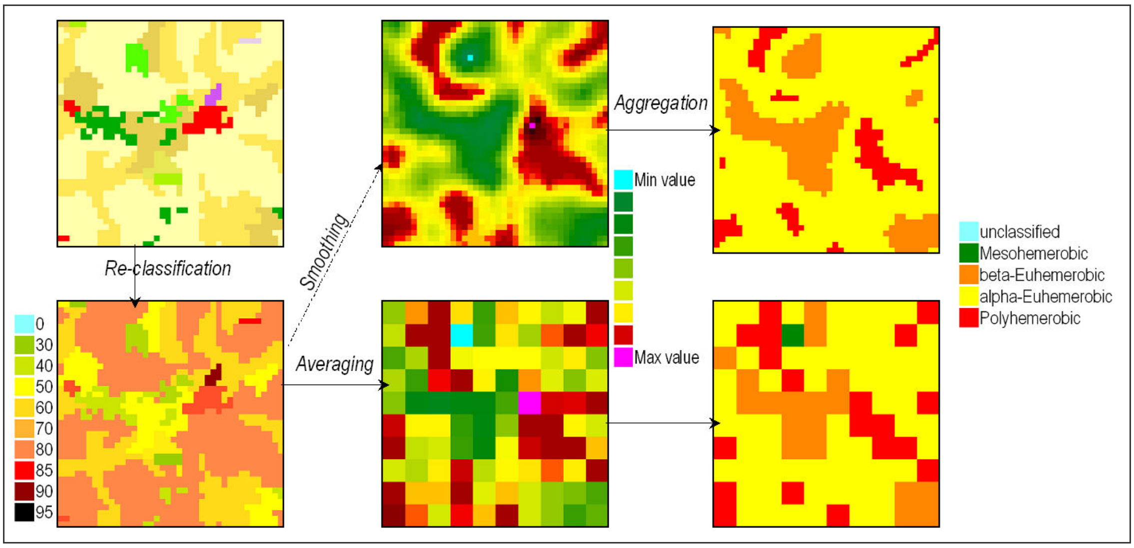

Figure 5.10 An example of the 'processing chain' from Land Use to Hemeroby map, in this case from the CLC data for a subset of 10*10 km in the northern part of the area (compare test block 1 in Figure 5.7 on page 216), around the rural town Sindal. Note that the linear feature in the upper right corner of the image is Sindal airfield which is in use, though not for regular services.

Two different approaches are presented in Figure 5.10 (as different branches of the 'flow chart'): smoothing with overlapping windows and averaging where windows do not overlap. For this illustration of method, the averaging was done for 1*1km (4*4 pixel) windows, while the smoothing was done for a circle around the central pixel with a radius of 3 pixels, using the Idrisi MapWalker (Hovey 1998). The minimum Hemeroby index value of app. 36 (accentuated with cyan colour) is found in Baggesvogn skov (forest, deciduous) and the highest value (magenta colour) of app. 84 in the centre of Sindal. For the resulting general Hemeroby classes it is worth noting that the polyhemerobic class represents the built environment as well as the 'core areas' of agricultural activity – whether this is a realistic representation of the environmental state is subject to discussion. The visual attractiveness of the maps will be improved if they are subjected to clean-up filtering, such as mode- or majority filtering or application of a low-pass (averaging) filter to the per-window averaged Hemeroby index-values. Such resulting images may be useful for illustrative purposes but of limited analytical use.

5.5 Results

In this section findings from the calculations on the LUC maps in the data set are presented, along the lines described in the Objectives section. Following these, a three-part structure has appeared: first the findings from the re-scaling of AAK data for selected test blocks are presented; then the various results from application of the M-W method to the different input types for the entire base-map area are presented; finally findings from calculation of Hemeroby values for the same area are displayed, compared with the 'traditional' spatial metrics and their relative position in a possible indicator framework are discussed.

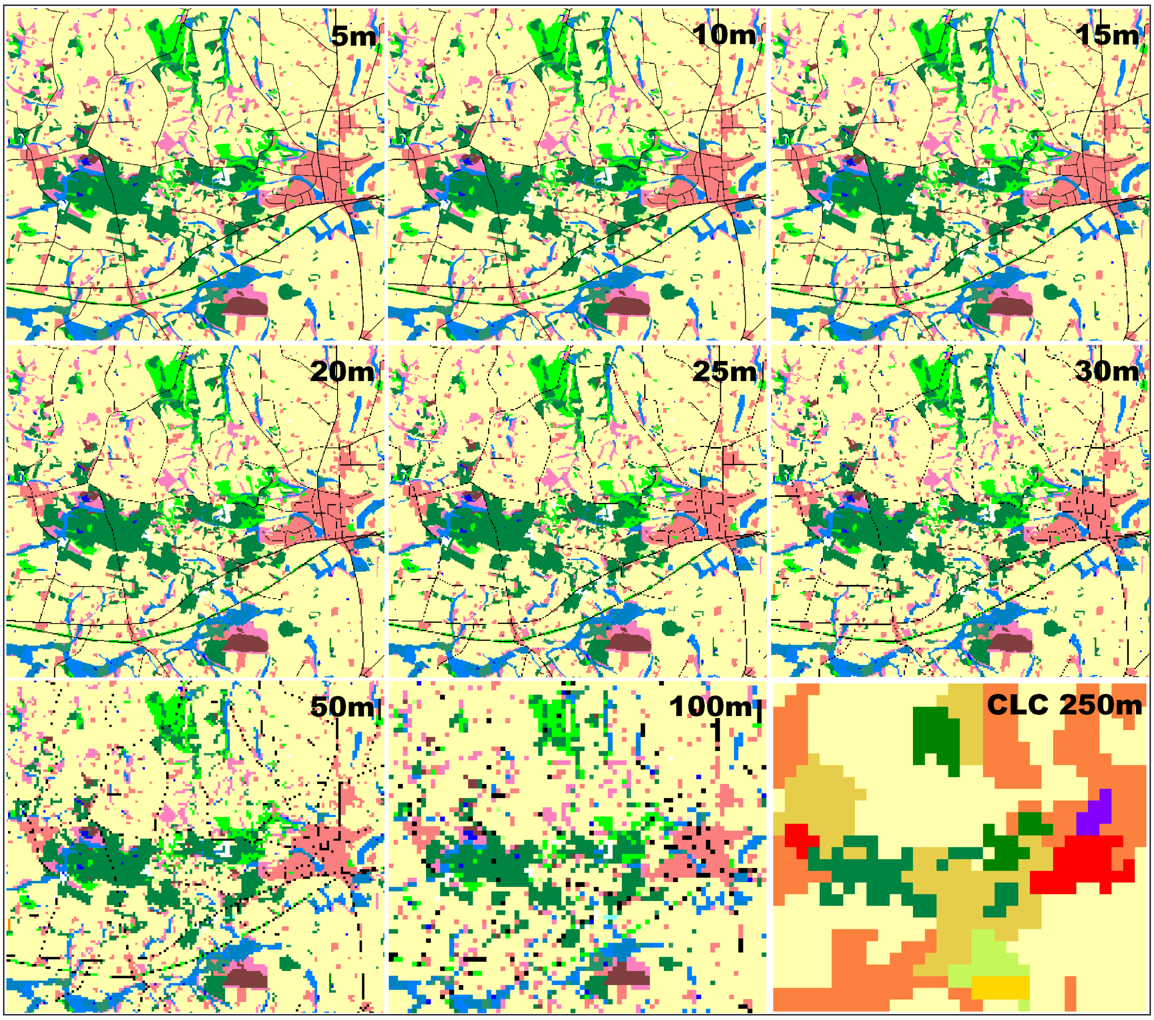

Figure 5.11 An 8*7 km subset of TB1 at the landscape thematic level, AAK images with the grain sizes used in this study – plus the corresponding subset from the CLC. The 5m grain size image is 1600*1400 pixels, the 100m grain size pixel only 80*70, and the CLC image only 32*28. To the left in the images the village Astrup, to the right the rural town Sindal, in between Bøgsted Plantage (plantation) and Slotved Skov (forest), to the north Baggesvogn Skov, supposedly the northernmost deciduous forest in Denmark.

5.5.1 Scaling properties of AAK data

In contrast to the exercise in Chapter 3 where a binary forest-non-forest map was degraded, the starting point here has been a multi-class land use map. As is well known, scaling effects can take place at three aggregation levels: patch, class and landscape (McGarigal and Marks 1995, Wu et al 2002). In this study, single patch properties are not considered, since the objects of study are forested landscapes rather than single forest patches. Separate classes are however investigated, when they are known or observed to have different (scaling) behaviour. Here the forest theme is used in the first place, but comparisons are also made to the nature- and landscape themes. The description of the scaling effects follows the order of metrics set up in Table 5.8.

Figure 5.11 shows the effects of spatial degradation applied to land use data, on a representative subset. It is clearly seen that linear features, such as roads and railway lines become fragmented, by being cut into pieces from resolutions around 20-25m, and at the largest grain size only appear as scattered points. On the other hand, the agricultural class which acts as landscape matrix here becomes more coherent as the barriers/corridors are dissolved, and at 100m grain size consists of a few patches. The forest and wetland patches assume more edgy or square shapes (implying that SqP should decrease – following the definition in section 2.3.4, equation 3. The same effect is seen for the towns, while the small rural settlements gradually ‘thin out’ with increasing grain size. Area proportions for total forest and nature classes change only little, while the very rare classes show the greatest changes. For the majority of classes, the change from 5 to 100m is well below one percent, relative to the area at 5m resolution, and there are no clear trends for decrease or increase of proportion. Other studies have shown that the changes in cover proportions with changes in grain size depend on the method applied in the transformation from fine to coarse images (Turner et al 1989, Wu et al 2000, Saura and Martinez-Milan 2000). The approach used here for spatial degradation, described in section 5.4.3, is similar to sampling at random points and actually ensures that the almost same cover proportions (and thus diversities) are found over the current range of grain sizes.

5.5.1.1 Patch count metrics

Table 5.12 shows patch counts for selected classes from the landscape thematic level from all three blocks, along with their area proportion and average patch size in hectares, at the highest resolution, 5m. Table 5.13 shows the proportion of the landscape occupied by the same series of classes for all resolutions, with metrics from test block 1 as examples.

Class	**broad-leaved forest**			**coniferous forest**			**wetlands**			**lake**		
block	**TB1**	**TB2**	**TB3**	**TB1**	**TB2**	**TB3**	**TB1**	**TB2**	**TB3**	**TB1**	**TB2**	**TB3**
P_{land}5m	2.375	2.019	2.587	9.119	5.913	7.412	3.489	3.634	4.174	0.404	0.419	0.336
Avg.patch size	0.958	1.055	1.527	2.177	2.622	3.386	2.292	2.361	3.006	0.125	0.136	0.169
5m	892	689	610	1508	812	788	548	554	500	1165	1110	717
10m	924	683	618	1482	787	764	545	560	469	1147	1111	700
15m	905	680	601	1385	755	722	555	572	470	1125	1073	674
20m	880	650	572	1325	742	695	555	591	475	1017	989	605
25m	861	656	582	1268	717	683	573	599	462	860	833	531
30m	827	668	571	1242	708	674	573	624	473	733	711	448
50m	740	661	541	1153	622	633	709	702	540	414	367	250
100m	343	305	282	576	311	349	384	389	346	137	105	77
Class	**built**			**traffic**			**agriculture**			**meadow**		
block	**TB1**	**TB2**	**TB3**	**TB1**	**TB2**	**TB3**	**TB1**	**TB2**	**TB3**	**TB1**	**TB2**	**TB3**
P_{land}5m	4.789	4.971	5.148	1.887	1.910	1.631	66.441	74.455	73.424	1.760	1.927	1.558
Avg.patch size	0.681	0.651	0.813	33.968	28.646	25.524	23.871	37.383	38.757	1.354	1.577	1.664
5m	2531	2749	2279	20	24	23	1002	717	682	468	440	337
10m	2623	2785	2310	17	18	27	952	652	635	497	453	320
15m	2368	2559	2043	353	347	330	627	350	371	504	478	326
20m	2143	2438	1886	2016	2143	2026	474	241	308	496	489	319
25m	2019	2316	1763	2641	2751	2524	409	198	241	492	503	327
30m	1910	2219	1688	2596	2758	2441	338	166	211	491	508	329
50m	1651	1914	1495	1596	1692	1477	246	96	123	485	543	382
100m	866	978	754	507	505	445	79	23	55	260	290	226

Table 5.12 Total count of separate patches of selected classes with different responses to image grain size (scaling behaviour).

Class	Deciduous		Confierous		Wetlands		Lakes		Built		Traffic		Agriculture		Meadows	
metric grain	P_land	size	P_land	size	P_land	size	P_land	size	P_land	size	P_land	size	P_land	size	P_land	size
5	2.375	0.959	9.119	**2.178**	3.489	2.293	0.404	**0.125**	4.789	0.682	1.887	33.986	66.44	**23.88**	1.760	1.355
10	2.376	**0.926**	9.106	2.212	3.488	2.304	0.405	0.127	4.791	**0.657**	1.886	39.941	66.46	25.13	1.761	1.276
15	2.372	0.945	9.141	2.381	3.487	2.267	0.401	0.129	4.786	0.729	1.887	1.929	66.43	38.22	1.760	**1.260**
20	2.373	0.973	9.125	2.485	3.495	2.272	0.405	0.144	4.792	0.807	1.880	0.336	66.44	50.57	1.755	1.277
25	2.369	0.991	9.102	2.584	3.491	2.193	0.403	0.169	4.795	0.855	1.885	**0.257**	66.48	58.52	1.753	1.283
30	2.382	1.039	9.136	2.654	3.497	2.202	0.404	0.199	4.765	0.900	1.911	0.266	66.43	70.91	1.763	1.295
50	2.375	1.159	9.089	2.846	3.488	**1.776**	0.407	0.355	4.809	1.051	1.876	0.424	66.43	97.49	1.752	1.304
100	2.383	2.528	9.137	5.771	3.466	3.284	0.423	1.124	4.843	2.035	1.861	1.335	66.28	305.25	1.765	2.469

Table 5.13 Cover proportions and average patch size in hectares for Test Block 1 of the classes used in Table 5.12. For each class the lowest apparent average patch size is marked as **bold**.

Clear differences between the various classes are observed in Table 5.12, both in terms of patch size and scaling behaviour. In all three blocks lakes are so small (being mostly ponds) that they gradually disappear up to 50m grain size, and rapidly to 100m. Still, the ‘sampling’ like nature of the map degradation assures that this cover type’s proportion of the landscape area remains the same. The stability of cover proportions is apparent in Table 5.13, as well as how the increased number of separate patches for the linear elements of the Traffic class leads to an apparent decrease in patch size. An unexpected result is seen in Table 5.12, namely that the class “meadows” show a relatively little decrease in the number of patches, indicating that the shape of the individual patches is very compact rounded or even square – which again would indicate that they are under agricultural management, and either used for grazing or set aside (lying fallow).

The forest theme was used for illustrating scale effects on patch numbers. Since the forest map is used as input, coherent forest areas, which contain different classes (forest types) will be counted as more than one patch. The gradual decrease in the number of forest patches is illustrated in Figure 5.12. The values are calculated by dividing the patch count number at the actual grain size by the number at the smallest grain size (where the largest number of patches is normally found, at least for forest classes).

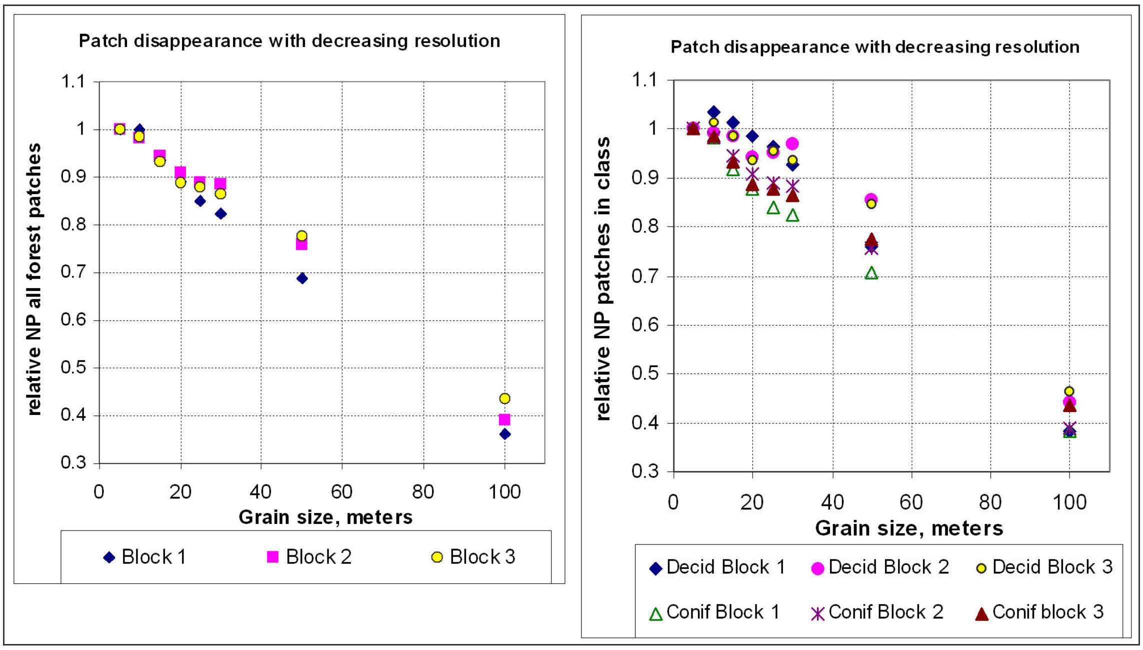

Figure 5.12 Scaling behaviour of the rasterised AAK data set in the three test blocks for number of forest patches, normalised to the amount at 5 m resolution. To the left counts of all patches, to the right counts of the two dominant classes: deciduous and coniferous.

The linear decreases shown in Figure 5.12 are in line with the findings of Wu (2003) who places the Patch Density metric among the metrics with a regular scaling behaviour – in the sense that they are predictable for changes in grain size, following a power law for metrics at landscape as well as at class level. The forest patches in Block 1 show the most rapid decrease with increasing grain size, especially the conifer class. This is in line with the observations in Table 5.12, that this block has the smallest patches – as a result of it having the most fragmented forests. However, even if the average size of deciduous patches is less than half of the coniferous patches, the *number of patches* decreases less rapidly – an indication that the patches of this class have more compact shapes.

5.5.1.2 Diversity metrics

Below SHDI is used as example of scaling behaviour for a diversity metric. For this area and these data sets SHDI has been found to be strongly correlated with the SIDI metric (R=0.990-0.998). Since the cover proportions for the themes and separate classes change so little, the metrics values are also stable across scales. This is apparent from Table 5.14 and Table 5.15, where the values of SHDI from the three test blocks, the three thematic resolutions and the eight grain sizes are compared.

The diversity metrics for the landscape subsets however depend on another ‘parameter’ for the calculation, namely whether the landscape matrix is included. This is particularly of interest for the themes that constitute well below half of the entire land area, such as forest and nature. When Table 5.14 and Table 5.15 are compared, it becomes apparent that the exclusion of the matrix not only results in higher metrics values, it also changes the ranking of the diversity of the blocks relative to each other. In this way it becomes apparent that the higher values of forest and nature diversity for block 1 are caused by the proportionally higher area of patches belonging to these themes there, as seen from the area percentages in Table 5.7. The “Grid” thematic level in Table 5.14 represents calculations made on the original AAK maps (having a larger number of different land-use classes, see Table 5.4), and shows that calculations at the Landscape thematic level give metrics values very close to these.

Matrix (internal background) included												
SHDI	**Forest**			**Nature**			**Land**			**Grid**		
Grain	TB1	TB2	TB3	TB1	TB2	TB3	TB1	TB2	TB3	TB1	TB2	TB3
5m	0.423	0.327	0.386	1.074	0.822	0.826	1.347	1.106	1.105	1.388	1.144	1.148
10m	0.423	0.327	0.386	1.073	0.822	0.826	1.346	1.106	1.105	1.388	1.144	1.148
15m	0.424	0.327	0.386	1.074	0.822	0.826	1.347	1.106	1.105	1.388	1.144	1.148
20m	0.423	0.327	0.386	1.074	0.823	0.825	1.346	1.107	1.104	1.388	1.145	1.147
25m	0.423	0.327	0.386	1.072	0.823	0.826	1.345	1.106	1.104	1.387	1.144	1.148
30m	0.424	0.327	0.387	1.073	0.822	0.826	1.347	1.106	1.105	1.388	1.144	1.148
50m	0.423	0.327	0.386	1.074	0.822	0.827	1.347	1.107	1.106	1.388	1.145	1.149
100m	0.424	0.325	0.387	1.078	0.818	0.824	1.352	1.099	1.103	1.394	1.136	1.146

Table 5.14 Diversity metrics values expressed as SHDI for the entire test block, i.e. including the landscape/metrics class.

Matrix (internal background) excluded						
SHDI	**Forest**			**Nature**		
Grain	TB1	TB2	TB3	TB1	TB2	TB3
5m	0.545	0.599	0.583	1.863	1.859	1.731
10m	0.546	0.599	0.583	1.864	1.859	1.731
15m	0.545	0.599	0.583	1.862	1.860	1.731
20m	0.544	0.600	0.584	1.862	1.859	1.731
25m	0.543	0.599	0.583	1.863	1.858	1.732
30m	0.545	0.597	0.584	1.861	1.858	1.731
50m	0.546	0.602	0.584	1.864	1.857	1.733
100m	0.542	0.601	0.578	1.868	1.855	1.724

Table 5.15 Diversity metrics values expressed as SHDI for the entire test block, but only for the patches/objects of interest.

The values of SIDI have a similar low variation with grain size, so only the values from 5m grains are used in Table 5.16, where the same themes and parameters are used. It is not surprising that higher values of SIDI representing greater evenness between class proportions are found for the calculations where the matrix class is excluded. The reason that the values for the forest class are relatively low, even with matrix excluded, is the dominance of coniferous forest.

	Matrix included											
SIDI	Forest			Nature			Land			Grid		
	TB1	TB2	TB3	TB1	TB2	TB3	TB1	TB2	TB3	TB1	TB2	TB3
5m	0.210	0.150	0.186	0.447	0.329	0.341	0.540	0.435	0.444	0.541	0.436	0.446

	Matrix excluded					
SIDI	Forest			Nature		
Grain	TB1	TB2	TB3	TB1	TB2	TB3
5m	0.335	0.386	0.385	0.805	0.811	0.769

Table 5.16 Diversity values expressed through the SIDI metric.

5.5.1.3 Fragmentation metrics

The number of landscape or “matrix” patches is included here as a measure of landscape fragmentation, following the considerations about “background patches” and forest structure in chapter 4. It was assumed here that the scaling behaviour of the number of (separate) patches could be used to describe the coherence and perforation of landscapes at the different thematic levels. The results for each of the thematic levels are shown in Figure 5.13. Block 2 clearly has the least perforated forest, while Block 1 has the most perforated or scattered nature. The increase in the number of patches at 20m grain size is due the inclusion of roads and railway lines in the matrix class. Where they pass through forest or other types of nature, these seem to be split into several separate patches. The opposite effect is seen for the agriculture class that constitute the matrix at landscape thematic level, here the patches become connected between 10 and 20m grain size, as the linear elements appear to dissolve (see Table 5.12).

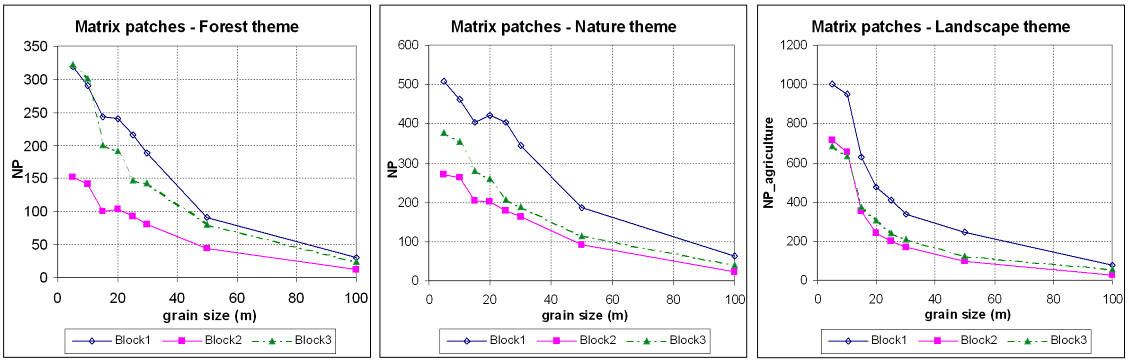

Figure 5.13 Scalograms for the number of matrix/background patches in the three test blocks, each with an area of 360km^2.

Figure 5.14 illustrates the fragmentation effect that occurs for the matrix class when images are degraded from 5m to up to 25m pixel sizes. Here it is small roads with nature type land uses on both sides that become split into smaller fragments (while the forest patches seem to become connected).

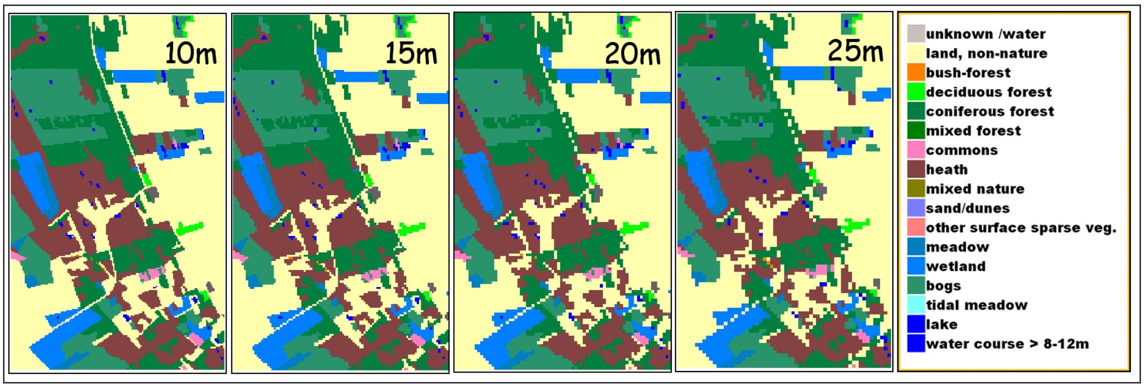

Figure 5.14 1.5*2.5 km subset from the northern part of Test Block 1 around the heath area ‘Rimmerne’, at the ‘nature’ thematic level with corresponding legend for the re-classified AAK map.

Both the Matheron index and the SqP metric are described here, as they have been found to behave quite differently in response to changes in grain and window size. Figure 5.15 shows the response of M to changing scale, a notable linear increase with grain size. For all three blocks the M value based on total forest area and forest-non forest edges (within each window) has slightly higher values than the M values for the individual classes, showing that forest as a combined/lower level land cover feature has a more complex shape than the separate forest classes. Block 1 stands out, having the most fragmented forest cover, which owes to the structure of the deciduous forest class in that area, while the other blocks and classes have very similar metrics values and scaling behaviour.

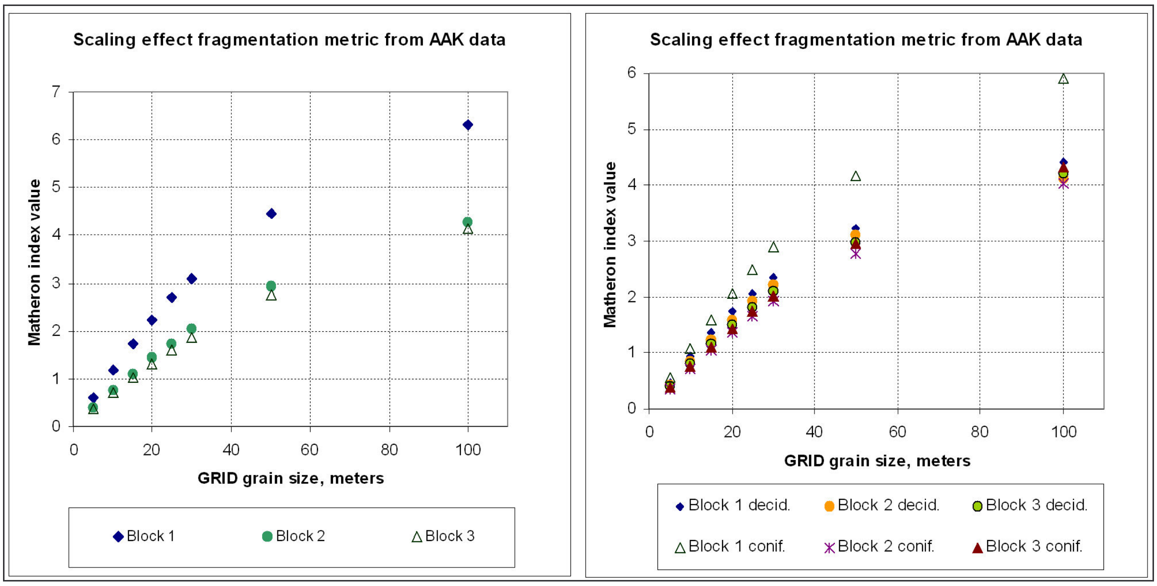

Figure 5.15 Scaling effects of changing grain size for the Matheron index., AAK data, forest thematic level.

The response of the SqP value to changing scale is illustrated in two slightly different ways in Figure 5.16 below, where the values are first plotted against grain size similar to the approach used in chapter 3 (see figure 3.13) and then against window size similar to the approach used in chapter 4. In both cases the response from this data set seems similar to that observed previously. It must be noted however, that the window sizes measured in meters represent a different number of pixels here compared with chapter 4, where medium resolution satellite data were used.

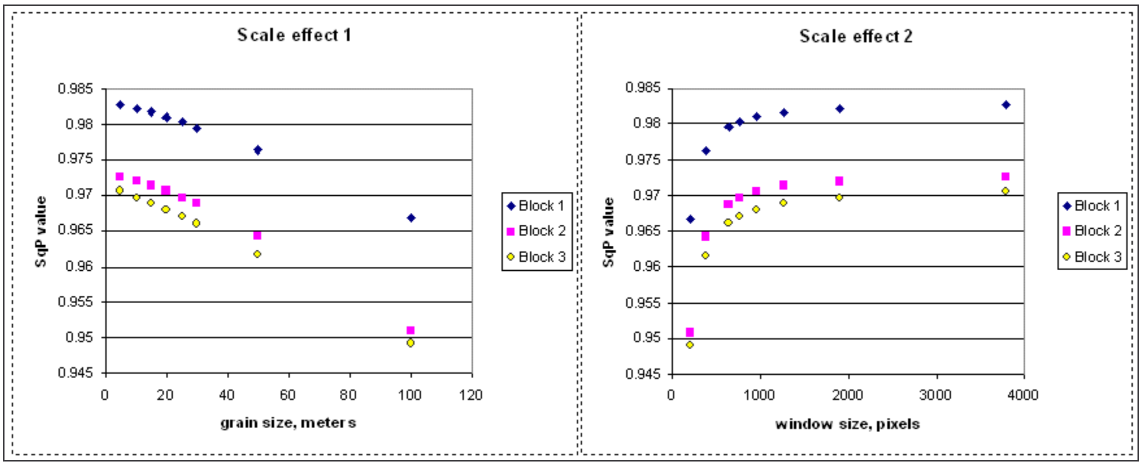

Figure 5.16 Two different approaches to depicting the scale dependence of the SqP metric: grain size and window size (extent). The occurrence of these two effects in combination is a consequence of having a fixed geographic window for data of changing resolution.

The behaviour of M and SqP is not surprising given the behaviour observed from Figure 5.11, where the coarsening of images correspond to higher apparent levels of fragmentation. As shown in Table 5.12, block 1 has the smallest patches, and that is clearly reflected in the values of both M and SqP, which more or less mirror the graphs for the patch counts. The relation between small patches and high fragmentation is confirmed by the significant correlations between NP (-total) and SqP and between NP and M for the AAK data at the thematic level 'forest' from the M-W analyses, where R values around 0.6 are found, as was also seen for the CLC data in chapter 4 (Table 4.19), though only at large window sizes. The results here show that scaling behaviour is heavily dependent on initial shape of the landscape elements.

5.5.2 M-W analysis of land cover data of different origins with different thematic resolutions

In this section of the study, the M-W methods were not used for creation of scalograms to examine the development of metrics values with grain size *per se*. M-W calculations were rather performed on different thematic resolutions for all images, and the results compared for the purpose of finding out which metrics are useful with these types of data, and for which window sizes. The calculations were carried out for five different window sizes, since initial tests showed large differences between values – and different correlations between themes and data sources at different window sizes. Therefore it was hypothesised that small windows would be useful for some purposes and larger windows for others. The average values of a number of metrics are shown in Table 5.17.

FOREST	AAK					CLC (250m grain)				
	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
PPU_N	8.063	6.139	5.365	5.010	4.814	2.245	1.427	1.226	1.151	1.117
PPU_NM	1.966	1.613	1.518	1.465	1.439	1.071	1.051	1.031	1.015	1.014
Richness	2.738	3.216	3.476	3.773	3.993	2.050	2.230	2.327	2.423	2.610
SHDI	0.293	0.429	0.459	0.474	0.484	0.056	0.126	0.159	0.211	0.299
ED(block)	71.56	60.56	54.58	51.88	50.42	25.49	16.73	12.38	10.19	9.23
M	2.857	2.386	2.220	2.113	2.084	12.045	7.458	5.753	4.734	4.372
SqP	0.587	0.757	0.817	0.852	0.879	0.187	0.263	0.332	0.383	0.440
	LCM					**LCP**				
	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
PPU_N	32.720	30.381	29.323	28.476	27.738	45.138	42.300	40.910	39.807	38.826
PPU_NM	2.907	2.555	2.429	2.353	2.306	3.093	2.726	2.582	2.508	2.451
Richness	3.733	3.733	3.986	3.981	3.993	6.016	7.479	8.147	8.545	8.766
SHDI	0.779	0.864	0.899	0.909	0.912	1.130	1.290	1.364	1.402	1.419
ED(block)	129.26	125.23	122.39	119.91	117.27	153.53	149.50	146.12	143.31	140.23
M	4.834	4.587	4.457	4.377	4.344	4.871	4.638	4.505	4.422	4.389
SqP	0.773	0.878	0.913	0.933	0.945	0.774	0.88	0.914	0.934	0.945

Table 5.17 Average values of spatial metrics for the forest theme from the available data types – for windows where forest was present. PPU_N (objects) and PPU_NM (matrix) represent patch densities as patch/km^2, normalised to the smallest window size of 1 km^2. ED(block) is the edge length of the window divided by the entire landscape area (not just the forest patches).

The metrics are observed to behave in a very similar way to what was seen in the previous chapter, in particular the M metric, where values from AAK data assume values similar to those from CLC 100m data for similar window sizes (geographical extent), and values from LCM and LCP assume values similar to those from FMERS data used in chapter 4, see figure 4.11. The SHDI diversity metric shows a similar behaviour to that seen for the medium-resolution data used in the study for chapter 4, with the LCM map giving values close to those from FMERS and AAK giving values close to those from CLC 100m (compare Table 5.17, Figure 4.11and Figure 4.12). The higher values of SHDI for the LCP data are due to the larger number of forest classes, as is also reflected in the values of the Richness metric. This metric however become quite useless for comparison between output cells representing sub-landscapes, when the windows are larger than 1 to 2 km, because the then most cells assume maximum values. This is especially the case for the satellite-based maps LCM and LCP. It is however interesting that for CLC data, Richness values increase steadily with window size (on the other hand 5 km only corresponds to a 20*20 pixels window).

The comparison of metrics values from different image sources in Table 5.17 shows that in spite of the fragmentation introduced to the AAK images through the sampling to 25m grain size, the patches are larger and more coherent than in the LCM and LCP images. For comparison, the average metrics values which are relevant at the landscape thematic level, are listed in Table 5.18. Similar to the observations from the test blocks, *all* of the metrics have higher values for the landscape theme. This is due to the larger number of classes, edges and patches that influence diversity/richness, fragmentation and patch count metrics respectively.

LANDSCAPE	**AAK**					**CLC**				
	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
PPU_N	30.781	27.445	26.059	25.201	24.337	2.086	1.697	1.529	1.441	1.373
PPU_NM	2.751	2.280	2.079	1.976	1.912	0.779	1.023	1.043	1.043	1.036
RICHNESS	7.926	11.366	13.064	14.086	14.883	1.964	3.035	4.044	5.005	5.818
SHDI_OBJ	0.878	1.021	1.103	1.156	1.204	0.232	0.515	0.748	0.951	1.102
ED_block	186.31	183.46	180.16	177.14	172.56	20.73	23.45	24.13	24.21	23.89
	LCM					**LCP**				
	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
PPU_N	114.744	106.613	102.641	99.992	97.009	150.071	140.931	136.293	133.117	129.265
PPU_NM	16.918	16.120	15.625	15.203	14.785	16.010	15.909	15.589	15.367	14.889
RICHNESS	8.722	9.687	9.909	9.962	9.985	12.961	15.790	16.870	17.474	17.730
SHDI_OBJ	1.271	1.148	1.189	1.217	1.236	1.414	1.508	1.556	1.588	1.617
ED_block	460.41	453.49	445.82	438.17	428.44	516.04	508.52	499.54	491.80	480.00

Table 5.18 Average values of spatial metrics for the landscape theme from the available data types under respective presence masks. The metrics are processed in the same way as for Table 5.17.

Statistics from processing of the metrics images showed high correlation between edge length- and (total) patch numbers, for instance: R= 0.898 at 1 km and R= 0.964 at 5 km window size for AAK data; R= 0.925 at 1km and R= 0.967 at 5 km window size for LCP data. Since the former metric is much faster to calculate, it could make an efficient substitute for the latter for describing one aspect of landscape fragmentation.

5.5.2.1 Agreement between data sources

The results presented here do not only show some clear differences between the behaviour of different metrics and types of metrics, they also illustrate the differences between the different thematic levels. In all of the three following tables, the AAK land use map provide one of the data sets, and correlation coefficients for agreement with one of the other data types are given for each thematic resolution and window size. The coefficients are typed in **bold** if the relations are significant at the 5% level (two sided). Table 5.19 shows the correlations for AAK and the basic land cover map LCM, both from the AIS.

These pairings of thematic levels clearly differ in their relations between metrics values and their responses to window size. For the forest theme, which is readily distinguished in satellite imagery (thus agreeing with the 'ground truth' of the AAK map), very good agreement is seen for the cover proportion metric. For the SHDI and SIDI, the best agreements are generally found for the landscape theme and the 'worst' for the nature theme, probably due to the difficulties with defining this theme from the LCM. However, the richness metric shows good agreement at this thematic level, where it seems to be de-coupled from the more complex diversity metrics. The M and SqP fragmentation metrics show rather poor agreements for the forest theme at small window sizes, the agreement however increases rapidly with window size.

correlations	Themes														
AAK-LCM	Forest					Nature					Landscape				
window size	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
n. obs.	*3597*	*963*	*449*	*255*	*172*	*3809*	*999*	*464*	*260*	*177*	*3808*	*999*	*464*	*260*	*177*
COVER	**0.901**	**0.924**	**0.930**	**0.928**	**0.900**	**0.572**	**0.581**	**0.546**	**0.637**	**0.669**	N/A	N/A	N/A	N/A	N/A
RICHNESS	**0.480**	**0.379**	**0.382**	**0.404**	**0.327**	**0.479**	**0.605**	**0.697**	**0.659**	**0.718**	**0.516**	**0.637**	**0.723**	**0.670**	**0.753**
SHDI_OBJ	**0.383**	**0.438**	**0.503**	**0.585**	**0.604**	**0.176**	0.048	0.010	-0.042	0.005	**0.578**	**0.678**	**0.717**	**0.727**	**0.757**
SIDI_OBJ	**0.331**	**0.411**	**0.496**	**0.575**	**0.598**	**0.124**	0.012	-0.031	-0.071	-0.039	**0.576**	**0.668**	**0.713**	**0.747**	**0.748**
EDGELENGTH	**0.738**	**0.788**	**0.812**	**0.815**	**0.836**	**0.609**	**0.699**	**0.761**	**0.791**	**0.812**	**0.613**	**0.748**	**0.827**	**0.860**	**0.887**
MATHERON	**0.211**	**0.214**	**0.244**	**0.311**	**0.440**	**0.144**	**0.071**	**0.387**	**0.259**	0.066	N/A	N/A	N/A	N/A	N/A
SQP	-0.002	0.002	**0.151**	**0.334**	**0.582**	**0.280**	**0.490**	**0.469**	**0.610**	**0.643**	N/A	N/A	N/A	N/A	N/A
NP_Matrix	**0.611**	**0.714**	**0.783**	**0.766**	**0.821**	**0.440**	**0.641**	**0.732**	**0.755**	**0.769**	**0.189**	**0.313**	**0.386**	**0.398**	**0.399**
NP_TOTAL	**0.669**	**0.737**	**0.774**	**0.786**	**0.810**	**0.583**	**0.661**	**0.724**	**0.732**	**0.768**	**0.545**	**0.643**	**0.721**	**0.745**	**0.788**

Table 5.19 Correlations between output cell values of spatial metrics from the AAK and LCM maps with grain size 25m.

Table 5.20 shows that there is generally better agreement between the AAK and LCP data, especially for the nature theme, probably because the LCP data could be re-classified to more realistic natural classes than the LCM data. However, the diversity metrics are not well correlated, and the fragmentation metrics M and SqP are at the same level as for the LCM data. For AAK data seen in relation to both LCM and LCP data, edge length and patch count metrics correlate well, especially the total number of patches agree well for all the thematic levels.

Table 5.21 shows relationships between the AAK and CLC data sets, which are considerably different in origin and spatial scale. The agreement on cover percentage for the nature theme is better than with the LCM and LCP data. Negative relations are observed for SqP values, even significant at small window sizes for the forest theme. The M index seems to be of little use for comparisons between these data sets, however good agreement is found for the diversity metrics. In general, the agreement for the cover metrics remains stable or increases slightly with increasing window size, and the Edge Length metric has a similar behaviour, providing significant correlations for all themes and extents; thus it is one of the most robust metrics. The diversity indices, which have poor agreements for the forest and nature themes show higher correlations for the landscape theme, even at the small window sizes, where the CLC metrics are based on few pixels.

correlations	**Themes**														
AAK-LCP	**Forest**					**Nature**					**Landscape**				
window size	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
n. obs.	*3625*	*966*	*450*	*256*	*172*	*3809*	*999*	*464*	*260*	*177*	*3808*	*999*	*464*	*260*	*177*
COVER	**0.886**	**0.909**	**0.915**	**0.914**	**0.891**	**0.657**	**0.668**	**0.636**	**0.722**	**0.752**	N/A	N/A	N/A	N/A	N/A
RICHNESS	**0.583**	**0.503**	**0.508**	**0.592**	**0.456**	**0.535**	**0.676**	**0.75**	**0.757**	**0.81**	**0.54**	**0.684**	**0.761**	**0.737**	**0.821**
SHDI_OBJ	**0.345**	**0.25**	**0.211**	**0.265**	**0.275**	**0.208**	**0.137**	**0.143**	**0.138**	**0.2**	**0.573**	**0.681**	**0.732**	**0.746**	**0.803**
SIDI_OBJ	**0.282**	**0.236**	**0.244**	**0.307**	**0.325**	**0.144**	**0.096**	0.091	0.094	0.141	**0.496**	**0.635**	**0.694**	**0.735**	**0.773**
EDGELENGTH	**0.747**	**0.8**	**0.827**	**0.825**	**0.846**	**0.654**	**0.753**	**0.808**	**0.833**	**0.856**	**0.638**	**0.766**	**0.838**	**0.866**	**0.893**
MATHERON	**0.208**	**0.221**	**0.236**	**0.322**	**0.487**	**0.159**	**0.101**	**0.43**	**0.316**	0.138	N/A	N/A	N/A	N/A	N/A
SQP	-0.024	-0.02	**0.114**	**0.248**	**0.575**	**0.257**	**0.472**	**0.423**	**0.592**	**0.683**	N/A	N/A	N/A	N/A	N/A
NP_Matrix	**0.613**	**0.714**	**0.784**	**0.763**	**0.819**	**0.469**	**0.659**	**0.742**	**0.767**	**0.803**	**0.242**	**0.406**	**0.491**	**0.507**	**0.557**
NP_TOTAL	**0.71**	**0.778**	**0.813**	**0.813**	**0.84**	**0.597**	**0.682**	**0.744**	**0.758**	**0.794**	**0.548**	**0.643**	**0.717**	**0.743**	**0.784**

Table 5.20 Correlations between output cell values of spatial metrics from the AAK and LCP maps with grain size 25m.

correlations	**Themes**														
AAK-CLC	**Forest**					**Nature**					**Landscape**				
window size	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
n. obs.	*2593*	*824*	*408*	*239*	*168*	*3642*	*998*	*461*	*260*	*177*	*3808*	*999*	*464*	*260*	*177*
COVER	**0.872**	**0.92**	**0.906**	**0.911**	**0.873**	**0.738**	**0.8**	**0.795**	**0.831**	**0.866**	N/A	N/A	N/A	N/A	N/A
RICHNESS	**0.2**	**0.195**	**0.315**	**0.278**	**0.407**	**0.356**	**0.34**	**0.378**	**0.354**	**0.375**	**0.36**	**0.429**	**0.542**	**0.544**	**0.546**
SHDI_OBJ	0.015	0	0.038	0.07	**0.183**	0.024	-0.079	-0.086	-0.076	-0.102	**0.512**	**0.647**	**0.649**	**0.631**	**0.549**
SIDI_OBJ	0.003	-0.013	0.027	0.074	**0.182**	0.021	-0.072	-0.056	-0.039	-0.117	**0.541**	**0.627**	**0.596**	**0.551**	**0.459**
EDGELENGTH	**0.531**	**0.639**	**0.65**	**0.672**	**0.719**	**0.522**	**0.66**	**0.705**	**0.733**	**0.751**	**0.39**	**0.525**	**0.614**	**0.67**	**0.72**
MATHERON	-0.012	0.018	0.088	**0.205**	**0.157**	-0.01	**0.126**	0.092	-0.007	**0.297**	N/A	N/A	N/A	N/A	N/A
SQP	**-0.172**	**-0.081**	-0.058	0.005	-0.144	-0.035	0.052	0.106	0.101	**0.175**	N/A	N/A	N/A	N/A	N/A
NP_Matrix	**0.092**	**0.39**	**0.555**	**0.356**	**0.418**	**-0.076**	**0.194**	**0.387**	**0.424**	**0.584**	0.001	**0.134**	**0.26**	**0.36**	**0.439**
NP_TOTAL	**0.42**	**0.477**	**0.501**	**0.484**	**0.547**	**0.425**	**0.497**	**0.488**	**0.491**	**0.44**	**0.303**	**0.352**	**0.38**	**0.418**	**0.392**

Table 5.21 Correlations between output cell values of spatial metrics from the AAK and CLC maps with 25m and 250m grain size. For small windows there are notably fewer observations, i.e. output cells with forest and to some degree nature presence in this pair of maps. Note that while the sides of the CLC grains are 10 times larger than the AAK grains, the *area* of them are 100 times larger than AAK grains, and the windows used thus have only 1/100 of the number of pixels.

Figure 5.17 represents a possible way of illustrating the outputs of the M-W calculations, comparing two data sources and stating the correlation coefficients. In this example the amount of “nature” areas is almost the same in the two maps used as inputs, but the AAK map has a more concentrated distribution compared to the blurred appearance of the LCP map. Average richness and edge length are higher for the LCP data, but the AAK data has a larger dynamic range (higher coefficients of variation for the Richness and Edge Length metrics). However, both data sets distinguish regions with different spatial arrangements of land use/land cover.

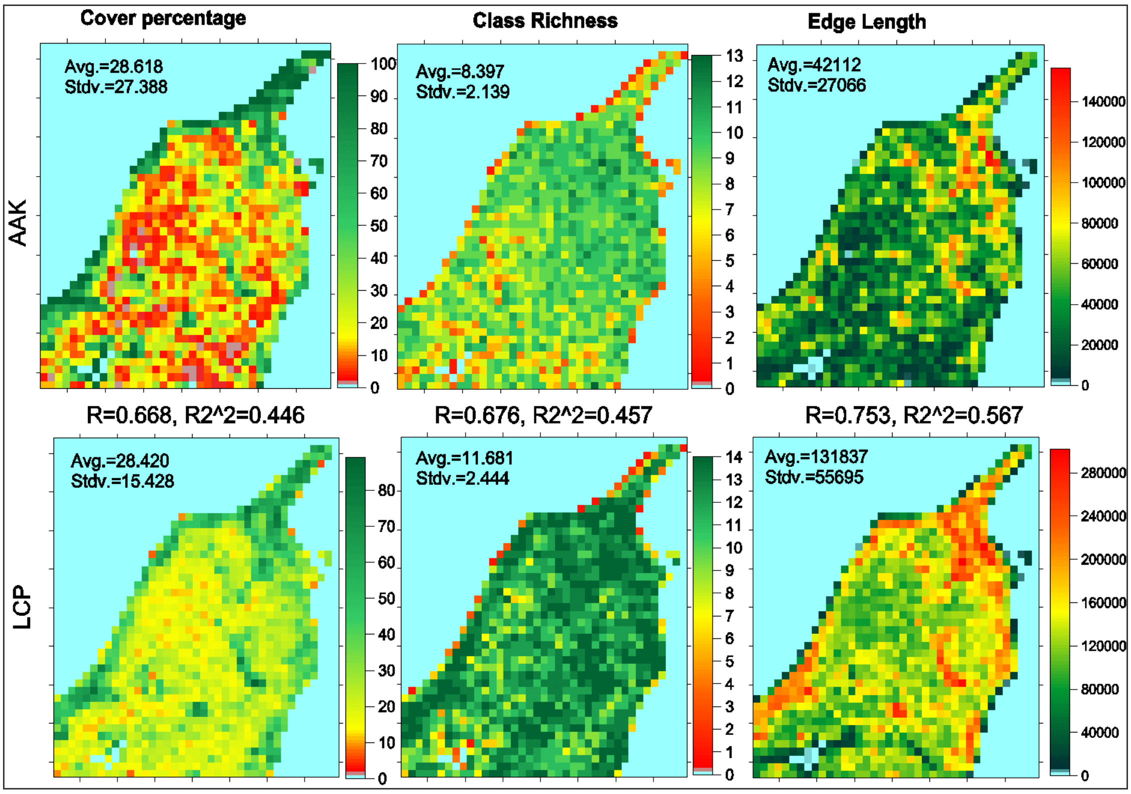

Figure 5.17 An example of pair-wise comparison of metrics maps from the different sources, here AAK and LCP for the nature theme, at window = output cell size 2km. The R-values correspond to those listed in Table 5.20.

5.5.2.2 Agreements between thematic levels

This section of the study examined whether (some or all) spatial metrics derived from maps of one thematic resolution e.g. landscape can be used to predict the metrics values at another e.g. forest. This would be useful, as redundant calculations and reporting could be avoided, given that it was justified to use just one set of metrics to describe landscape and nature in the study area. As examples of the results, the respective correlations for four of the metrics from the

AAK and the LCP data respectively are shown in Table 5.22 and Table 5.23, with significant correlations in **bold** type. The Matheron index has not been extracted for the landscape thematic level, and thus only forest and nature levels can be compared.

AAK	SHDI			NP			Edge Density			Matheron
relation: window size:	F-N	F-L	N-L	F-N	F-L	N-L	F-N	F-L	N-L	F-N
1km	**0.379**	**0.210**	**0.372**	**0.729**	**0.590**	**0.778**	**0.835**	**0.743**	**0.871**	**0.603**
2km	**0.434**	-0.033	**0.111**	**0.800**	**0.657**	**0.816**	**0.863**	**0.786**	**0.884**	**0.606**
3km	**0.494**	**-0.201**	0.009	**0.844**	**0.710**	**0.850**	**0.876**	**0.819**	**0.901**	**0.611**
4km	**0.481**	**-0.266**	-0.011	**0.872**	**0.738**	**0.870**	**0.917**	**0.881**	**0.926**	**0.621**
5km	**0.489**	**-0.440**	**-0.185**	**0.894**	**0.760**	**0.880**	**0.865**	**0.818**	**0.881**	**0.628**

Table 5.22 Correlations between metrics values for different thematic levels, AAK data. The data sets are based on the same data source = AAK, with same grain size= 25m. F-N denotes correlations between forest and nature thematic levels, F-L between forest and landscape, and N-L between nature and landscape levels.

For the AAK data, the most remarkable result is the negative correlation between forest and landscape levels. These results indicate high forest diversity low landscape diversity, and vice versa, especially when comparisons are made for larger windows. The other, structural metrics show good agreements with slightly lower correlations for the forest-landscape relationships.

LCP	SHDI			NP			Edge Density			Matheron
relation: window size:	F-N	F-L	N-L	F-N	F-L	N-L	F-N	F-L	N-L	F-N
1km	**0.569**	**0.383**	**0.786**	**0.940**	**0.882**	**0.983**	**0.823**	**0.686**	**0.891**	**0.477**
2km	**0.481**	**0.242**	**0.799**	**0.933**	**0.860**	**0.976**	**0.824**	**0.699**	**0.889**	**0.477**
3km	**0.446**	**0.163**	**0.814**	**0.946**	**0.889**	**0.982**	**0.823**	**0.732**	**0.907**	**0.575**
4km	**0.390**	0.068	**0.816**	**0.949**	**0.896**	**0.985**	**0.838**	**0.740**	**0.914**	**0.590**
5km	**0.275**	-0.009	**0.810**	**0.961**	**0.917**	**0.987**	**0.770**	**0.690**	**0.891**	**0.457**

Table 5.23 Correlations between metrics values for different thematic levels, LCP data. The data sets are based on the same data source = LCP, with same grain size= 25m.

The LCP data yield very similar results, though the SHDI values are positively and significantly correlated for the forest-landscape relation for windows of size up to 3 km. Window size strongly influences the agreement between the SHDI diversity metric for the forest theme on one side and the nature or landscape theme on the other, but not the agreement between the nature and the landscape theme. For the NP and ED structure metrics and the Matheron index describing fragmentation, there is no or little such influence from window size. For patch count metrics, the values are higher than for AAK data. This is illustrated in Figure 5.18, where the landscape-forest and landscape-nature relations are plotted for the two data sets, and trend lines with regression equations are used to illustrate the agreements.

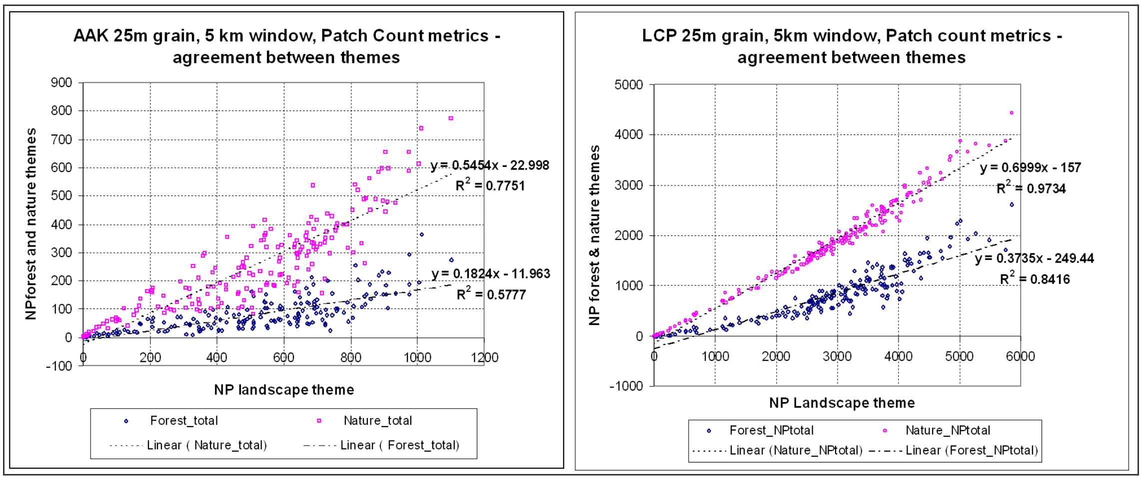

Figure 5.18 Output (5km) cell-by-cell plots of patch count metrics values between the landscape thematic level and the forest and nature levels for AAK data (left) and LCP data (right).

Figure 5.19 shows similar relations for the SHDI diversity metric, this time comparing the relations nature-forest and landscape-forest for AAK data where the shift from positive to negative regression is most pronounced.

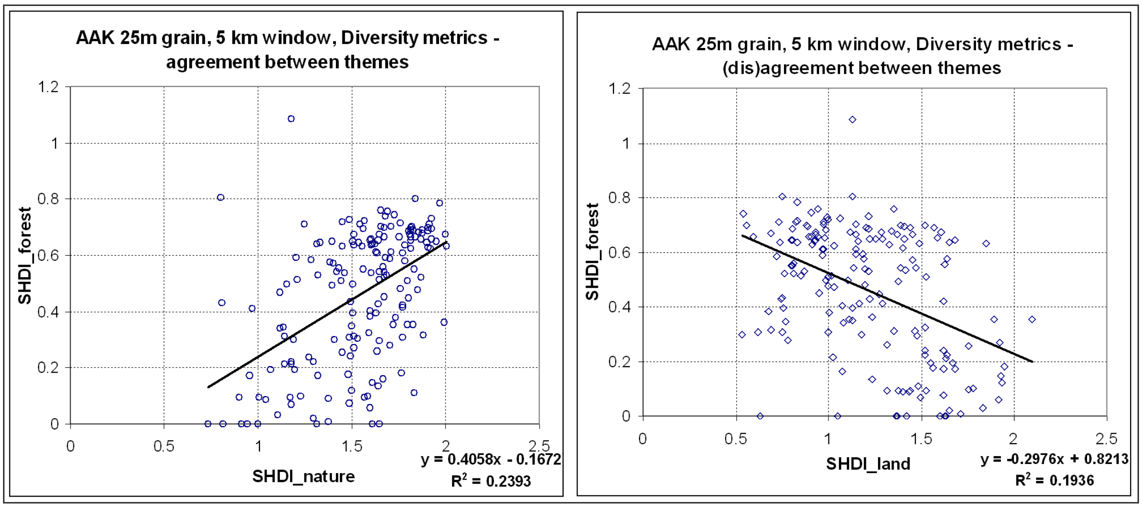

Figure 5.19 Output (5km) cell-by-cell plots of patch count metrics values between the nature and the forest thematic levels (left) and between the landscape and the forest thematic levels (right) for AAK data.

Finally, the inter-thematic relations for the Matheron index are visualised in Figure 5.20, with trend lines describing the relations. As seen in Table 5.17, the average values of M decrease with increasing window size. The graphs in Figure 5.20 also indicate that the higher metric values for small window sizes could be due to 'outliers' like the cell with a value of 25 in both images, and that larger windows minimise the chances of having extreme values. Such values are typically found for windows with only one or a few forest or nature pixels present, and the risk of including such windows decreases with larger window sizes.

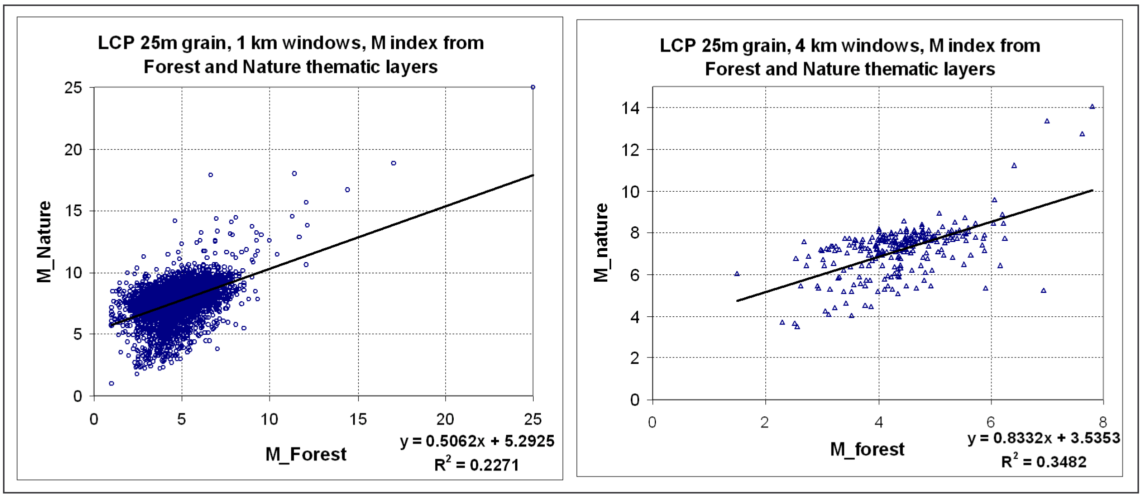

Figure 5.20 Changing relation between the Matheron index for forest and for nature thematic layers with increased window size.

5.5.2.3 Assessing the influence of terrain features on spatial metrics

It is no surprise that land cover is related to land forms, and examination of the topographical maps of the study area confirms that it is also the case in Vendsyssel – as for instance a comparison of Figure 5.1 and Figure 5.3 demonstrates the link between geomorphology and historical land use. Large old forests are found on the moraine ridges, spruce plantations mostly on dunes, while the Yoldia plains have little forest as they are mostly used as arable land (see Hansen 1964). The following two approaches are used for relating landscape structure, represented by spatial metrics of land cover, to the physical setting represented by terrain and geomorphology:

- Terrain form is expressed through elevation and slope, averaged to fit the output cells of the M-W analysis;

- Geomorphology is expressed through an aggregated thematic map of major land forms.

AAK and LCP maps are compared, in order to examine whether they also have different behaviour for these derived features.

In Table 5.24, the correlation coefficients are shown for the standard set of metrics for the forest theme from the AAK map, and average elevation and slope from the DEM. In comparison with the results in the sections above, values are remarkably stable with changing window size. For all metrics at all window sizes correlation is better with slope than with elevation.

AAK Forest	**Elevation** correlation with					**Slope** correlation with				
25m grain	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
n. obs.	2206	656	338	203	134	2206	656	338	203	134
COVERALL	**0.174**	**0.187**	**0.154**	**0.13**	0.113	**0.304**	**0.346**	**0.315**	**0.283**	**0.263**
EDGELENGTH	**0.268**	**0.300**	**0.362**	**0.414**	**0.433**	**0.454**	**0.508**	**0.498**	**0.515**	**0.515**
MATHERON	**0.149**	**0.202**	**0.220**	**0.284**	**0.309**	**0.300**	**0.371**	**0.369**	**0.394**	**0.413**
RICHNESS	**0.235**	**0.241**	**0.313**	**0.337**	**0.328**	**0.265**	**0.255**	**0.269**	**0.259**	**0.239**
SHDI_OBJ	**0.197**	**0.174**	**0.199**	**0.245**	**0.180**	**0.227**	**0.147**	**0.096**	**0.094**	**0.018**
SIDI_OBJ	**0.183**	**0.163**	**0.184**	**0.238**	**0.165**	**0.216**	**0.143**	**0.098**	**0.102**	**0.015**
SQP	**0.182**	**0.222**	**0.33**	**0.355**	**0.366**	**0.263**	**0.320**	**0.271**	**0.241**	**0.242**
NP_C1M	**0.097**	**0.127**	**0.107**	**0.075**	0.083	**0.216**	**0.288**	**0.258**	**0.213**	**0.201**
NP_TOTAL	**0.327**	**0.390**	**0.460**	**0.531**	**0.550**	**0.483**	**0.568**	**0.561**	**0.597**	**0.587**

Table 5.24 Correlations between metrics values and average elevation and slope, AAK forest theme. Significant correlations are marked in **bold** types.

For LCP data the picture is not so clear, as shown by Table 5.25. The diversity metrics have better agreements with elevation than with slope, the structure metrics have lower correlation coefficients for both map types and for the Matheron index they assume negative values for both elevation and slope. These negative relations could be due to the presence of more concentrated forest on areas with high slopes, given that forest in the LCP data from the outset (at small coverage fractions) will appear much more as small separate patches than in AAK data at the same spatial resolution. At higher forest concentration, larger and more coherent patches will be observed, resulting in a relative decrease in forest fragmentation.

LCP Forest	**Elevation** correlation with					**Slope** correlation with				
25m grain	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
n. obs	3015	789	360	209	137	3015	789	360	209	137
COVERALL	**0.092**	**0.075**	0.042	-0.006	-0.047	**0.218**	**0.211**	**0.162**	**0.115**	0.07
EDGELENGTH	**0.133**	**0.174**	**0.179**	**0.184**	**0.185**	**0.261**	**0.254**	**0.205**	**0.181**	**0.177**
MATHERON	**-0.097**	**-0.097**	**-0.098**	-0.073	-0.132	**-0.049**	**-0.109**	**-0.162**	**-0.127**	**-0.189**
RICHNESS	**0.212**	**0.208**	**0.182**	**0.178**	**0.152**	**0.299**	**0.246**	**0.158**	**0.125**	0.04
SHDI_OBJ	**0.25**	**0.32**	**0.362**	**0.364**	**0.442**	**0.29**	**0.307**	**0.279**	**0.258**	**0.31**
SIDI_OBJ	**0.236**	**0.3**	**0.335**	**0.338**	**0.409**	**0.239**	**0.24**	**0.222**	**0.204**	**0.253**
SQP	**0.038**	**0.112**	**0.111**	**0.14**	0.122	-0.03	**-0.072**	**-0.142**	-0.085	-0.096
NP_C1M	**0.13**	**0.157**	**0.134**	**0.119**	0.1	**0.239**	**0.264**	**0.236**	**0.189**	**0.175**
NP_TOTAL	**0.234**	**0.299**	**0.324**	**0.339**	**0.345**	**0.342**	**0.348**	**0.312**	**0.304**	**0.294**

Table 5.25 Correlations between metrics values and average elevation and slope, LCP forest theme. Significant correlations are marked as **bold**.

The landscape thematic level is markedly different from the forest level, as shown by Table 5.26. For the AAK data, correlation coefficients are higher except for the total number of patches, which also is a remarkable metric here, in the sense that the correlations with elevation are higher than with slope. The edge length metric, in combination with slope, gives values very similar to those seen for the forest theme, but higher values for the combination with elevation.

AAK Landscape	**Elevation** correlation with metrics					**Slope** correlation with metrics				
25m grain	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
EDGELENGTH	**0.285**	**0.419**	**0.489**	**0.545**	**0.592**	**0.399**	**0.441**	**0.436**	**0.494**	**0.489**
RICHNESS	**0.337**	**0.346**	**0.204**	0.112	-0.005	**0.358**	**0.271**	0.095	0.054	0.034
SHDI_OBJ	**0.088**	0.06	0.004	-0.015	-0.039	**0.318**	**0.28**	**0.219**	**0.169**	**0.205**
SIDI_OBJ	0.037	0.006	-0.042	-0.06	-0.075	**0.286**	**0.248**	**0.196**	**0.139**	**0.176**
NP_C23M	**0.137**	**0.17**	**0.186**	**0.175**	**0.233**	**0.274**	**0.312**	**0.314**	**0.331**	**0.39**
NP_TOTAL	**0.326**	**0.472**	**0.541**	**0.598**	**0.643**	**0.369**	**0.422**	**0.425**	**0.498**	**0.498**

Table 5.26 Correlations between metrics values and average elevation and slope, AAK landscape theme.

While the landscape level diversity metrics seem not to be related to elevation, the structure/fragmentation metrics are more closely related to this terrain feature than to slope. Class richness correlates significantly with both elevation and slope for small, but not for larger windows. This is likely to be due to this metric almost reaching its maximum value (equal to the total richness of patch types in the test area) at a window size of 3 to 4 km, as seen in Table 5.18.

At the landscape thematic level the metrics derived from the LCP data exhibit little correlation with elevation and hardly any with slope, not even for the edge length metric. No obvious explanations can be given for the negative correlations between the diversity metrics and elevation, since elevation and richness are positively correlated. The reason for the negative correlation cannot be a larger number of classes at low elevations, as seen in Table 5.27, it is thus likely to result from a more even distribution of the classes found there (or a more uneven distribution of class sizes at higher elevations).

In general, values of landscape metrics from the AAK land use/land cover data correlate better with measures of terrain features than metrics from the LCP satellite based land cover data. Thus, AAK data were chosen for illustration in Figure 5.21 of some of the relations between average 'terrain metrics' and the landscape metrics forest cover and number of patches. Note the 'peak' in forest cover percentage at low elevations, caused by the plantations on sandy soil along the west coast.

LCP Landscape	**Elevation correlation with metrics**					**Slope correlation with metrics**				
25m grain	1km	2km	3km	4km	5km	1km	2km	3km	4km	5km
EDGELENGTH	**0.117**	**0.195**	**0.238**	**0.246**	**0.275**	**0.156**	**0.147**	**0.105**	**0.136**	0.134
RICHNESS	**0.118**	**0.13**	**0.122**	**0.16**	**0.148**	**0.154**	**0.093**	0.032	0.084	0.036
SHDI_OBJ	**-0.059**	**-0.12**	**-0.164**	**-0.208**	**-0.235**	**0.107**	**0.074**	0.026	-0.037	-0.041
SIDI_OBJ	**-0.074**	**-0.139**	**-0.188**	**-0.238**	**-0.27**	**0.114**	**0.087**	0.04	-0.019	-0.027
NP_C23M	**-0.137**	**-0.147**	**-0.133**	**-0.156**	-0.08	**-0.116**	**-0.145**	**-0.185**	**-0.18**	**-0.158**
NP_TOTAL	**0.111**	**0.17**	**0.195**	**0.206**	**0.24**	**0.192**	**0.191**	**0.145**	**0.166**	**0.164**

Table 5.27 Correlations between metrics values and average elevation and slope, LCP landscape theme.

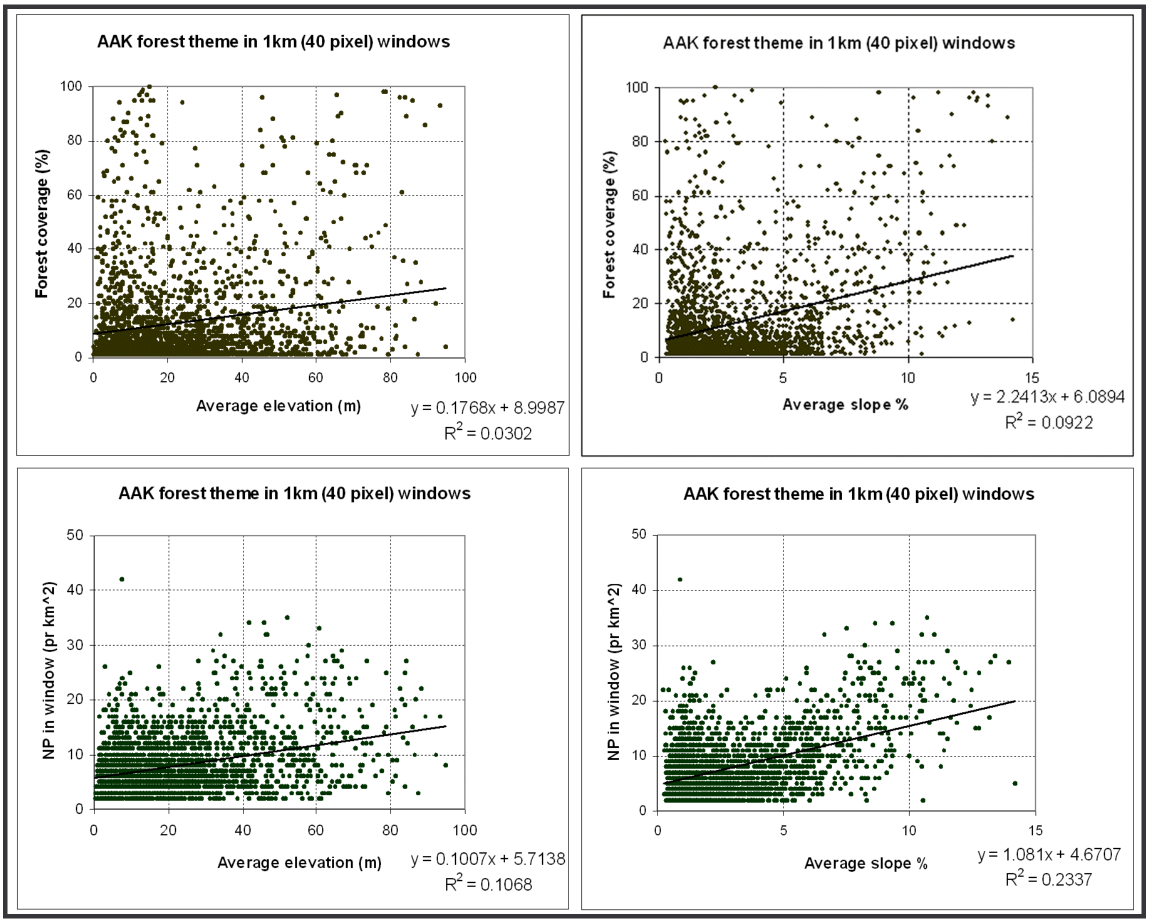

Figure 5.21 Scatter-plots of selected relations between terrain features and structural metrics for the forest theme from the AAK map in 1km windows.

The results from stratification by geomorphological type show clear differences in metrics values. Table 5.28 below summarises the metrics values and their standard deviations for the nature theme from the AAK data, while Table 5.29 summarises similar values for the LCP data, where also the nature theme has been selected as example. In Table 5.28, Proportion refers to the number of pixels where the Nature theme is present, relative to the total number of pixels in the stratum.

Mean	COVER pct.	EDGE LGT	MATH	RICHN.	SHDI	SIDI	SQP	NP_M	NP TOTAL	Pro-portion	Pixels incl.
Littorina or yonger	21.21	9094	2.81	5.179	0.789	0.42	0.588	2.098	12.161	0.913	938
Yoldia	14.53	10960	3.282	6.332	1.148	0.585	0.67	2.16	17.196	0.962	960
Dunes	67.20	16324	2.584	6.048	0.873	0.458	0.549	4.129	19.777	1.000	417
Young moraine	23.20	13664	3.297	6.579	1.084	0.549	0.662	2.759	20.32	0.964	1042
Artificially drained	28.08	11329	3.045	4.692	0.755	0.415	0.623	2.5	14.808	0.929	26
St.dev.	**COVER pct.**	**EDGE LGT**	**MATH**	**RICHN.**	**SHDI**	**SIDI**	**SQP**	**NP_M**	**NP TOTAL**	**Pro-portion**	**pixels incl.**
Littorina or yonger	22.51	7245	1.084	2.17	0.482	0.248	0.197	1.899	9.747	N/A	938
Yoldia	13.22	7292	0.914	1.982	0.447	0.207	0.132	1.853	11.04	N/A	960
Dunes	29.30	8055	1.23	1.865	0.396	0.199	0.24	3.325	11.754	N/A	417
Young moraine	22.08	8953	1.045	2.174	0.46	0.215	0.146	2.304	13.103	N/A	1042
Artificially drained	27.70	6332	1.125	2.243	0.509	0.262	0.161	2.209	9.831	N/A	26

Table 5.28 Spatial metrics from AAK, Nature theme values by (dominant) geomorphologic type in 1 km windows

Mean	COVER pct.	EDGE LENGTH	MATH	RICHN.	SHDI	SIDI	SQP	NP_C1M	NP TOTAL	pixels included
Littorina or yonger	26.08	34119	7.7	9.156	1.253	0.581	0.861	5.781	90.201	1027
Yoldia	21.07	31872	8.027	9.245	1.13	0.514	0.873	3.777	83.57	998
Dunes	54.91	50585	6.634	11.144	1.481	0.669	0.828	18.376	133.17	417
Young moraine	27.64	36252	7.483	9.994	1.197	0.532	0.86	6.144	100.848	1081
Artificially drained	23.29	26054	7.571	5.929	0.614	0.286	0.858	4.036	48.5	28
St.dev.	**COVER pct.**	**EDGE LENGTH**	**MATH**	**RICHN.**	**SHDI**	**SIDI**	**SQP**	**NP_C1M**	**NP TOTAL**	**pixels included**
Littorina or yonger	14.63	12251	1.402	2.495	0.435	0.189	0.05	6.053	39.53	1027
Yoldia	8.93	9176	0.923	2.375	0.425	0.188	0.017	3.646	31.493	998
Dunes	18.05	12607	1.802	2.442	0.424	0.156	0.066	9.201	50.46	417
Young moraine	17.04	13980	1.308	2.679	0.502	0.212	0.038	6.57	53.978	1081
Artificially drained	10.44	8199	1.419	3.184	0.545	0.254	0.02	3.343	21.251	28

Table 5.29 Spatial metrics from LCP, Nature theme values by (dominant) geomorphologic type in 1 km windows. Presence proportion is not stated for this image, as ‘nature’ pixels are found in all output cells, and all values thus will be unity (1).

From theses tables, clear differences between the strata are visible, most obvious for the cover percentage, where both data types indicate that most nature is found in the Dunes stratum, and least on Yoldia, in line with the description of the landscape given above. For the AAK data, the highest average richness of classes is found in the Young Moraine stratum, and the highest diversity metrics values in Yoldia, while for the LCP data, the highest values of both are found in the Dune stratum. The relatively low values for the cover percentage of LCP nature in the Dunes is partly due to the presence of the land cover class ‘unvegetated’, which has been re-classified to the matrix class (internal background). The small Artificially Drained stratum has lowest diversity metrics values for both data sets, which is not surprising since they have been reclaimed for agricultural purposes and are still today used for either grazing or crops. Figure 5.22 shows the separability between individual strata for a pair of metrics for the AAK and LCP data respectively, and is intended to indicate, how well spatial metrics discriminate between geomorphological regions. The LCP data have smaller standard deviations of the average metrics values within the strata and thus a visually better separation between the strata, where Artificially drained areas, Yoldia and Dunes are almost completely separated from each other.

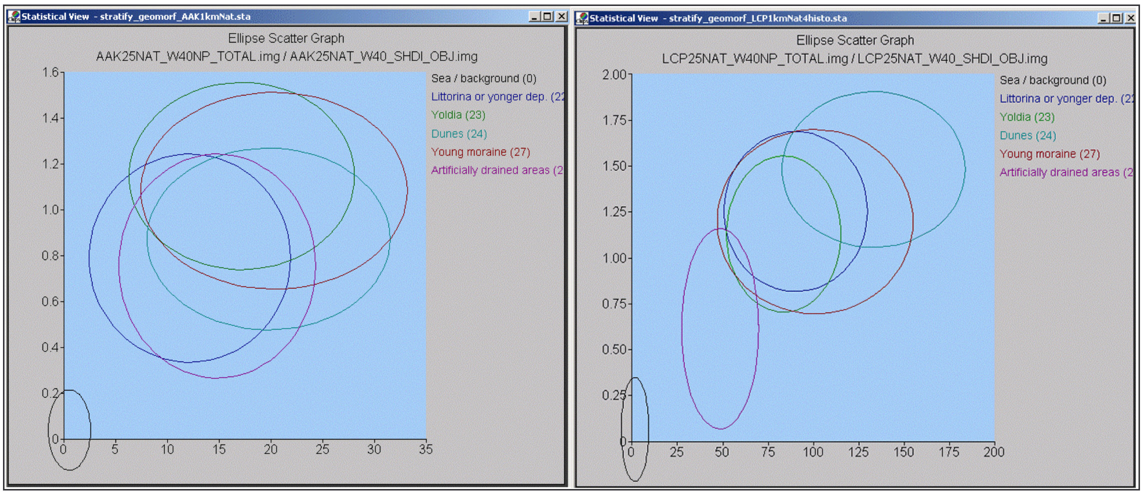

Figure 5.22 Scatter graphs of combination of the NP (x-axes) and SHDI (y-axes) metrics values in the geomorphological strata for AAK and LCP data, nature thematic level. These ellipse plots are based on average values (position), standard deviations (size) and the correlation between the bands (direction).

5.5.3 Hemeroby calculation and mapping

The Hemeroby index defined above is so simple and fast to calculate, that it tempts the user to directly apply it to large areas and all sorts of land use data sets, like the CLC at European level. However, caution is needed, and some investigations of the behaviour of this metrics in relation to scale, window size and other metrics should be carried out. Neither is it clear just how the calculation of this metric should be implemented and how maps of the resulting values should be presented. Thus, the AAK and CLC data sets were used for some test runs of index calculation, reporting of statistical properties and display in combination with environmental vector data from various sources. For the re-classification of CLC data to NDP-value images, it was decided to include the classes Lagoons and Estuaries as part of the landscape, even though Water (mostly open sea) is excluded. This is done with a nature management application in mind, since the ‘land cover types’ constitute important habitats for birds, and these areas in Denmark provide important rest and feeding grounds for migratory birds, also at the continental and global level (European commission, DG XI 1999, Bach et al 2001) and Denmark has a special obligation to preserve and protect the habitats found there (Bertelsen 2003, p. 5).

5.5.3.1 Agreement between data sources

A central question for this part of the project is whether Hemeroby values from the CLC can substitute values from AAK or similar high-resolution land use data – even though they are calculated using data an order of magnitude coarser. To answer this the values from the land use maps, re-classified to NDP values, were averaged to the same output cell size, following the ‘flow chart’ in the bottom line of Figure 5.10, page 228, and correlations of the resulting Hemeroby values carried out. The results are listed in Table 5.30.

window size	n.obs.	AAK pixels	IHI AAK	AAK st.dev.	CLC pixels	IHI CLC mean	CLC st.dev.	corr. (R)
1km	3710	40*40	67.946	14.333	4*4	65.681	15.994	**0.814**
2km	955	80*80	67.703	12.775	8*8	64.917	14.773	**0.851**
3km	435	120*120	67.812	11.505	12*12	64.714	13.405	**0.823**
4km	241	160*160	67.362	11.085	16*16	64.327	12.718	**0.878**
5km	164	200*200	67.558	10.082	20*20	63.800	12.351	**0.84**

Table 5.30 Values of integrated Hemeroby index (IHI) from AAK and CLC data respectively, with standard deviations and correlation coefficients from regression of Hemeroby values from AAK and CLC data with varying moving-window sizes.

The R-values are slightly higher than for the relation between cover fraction values for the AAK-CLC comparison at the nature thematic level (Table 5.21) and slightly lower than at the forest thematic level, in both cases over the entire range of window sizes. This similarity between agreement for cover proportion and Hemeroby index values is not surprising, since the cover proportion is the metric that come closest to being an average of pixel values (in principle of presence=1, absence=0). A visual impression of the relation for the smallest and largest windows used is given in Figure 5.23.

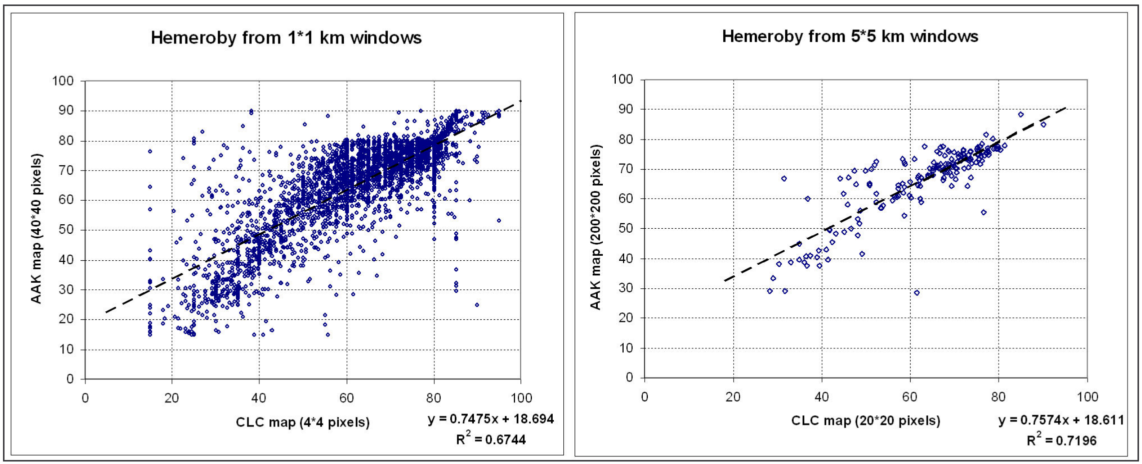

Figure 5.23 The relationship between Hemeroby values derived from AAK and CLC displayed as scatter plots.

The good agreement between values from AAK and CLC is assured through the existence of classes such as “Agriculture with natural vegetation” and “Complex vegetation patterns” in the CLC legend, with lower NDP values than the ‘pure’ Arable Land class. This compensates for the scaling effect of excluding small patches of natural vegetation which takes place when land use map with grain size 250m is made. In other words, the multi-functionality of mixed land use classes is incorporated in the weighting of human impact/pressure through the NDP values of these classes (Table 5.10), which is again reflected in the integrated Hemeroby index values.

5.5.3.2 Agreement with spatial metrics

As well as being an alternative to spatial metrics, the Hemeroby index can also be seen as a supplement to the suite of metrics. In that capacity it was compared with the other metrics, including the terrain features for the AAK data (Table 5.31) and the CLC data (Table 5.32). As for the correlations between spatial metrics from different data sources, it was assumed that metrics values for cover fraction and fragmentation metrics would be meaningless at the landscape thematic level (refer discussion in section 5.4.4).

For the AAK data, at the forest thematic level, the Hemeroby index is negatively correlated with cover fraction, i.e. the higher Hemeroby in the window, the less forest, not a surprising finding. More counter-intuitive is the observation of positive correlation between Hemeroby and the diversity metrics – for the forest and nature thematic levels, in contrast to clearly negative values for the landscape level. A possible explanation to this phenomenon is that the diversity metrics for the forest and nature themes only are calculated for (the relevant) parts of the window, and thus the positive correlations are caused by higher diversity of forest and nature areas *within* landscapes with human influence /higher land use pressures (in contrast to e.g. windows with mainly coniferous forest and (thereby) low Hemeroby index values).

AAK-Hemeroby	**Forest**					**Nature**					**Landscape**				
metric type	**1km**	**2km**	**3km**	**4km**	**5km**	**1km**	**2km**	**3km**	**4km**	**5km**	**1km**	**2km**	**3km**	**4km**	**5km**
n. obs.	2206	656	338	203	134	2960	794	362	209	137	3086	796	362	209	137
COVER	**-0.564**	**-0.577**	**-0.562**	**-0.524**	**-0.59**	**-0.97**	**-0.974**	**-0.975**	**-0.977**	**-0.98**	**N/A**	**N/A**	**N/A**	**N/A**	**N/A**
RICHNESS	**-0.042**	0.013	0.025	**0.186**	**0.18**	**-0.106**	**0.094**	**0.156**	**0.234**	**0.095**	-0.03	**0.148**	**0.176**	**0.322**	0.098
SHDI_OBJ	**0.095**	**0.332**	**0.461**	**0.578**	**0.607**	**0.116**	**0.386**	**0.494**	**0.55**	**0.559**	**-0.466**	**-0.534**	**-0.56**	**-0.52**	**-0.713**
SIDI_OBJ	**0.108**	**0.321**	**0.442**	**0.542**	**0.585**	**0.128**	**0.358**	**0.441**	**0.496**	**0.504**	**-0.533**	**-0.607**	**-0.626**	**-0.599**	**-0.74**
EDGELENGTH	**-0.441**	**-0.492**	**-0.382**	**-0.216**	**-0.232**	**-0.449**	**-0.379**	**-0.322**	**-0.19**	**-0.179**	**-0.094**	0.041	**0.104**	**0.257**	**0.27**
MATHERON	**-0.182**	**-0.223**	**-0.226**	-0.07	-0.157	**0.191**	**0.353**	**0.421**	**0.524**	**0.443**	N/A	N/A	N/A	N/A	N/A
SQP	**-0.1**	**-0.129**	**0.029**	**0.336**	**0.265**	**0.343**	**0.611**	**0.68**	**0.739**	**0.741**	N/A	N/A	N/A	N/A	N/A
NP_Matrix	**-0.418**	**-0.481**	**-0.438**	**-0.37**	**-0.424**	**-0.426**	**-0.524**	**-0.571**	**-0.497**	**-0.629**	**-0.198**	**-0.257**	**-0.274**	**-0.23**	**-0.239**
NP_TOTAL	**-0.331**	**-0.367**	**-0.236**	-0.072	-0.062	**-0.284**	**-0.194**	**-0.111**	0.007	0.029	**0.073**	**0.231**	**0.316**	**0.426**	**0.439**
Elevation	**0.105**	**0.094**	**0.14**	**0.187**	**0.203**	**0.136**	**0.141**	**0.155**	**0.196**	**0.205**	**0.114**	**0.139**	**0.155**	**0.196**	**0.205**
Slope	**-0.133**	**-0.125**	**-0.103**	-0.052	-0.036	**-0.151**	**-0.132**	**-0.124**	-0.036	-0.028	**-0.173**	**-0.133**	**-0.124**	-0.036	-0.028

Table 5.31 Correlations between output cell values of Hemeroby and the suite of spatial metrics for AAK land use data. Significant relations are marked by **bold** types.

For the AAK data, at the nature thematic level the Hemeroby index is positively correlated with fragmentation metrics and strongly negatively correlated with the cover fraction metric. Hemeroby is positively correlated with SqP values, probably showing that this could be a good structural indicator of naturalness – noting that the M and SqP metrics are binary functions, comparing forest-non forest and nature-non nature areas – and as above, the Hemeroby values integrate characterisation of land use *outside* the forest and nature patches. The fact that there are negative correlations between Hemeroby and NP_total for the forest and nature levels but positive correlations for the landscape level, is likely to be caused by the observed fragmentation /splitting of artificial/urban land use classes like roads and railway lines shown for the 25m grain image in Figure 5.11.

CLC-Hemeroby	**Forest**					**Nature**					**Landscape**				
metric type	**1km**	**2km**	**3km**	**4km**	**5km**	**1km**	**2km**	**3km**	**4km**	**5km**	**1km**	**2km**	**3km**	**4km**	**5km**
n. obs.	661	305	199	142	105	1480	558	307	193	134	3086	796	362	209	137
COVER	**-0.62**	**-0.56**	**-0.53**	**-0.61**	**-0.61**	**-0.84**	**-0.87**	**-0.87**	**-0.88**	**-0.9**	N/A	N/A	N/A	N/A	N/A
RICHNESS	-0.01	**-0.19**	**-0.22**	**-0.17**	-0.09	**-0.13**	**-0.47**	**-0.58**	**-0.57**	**-0.65**	**-0.4**	**-0.43**	**-0.49**	**-0.38**	**-0.42**
SHDI_OBJ	**-0.21**	**-0.2**	**-0.18**	**-0.14**	-0.03	**-0.49**	**-0.58**	**-0.6**	**-0.6**	**-0.62**	**-0.54**	**-0.52**	**-0.49**	**-0.46**	**-0.45**
SIDI_OBJ	**-0.2**	**-0.2**	**-0.18**	**-0.14**	-0.01	**-0.48**	**-0.56**	**-0.55**	**-0.57**	**-0.56**	**-0.53**	**-0.48**	**-0.45**	**-0.41**	**-0.38**
EDGELGT.	**-0.16**	**-0.35**	**-0.43**	**-0.43**	**-0.47**	**-0.13**	**-0.48**	**-0.57**	**-0.52**	**-0.55**	**-0.42**	**-0.46**	**-0.46**	**-0.33**	**-0.29**
MATHERON	**-0.16**	**-0.3**	**-0.38**	**-0.37**	**-0.43**	**-0.12**	**-0.21**	**-0.24**	**-0.19**	**-0.29**	N/A	N/A	N/A	N/A	N/A
SQP	**-0.35**	**-0.18**	**-0.21**	**-0.19**	**-0.11**	**-0.48**	**-0.19**	0.017	0.097	0.061	N/A	N/A	N/A	N/A	N/A
NP_Matrix	0.013	**-0.2**	**-0.36**	**-0.29**	**-0.55**	**0.498**	**0.189**	**-0.11**	-0.06	**-0.38**	**0.54**	**0.305**	**0.212**	**0.208**	**0.145**
NP_TOTAL	**-0.11**	**-0.25**	**-0.38**	**-0.31**	**-0.31**	**-0.11**	**-0.44**	**-0.6**	**-0.51**	**-0.63**	**-0.39**	**-0.42**	**-0.48**	**-0.32**	**-0.42**
Elevation	**0.106**	**0.201**	**0.246**	**0.268**	**0.291**	**0.244**	**0.24**	**0.28**	**0.267**	**0.268**	**0.121**	**0.162**	**0.207**	**0.244**	**0.266**
Slope	**-0.07**	-0.02	-0.01	0.056	0.04	0.005	-0.03	-0.03	0.022	0.003	**-0.18**	**-0.13**	-0.09	-0	0.005

Table 5.32 Correlations between output cell values of Hemeroby and the suite of spatial metrics for CLC land use data. Significant relations are marked as **bold**.

For the AAK Data, at all three thematic levels, the Hemeroby index is positively correlated with terrain elevation and negatively with slope, though in the case of the latter this is only significant up to window size 3km. An interpretation of this could be, that the more natural land use classes are typically found on sloping terrain, but on the other hand they are mostly found along the coast, especially on Skagens Odde and in other dune formations, with relatively low elevations. The fact that there is a larger concentration of nature type land cover near the coast than on the Yoldia plains also contribute to the positive correlation between Hemeroby and elevation. For the CLC data the same very significant relationship between Hemeroby and cover fraction are found, with the highest correlations expressed for the nature thematic level. Here the correlations Hemeroby-diversity metrics are constantly negative, with relatively high values for the forest and landscape themes. This could be due to the low number of pixels within the windows, which gives a low probability of finding several different land use classes within the same window - as indicated by the low average values of Richness in Table 5.17 and Table 5.18. The negative correlations between Hemeroby values and NP_total appear because the dominant land cover class (agriculture) here is assigned high NDP values, so that windows with only little forest or nature (few patches) will have high Hemeroby index values. For the CLC data, the correlation coefficients for the Hemeroby - NP_matrix regressions all decrease rapidly with increasing window size. For the small windows, NP_Matrix values above zero will simply indicate the presence of matrix/agriculture with high NDP values while for larger windows, high NP_Matrix values will indicate the presence of perforated forest or nature. This confirms predictions from percolation theory and neutral model studies that, before many gaps/openings appear, a certain amount of patch area has to be present (Gardner et al 1987, With 1997). Correlations with elevation are similar to those from the AAK data, but no relation is identified for slope.

The results above indicate that, for CLC data (or other medium-resolution images/maps) Hemeroby indices and spatial metrics values should be calculated for relatively large geographical windows, in order to have clear interpretations of the metrics and their mutual relations.

5.5.3.3 Display and mapping of Hemeroby indices

Before the Hemeroby index values were transformed back to categorical values corresponding to the Hemeroby classes of Table 5.11, histograms of the distribution of the index values were constructed at window sizes of 1, 2, 3 and 5km, see Figure 5.24. The structure of the different types of input data are clearly reflected in the shape of the curves. Especially at 1 and 2 km, the presence of windows with purely agriculture (CLC category 2.1.1: non-irrigated arable land) is distinct. Since this class has been assigned an NDP factor of 0.8 (80 in the integer maps), this is the value of the Hemeroby index for a large number of output cells. This effect is not so accentuated for the AAK data, due to the larger number of pixels in each window, with increased probability of finding other classes than ‘arable land’ there. It is not surprising that for both data types, the over-all image variability decreases with increasing window size, as seen in Table 5.30, and that it is reflected in the histogram curves being more concentrated around the mean values.

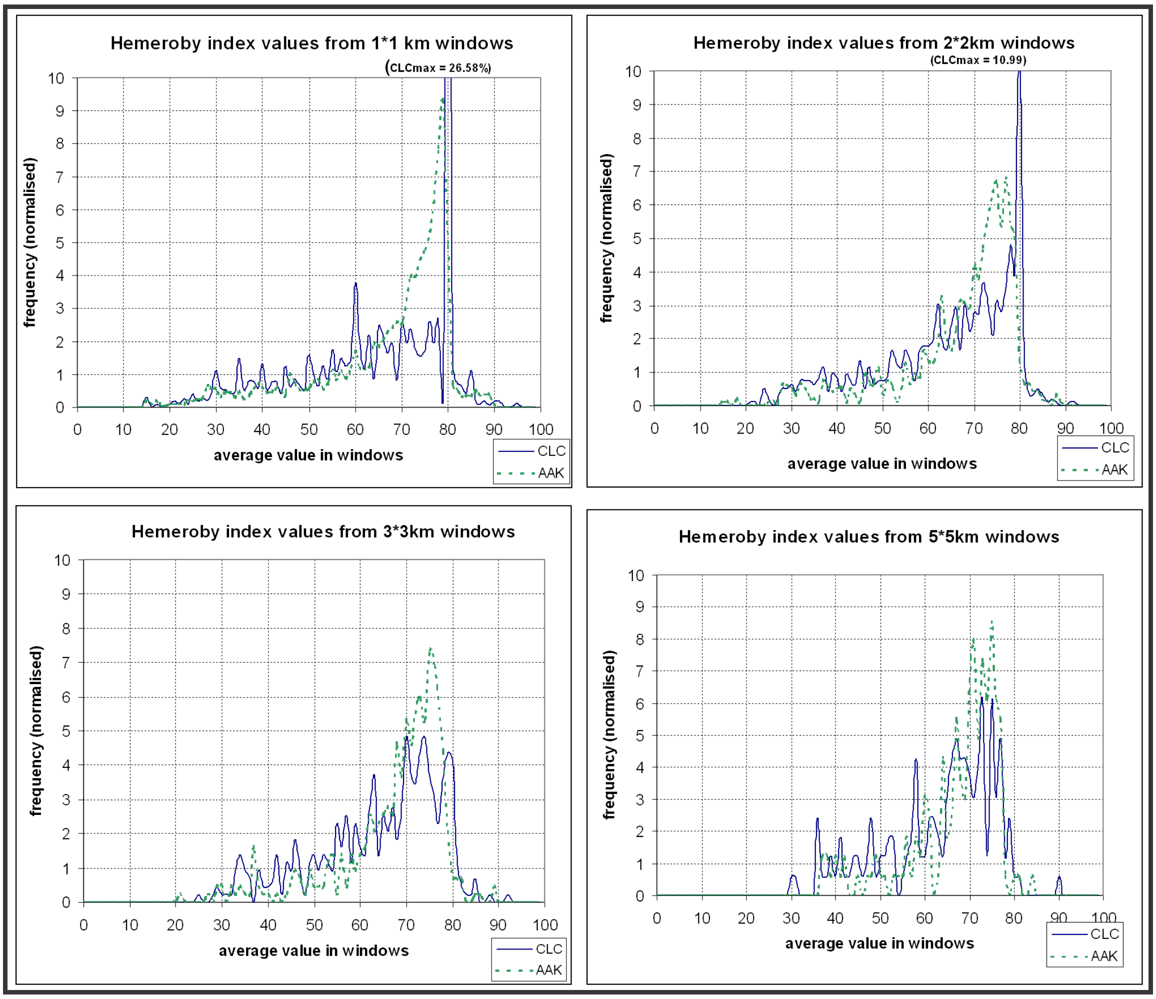

Figure 5.24 Combined histograms of Hemeroby values distribution for AAK and CLC data for window sizes from 1 to 5 km. Note that the number of observations (output cells) decrease from 3710 at 1km extent to 164 at 5km extent.

From Figure 5.22 it was obvious that if Hemeroby maps were to be made from the 1km averages that would allow comparison of AAK and CLC data, an alternative classification was necessary. Thus, the intervals of Table 5.11 were modified so that the label Polyhemrobic was assigned to values >= 78 (instead of above 80) for both datasets, in order to include the peaks of both histograms and to have a certain amount of pixels in the highest Hemeroby class. Furthermore, it was preferred that the same re-classification strategy was applied to both data sets[35]. The results, including majority filtering in a 3*3 kernel as the ‘clean-up’ operation, are shown in Figure 5.25 below.

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[35] Alternatively, the re-classification could be based on equally sized intervals (percentiles) of Hemeroby index values from the two data sets.

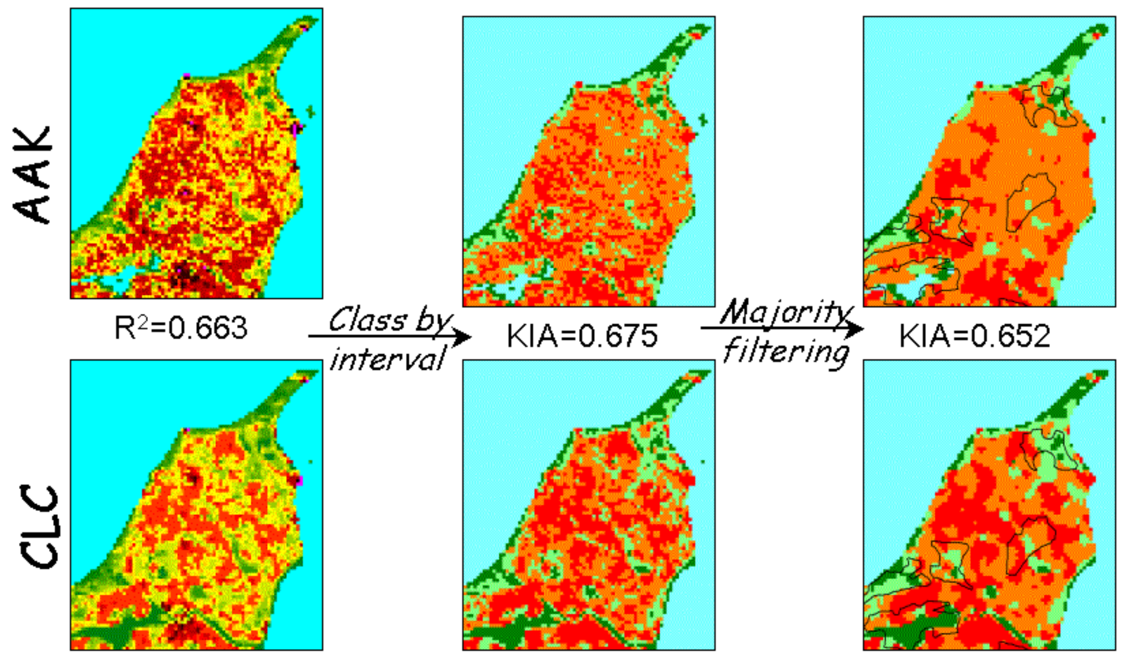

Figure 5.25 Approaches to creating Hemeroby maps of the study area. Inserted vector-file in images to the right: larger undisturbed landscapes according to the regional development plan (data from the regional authority, see Nordjyllands Amt (2001).

A cross-tabulation analysis of the Hemeroby-class maps, raw as well as filtered, showed that the filtering does not result in better agreement between the two maps. The Kappa Index of Agreement (KIA, entire matrix, calculated using Idrisi) was found to be: for the un-filtered maps: 0.6751; for maps subjected to a 3*3 mode filter: 0.6522.

An alternative to this ’clean-up’ operation, which was performed in order to improve map appearance, could be smoothing of the ”Hemeroby surface”, either through filtering of the averaged image as shown above or through creation of a surface with overlapping windows, such as can be created with the Idrisi MapWalker (Hovey 1998), which is used in the concluding example here. Actually, a similar approach can be used with other spatial metrics, such as for maps of diversity classes or fragmentation classes, perhaps based more on histogram analyses than on ecological interpretation of metrics values, as the interval limits would change between different data sets. Potential uses of Hemeroby maps include input to models of environmental impact, use as basal layers for regionalisation efforts - or simply as base maps for illustration of certain themes like in the example in Figure 5.26 below.

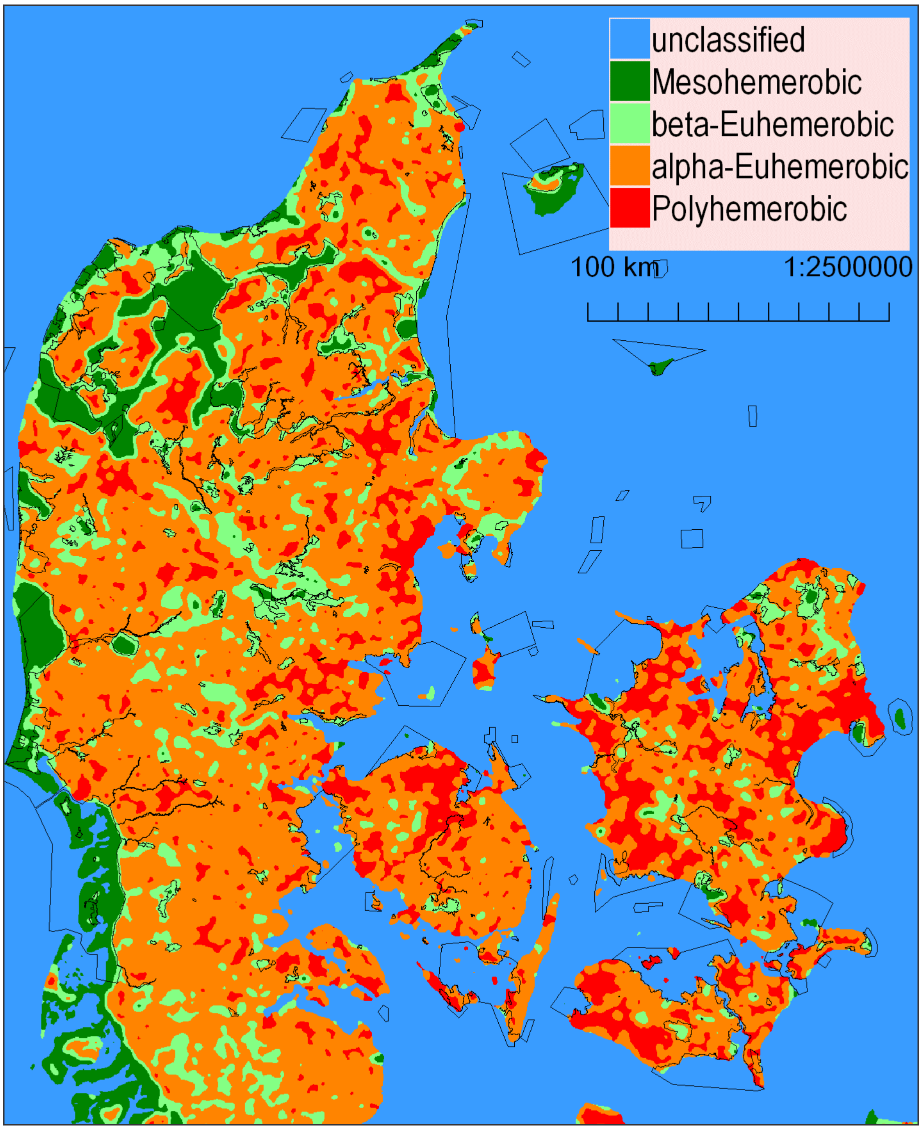

Figure 5.26 "Hemeroby map" of Denmark based on CLC data, extracted with 'smooth' averaging in circular windows (with diameter 13 pixels, corresponding to an area of 8.3 km^2), classification by intervals and clean-up filtering. The vector theme shows appointed EU habitat areas (Bertelsen 2003), acquired from AIS, updated July 2003. These areas constitue the Danish contribution to the Natura2000 network (European Commission 1999).

Figure 5.26 shows one of many possible approaches to map the distribution of Hemeroby classes at the national level. For the study area in Vendsyssel, it is clearly areas with low Hemeroby index values that have been appointed, like heath lands, forest areas and the raised undisturbed bog area in Store Vildmose. For the rest of the country, it can be noted that areas with a long history of intense agricultural use like western Zealand and the plain west of Copenhagen stand out as being polyhemerobic, while suburban zones like the forested area north of Copenhagen does not seem to be under pressure. In general, the objective of producing a map that would highlight the parts of Denmark that are most intensively used by agriculture and dense settlement was met.

5.6 Discussion

In this section, the questions that emerged from the cultural environment project are addressed, using the data sets available and the landscape ecological – spatial metrics approach. The points stated in the Objectives section will thus be addressed in the light of the results obtained in this study, and the questions answered as far as it is possible.

1) Thematic scaling properties

Data from the three test blocks showed the values of diversity metrics to increase with increasing number of classes in the input images (higher thematic resolution). As expected, the values of structural metrics such as edge length and patch number were observed to increase with the inclusion of more classes. Metrics values were also notably influenced by the exclusion or inclusion of matrix, as expected in the methodological considerations, and confirming the warning by McGarigal and Marks (1995), that metrics values will differ significantly, as also demonstrated by Gallego et al (2000). This was especially seen for the diversity metrics SHDI and SIDI, where comparisons were made at the forest and landscape thematic levels and the highest values were found for calculations with matrix excluded – typically resulting in a greater evenness of the class distribution.

2) Influence of spatial resolution

Changing spatial scale influenced metrics values, though in different ways for different types of metrics. The cover proportion metrics showed practically no response, and (as a consequence) the also the diversity metrics showed very little response. Patch count metrics, in terms of total patch numbers as well as counts of background/matrix patches decreased linearly with increasing grain size, but with different slopes of the scalogram curves for different classes. This is in line with the observations by Wu (2003), who compared landscape and class level metrics for different types of landscapes and found distinct differences in scalogram shapes. Fragmentation metrics increased in a linear or logarithmic way. Some artificial fragmentation effects were observed for the AAK data when converted to grids with 25m grain size (see also the scalograms in Figure 5.13), a resolution which is otherwise practical for comparison with LCM and LCP data. Thus it would be advisable to either use images with smaller grain size or to apply a more sophisticated aggregation method that preserves or rapidly removes linear elements during aggregation of classes and map generalisation, such as those described by Goffredo (1998) and Büttner et al (2002). Preserving object shapes and thereby values of structural metrics is not always possible. However, with increased availability of computer speed and memory, there is no practical reason why land use data should be aggregated to larger grain sizes (before spatial metrics are calculated) – apart from needs to compare metrics values from images with similar grain size or to save computation time for very large area calculations.

3) Comparability of data for landscape characterisation

Moving-windows analyses showed that the different data sets to a large extent are comparable, even when they have differences in the absolute values of the metrics. For instance, the total number of patches counted within each window would be four times higher for LCM data than for AAK data, even with the same number of classes present (Table 5.17 and Table 5.18). Also diversity and fragmentation metrics were twice as high or more from LCM and LCP data relative to AAK data, and even higher relative to the CLC data. The main reason for these differences lies in the origin of the data: the AAK coming from vectors based on existing topographic maps and interpretation of aerial photos, and the LCM/LCP data from semi-automated classifications of satellite imagery. The AAK and LCM/LCP data agreed well for the forest thematic level, especially on cover proportions, and less so at the nature thematic level. For the diversity metrics, the best agreements were found at the landscape level. The edge length metric appears to be quite robust, and good agreements are found between these data sources at all window sizes and thematic resolutions. Thus, basic elements of forest structure can be derived from for instance the land cover maps (potentially updated on a yearly basis) and used to predict (changes in) metrics values from the AAK land use data, which potentially serve as a base map for environmental monitoring.

4) Comparisons between maps at different thematic resolutions

Agreements between metrics values at different thematic levels are reported for AAK and LCP data, since they represent “end points” in terms of number of classes and in where the focal points of classification have been (land use vs. vegetation types). The pattern of agreements and disagreements were however very similar, compare Table 5.22 and Table 5.23. Some metrics ‘translate’ well between thematic levels, in particular the patch count metric NP and the closely related (highly correlated) metric of edge density. In general the best agreements are found between the forest and the nature level, and the worst between the forest and the landscape levels, where the disparity is the largest in terms of number of classes.

5) Influence of terrain features on metrics values

The inclusion of the (averaged) terrain parameters slope and elevation showed that some metrics were highly correlated with these, and that it may be possible to predict (average) metrics values from terrain, at least at some window sizes and thematic resolutions. For the AAK data at forest thematic level, all metrics values turned out to be positively, and with two exceptions, significantly correlated with elevation and slope; the total number of patches and edge length having the highest coefficients. For the LCP-forest data, such relationships were not apparent and negative coefficients arose for the relationships between slope and M and between slope and SqP. At the landscape thematic level for the AAK data, edge length and total patch number again agreed well with both elevation and slope, diversity metrics only with slope. For the LCP data at the landscape level, only vague relations appear.

The use of basic geomorphological types as a mask for stratification showed some significant differences between the strata in terms of metrics values. As expected, most nature was found in the Dunes stratum, which also had the highest diversity metrics values for the LCP data. The AAK data also pointed to Dunes as having most nature content, but for this data type the highest diversity - and fragmentation - values were found for Young Moraine. These results and possible visualisations of 'structural separability' like in Figure 5.22 show the feasibility of characterising landscape types with spatial metrics and points to the possibility of predicting vegetation patterns and the appearance (texture) of landscapes from their three dimensional shape or their geomorphological history.

6) Options for description of landscapes using spatial metrics

The results presented so far show the potential of spatial metrics to characterise and classify landscapes according to their composition and structure of their land use/land cover classes. For instance, a combination of a diversity metric, a fragmentation metric (at the landscape level an edge length metric) and cover proportion (or at the landscape level a patch count metric which is normally highly correlated with cover proportion) together span the 'space' of most possible landscape configurations, and should thus be sufficient to characterise the landscapes within the windows. This could be in the form of summary statistics or artificially coloured images with the mentioned parameters controlling image display parameters Red, Green and Blue (RGB) or Intensity, Saturation and Hue (ISH). The exact choice of metrics would depend on the preferred grain size of the map, the size of the M-W in the calculations and the data type and thematic resolution used, and be guided by the correlations between metrics values found here. These methods remain to be tested for applicability in the DACE project.

7) Use of the Hemeroby index

A Hemeroby index as proposed by Steinhardt et al (1999) was implemented using a M-W approach and the Naturalness Degradation Potential (NDP) coefficients defined by Brentrup et al (2002) for CLC classes, which could also be applied to AAK data. A good agreement was observed between the values of the Hemeroby index derived from AAK and CLC data respectively. Visually expressive illustrations can be made using the reclassification-averaging approach described in section 5.5.3.3, see also Table 5.11. Given that Hemeroby has been defined as a measure of unnaturalness, it is considered a satisfying result, that the Hemeroby index used here shows strong negative correlation with the coverage fraction of the classes appointed to the nature theme. The Hemeroby index is however only positively correlated with metrics of fragmentation for the nature theme from AAK data, for the CLC data the coefficients are significantly negative for both the nature and landscape themes, but this can partly be attributed to the small window sizes in terms of pixels.

Based on the apparent usefulness of a Hemeroby index, it is proposed to generalise the Hemeroby index to an Integrated Hemeroby Index: IHI_{Dx} where D denotes the diameter of the window and x is either S for square or C for circle. As shown in Table 5.30, average values of the IHI will be almost identical even though different window sizes are used. It is rather the variability within the study area that will change with window size and overlap. These relations discussed here were established for the test area, but later on it would be worth comparing CLC and AAK data from other parts of Denmark. To that end the 25*25km blocks of AAK vector data represent good samples – also for instance for looking into the relations between Hemeroby indices and spatial metrics.

5.7 Conclusions – implications for landscape monitoring

For this study, the moving-windows method was useful for further investigation of the behaviour of spatial metrics in response to changing resolution and window size as well as thematic resolution. The M-W approach also proved to be well suited for creating maps to illustrate large-area landscape patterns. Scalograms showing metrics values as function of grain size proved to be useful tools for assessment of individual metrics in limited areas such as the test blocks used in this study. In this study scalograms were used to confirm that landscape pattern is spatially correlated and dependent on scale (Wu 2003, Wu et al 2002) also on the thematic level.

The AIS data were well suited for the analyses carried out in this study, the AAK data especially fulfilled their purpose. When these were transformed to raster format, realistic land use maps were obtained, which could be used not only for monitoring/change detection (Groom and Stjernholm 2001) but also for landscape characterisation. However the CLC data of lower resolution (250m grain size) can substitute the AAK raster data (at 25 m grain size) for calculation of Hemeroby index values over large areas, as index values from these two sources are strongly correlated. The Hemeroby index itself turned out to be a useful indicator of pressure on landscapes from human activity. While AAK and CLC data are well suited for creating maps of unnaturalness (which is one definition of Hemeroby), LCP data might be useful for creating contrasting maps of naturalness. Where these coincide with high values, potential areas with conflicting interest and/or nature under pressure have been identified. Thematic maps of Hemeroby index values can provide background information for planning in the open land, although how it is best implemented on landscape management remains to be tested. The inclusion of terrain parameters can provide supplementary spatial information for landscape stratification (before metrics are calculated) as well as segmentation (when used together with spatial metrics).

For characterisation of smaller areas, such as individual cultural environments, a combination of contextual and patch/object specific metrics can possibly be used. In raster-GIS analyses it would even be possible to combine metrics derived with different window sizes, as long as the output cell size remains the same. This approach is likely to provide landscape indicators that supplement those proposed by Fry et al (2003) and required for selection and management of cultural environment areas in Denmark. It will thus be applied within the framework of the DACE project. The Hemeroby index, based on AAK maps will be used in the following chapter, to assess landscape-level changes in naturalness following different afforestation scenarios.
