7 Conclusions

7.1 Summary of key findings

In this thesis, new approaches to calculation and communication of metrics of landscape structure have been defined and implemented. Use of the 'moving-windows' approach has made it possible to calculate metrics values throughout the study areas and to visualise and statistically analyse regional differences. At the same time, it was shown that spatial metrics have the potential to function as indicators of landscape structure and diversity.

Shape metrics, especially the Matheron index, proved usable for quantification of fragmentation, while it was found that patch count metrics should be used with care due to sensitivity to grain size, and that the SqP index appeared to be highly sensitive to extent (window size). Which specific metrics to use for a particular environmental assessment will depend on the issues of monitoring and the management objectives for the landscape, forest or nature area of interest. However, all outputs from the moving-windows approach could be used in geo-referenced image format, and combined with data from other sources (ground based mapping and observations) using standard GIS software.

An example of a possible application was shown with the creation of different afforestation scenarios for the study area in northern Jutland, reflecting different land use strategies. Maps showing the changes in selected metrics values were found to well illustrate the effects of different strategies and point to potential management conflicts, such as decreased forest fragmentation leading to decreased landscape diversity.

The Hemeroby concept was quantified through assignment of 'Nature Degradation Potential' values to land cover classes and a spatial dimension added through the use of 'moving-windows' for creation of Hemeroby (naturalness) maps. These were found to provide a useful overview of land use intensity, with potential for use in landscape level environmental management and planning.

7.2 Limitations to the study

An obvious limitation to the use of spatial metrics (of landscape structure) as indicators is the quality of the input data, i.e. maps or satellite images. Often a higher thematic resolution, than what is normally available from Land Use and Land Cover data, is needed for meaningful comparisons for assessment of forest and nature/habitat diversity. It was however found that binary forest-non-forest maps constitute a sufficient input for analysis of forest fragmentation.

In this study it was not possible to establish relations between metrics values and observed biological diversity, due to lack of ground reference data and biological records. Once such data become available, preferably from observation grids, an approach taken in some ongoing botanical and wildlife inventories, it should be possible to statistically relate species richness and other measures of biological diversity to metrics values from moving-windows calculations.

In the calculation of metrics of landscape structure, information on absolute or relative edge length is utilised. Metrics values are thus affected by boundary and edge effects, in particular at map borders and where different data sources are combined (overlaid/merged). It was also found necessary to distinguish between the internal external and 'background classes', the latter being excluded from calculation of metrics values. This was particularly done in order to eliminate the effects of having large windows include relatively large sea areas, causing edge effects at the coasts as well as apparently lower forest cover with increasing window size. Further development is needed to fully overcome such potential sources of error and provide un-biased and scale-independent metrics values and maps.

7.3 Possible future work

The methods described in this thesis could without difficulty be integrated into a broader land classification system, where for instance cultural and socio-economic factors are included. This is typically required for assessment of agri-environmental issues, potential afforestation or nature protection. In such a land classification system, moving-windows outputs should be used as layers of geo-referenced maps, where different aspects of landscape structure are depicted. This also seems the best way to integrate landscape metrics and Hemeroby (index) values. When maps of metrics values are combined with data from ecological inventories, more advanced statistical approaches, than the ones used here, will be needed, especially if the aim is to relate metrics at different levels of a spatial hierarchy to Alpha, Beta and Gamma diversity (see Figure 2.2) respectively. Combining the calculated metrics values with biological observations will also help define *threshold values* for spatial metrics, to be applied for planning purposes and assessment of alternative scenarios.

Metrics of forest structure can be used to evaluate a country's compliance with international conventions of sustainable forest or landscape management. For this to be applied operationally, image processing must be standardised, with regards to (amongst other things) resolution and quality of input data, classification algorithms used and verification through use of ground control data.

In these studies, raster images of real-world landscapes have been used throughout, based on the assumption that biological diversity and ecological functions are related to landscape structure, as it appears in land use/land cover maps. However, modelling of different species response to changes in forest and landscape structure is possible using spatially explicit meta-population models, preferably in combination with simulated land cover maps derived using neutral models. This will directly provide examples of habitat maps or high-resolution land cover maps, help establish mathematical links between ecological theory and applied landscape ecology, and minimise errors from the sensor-to-map processing chain for research of metrics (scaling) behaviour *per se*. Individual- or population based ecological models and neutral landscape simulated maps also have the potential to evaluate the use of classified imagery from new EO data sources with high spatial and/or spectral resolution.

The temporal scale/dimension is only included here to a lesser extent, through afforestation scenarios. There is however a strong potential to perform comparison with historical maps and data in the form of archived aerial photographs back to (early 20th century) and satellite images (back to 1972). The relation between changing land use practices and development of landscape structure remains a challenging subject, that calls for further studies, which will be carried out for example within the framework of the cultural environment atlas (DACE) project. In this project, a central task is identification of areas with particular spatial structures, reflecting modes of production and land use strategies, in past as well as present landscapes. Thus, topographic maps from the 19th and 20eth century are being digitised and interpreted, with a standardised (land cover) legend, and one of the next steps of the project involves calculation of relevant spatial metrics, possibly supplemented by Hemeroby index values from contemporary land use data. This will allow changes to be quantified and regional differences to the identified.

Some strengths and limitations of spatial metrics have been identified in this study. The knowledge gained can assist in the selection of data and indicator metrics in **monitoring frameworks** such as those outlined in Figure 2.6 and 2.7. Outputs in map format from moving-windows analysis can be combined with vector GIS data and can thus serve as input to (for instance) environmental impact analysis. The examples provided by the interlinked studies carried out for this thesis have proven the separate steps of the landscape analysis proposed in Figure 2.7 to be feasible. The choice of data sources, classification approaches and the suite of spatial metrics to use will however ultimately depend on the objectives of the actual monitoring initiative.

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