THE ROLE OF REMOTE SENSING AND GIS FOR AN OPERATIONAL STATE-WIDE ENVIRONMENTAL MONITORING

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ABSTRACT

Remote sensing image analysis systems and geographic information systems (GIS) show great promise for the integration of a wide variety of spatial information supporting tasks such as urban and regional planning, natural resource management, agricultural studies and topographic or thematic mapping. Current and future remote sensing programs are based on a variety of sensors that will provide timely and repetitive multisensor earth observation on a global scale. GIS offer efficient tools for handling, manipulating, analysing and presenting spatial data that are required for sensible decision making in various areas. To combine the power of both spatial technologies, however, efficient synergistic processing techniques have to be developed to cope with large multisensor image datasets and to automatically extract information for GIS. This paper describes the role of remote sensing and GIS for an operational monitoring. The inspiration for this paper came from the project "Environmental Monitoring – State-wide Comparative Landuse Classification in Lower Saxony Focusing on Moor and Pasture Areas". Goals of this project are a continuos landuse/landcover analysis based on the classification of remotely-sensed imagery and a consequent change analysis of the state of Lower Saxony. Additional methods are being developed to make use of satellite imagery for assessing ecologic conditions of peat, boglands and pasture areas. Working in an integrated GIS/remote sensing environment allows taking advantage of the functionalities of both GIS and remote sensing image analysis techniques.

1. INTRODUCTION

We are modifying our environment at unprecedented rates and scales. We can, however, debate the specific spatial dimensions, rates and significance of these changes. Throughout history, technology has always been a key factor facilitating change. Today's technology can create environmental change at previously unknown spatial and temporal scales. Yet, it also offers us the ability to facilitate our investigations leading to a more complete understanding of human impact on our environment. Through appropriate use of technologies we can move a significant step towards an environmentally sound management of the Earth's natural resources. Planning and development can no longer take these natural resources for granted. We have to consider not only the needs of current generations but also those of future generations.

Significant among these technologies are remote sensing and geographic information systems (GIS). Remote sensing devices on aeroplanes and satellites are capable of recording environmental information at staggering rates with significant economies of scale for many purposes. GIS can integrate these data with other spatial data (e.g. maps) and non-spatial data (e.g. tables or text) to facilitate new forms of analyses. It has to be noted, however, that these technologies are crossing the boundaries of many traditional disciplines, and the development of academic programs in "Remote Sensing and GIS for Environmental Monitoring and Management" poses a challenge to established programs [Ehlers, 1995].

Remote sensing technology and GIS are both tools for managing spatially distributed information in large quantities and at a variety of scales. Both provide a systemic or synthetic view of spatial information. Both increase the capabilities of human decision-makers and planners to grasp relationships at larger scales and in more complex settings than has hitherto been possible. GIS and image processing systems tend to two different forms of representing spatial information, i.e., vector and raster representation. These representations are characterised by different algorithms for spatial analyses, although the end results are, in theory, comparable [Ehlers, 1992].

Section 2 gives an overview about the case study. It shows the main tasks of the environmental monitoring project. A review of imagery used is given in section 3 followed by a description of the ground truthing campaign and the integration of these data (section 4). After describing the geometric pre-processing in section 5, the results of the classification are presented in section 6. This section shows also the advantage of an integrated GIS/remote sensing environment. Section 7 gives a conclusion.

2. THE CASE STUDY

The "Environmental Monitoring - State-wide Comparative Landuse Classification in Lower Saxony Focusing on Moor and Pasture Areas" may serve as a convincing example of the operational use of integrated GIS/remote sensing technologies. This project is supported by Lower Saxony's Department of Environment and the German Space Agency (DARA) and started in July 1994. The overall goal of the project is to assess the capabilities of satellite remote sensing for the analysis of landuse changes, especially in moor and pasture areas. These areas are recognised as areas crucial to the mission of the Department of Environment and therefore to be placed under an extended level of protection. It is of critical importance, however, to have accurate and current information about the ecological and economic state of these sensitive areas.

The Environmental Monitoring Project which is conducted jointly by the GIS and Remote Sensing Section of the Institute for Spatial Analysis and Planning in Areas of Intensive Agriculture (ISPA) and the Lower Saxony's Department of Environment, consist of the following tasks:

- New landuse classification for the area of Lower Saxony by means of Landsat-TM data;
- Change detection with respect to 1990/91 classification;
- Differentiated analysis for moor and pasture areas;
  - differentiated ecological analysis;
  - economic cost benefit analysis;
- Analysis of data fusion techniques;
- Development of an operational monitoring concept with multitemporal satellite data.

In selected pasture and moor areas, methods for multisensor data fusion have being developed and tested. The results of this testing show which techniques are useful for pasture and moor monitoring at an operational level.

Analyses are carried out in an integrated GIS/Remote Sensing environment which facilitates combined processing of ground truth measurement, scanned aerial photography and multisensoral imagery from SPOT, Landsat-TM and ERS-1 satellites. Results of this approach will be presented and discussed in the following sections.

3. DATABASES

The a state-wide monitoring of Lower Saxony requires of 4 -¼ Landsat-TM-Scenes. This imagery could be acquired for a time frame of only two month in 1994. A state-wide Landsat-TM classification for the period of 1990/91 alredy exists. Data fusion is accomplished by Spot-Pan and Spot-XS imagery. For special test sites, scanned aerial colour infrared images were available. These aerial photos are used to support the definition of test areas and to check the accuracy of the classification. Topographic maps at a scale of 1:5000 were used as the geometric basis for mapping test areas and to rectify the aerial photos. The geologically defined boglands were retrieved automatically from our images by masking them out with digitised thematic maps (scale 1:25000). These maps depict bogland as defined by geologic standards (peat layers >30 cm).

Digital data from the German Authorative Topographic Cartographic Information System (ATKIS) are used for the visualisation of root-mean-square error in the rectification process. The use of ATKIS as a masking layer for individual classes proved to be a failure though, because, for example, farmland and pasture areas must have a minimum size of one hectare to be included into the ATKIS database. In addition, ERS-1 data were used to test their applicability for data fusion in monitoring boglands; the results, however, were not satisfactory. Table 1 is a summary of the data sources used. Figure 1 shows an overview about the Landsat-Scenes.

Database	Electromagnetic Spectrum / Map System	Resolution / Scale
SPOT	panchromatic	10m
Landsat TM	VIS/NIR/TIR*	30m (120m TIR)
ERS-1	Radar	12,5 - 30m
digitised aerial photos	colour infrared	2m
ATKIS	topographic	1:25000
DGK 5 (German base map)	topographic	1:5000
thematic maps	Geologic (bogland)	1.25000

* VIS = visible spectrum; NIR = near infrared; TIR = thermal infrared

Table 1: GIS-Database: Remote Sensing Images and Maps

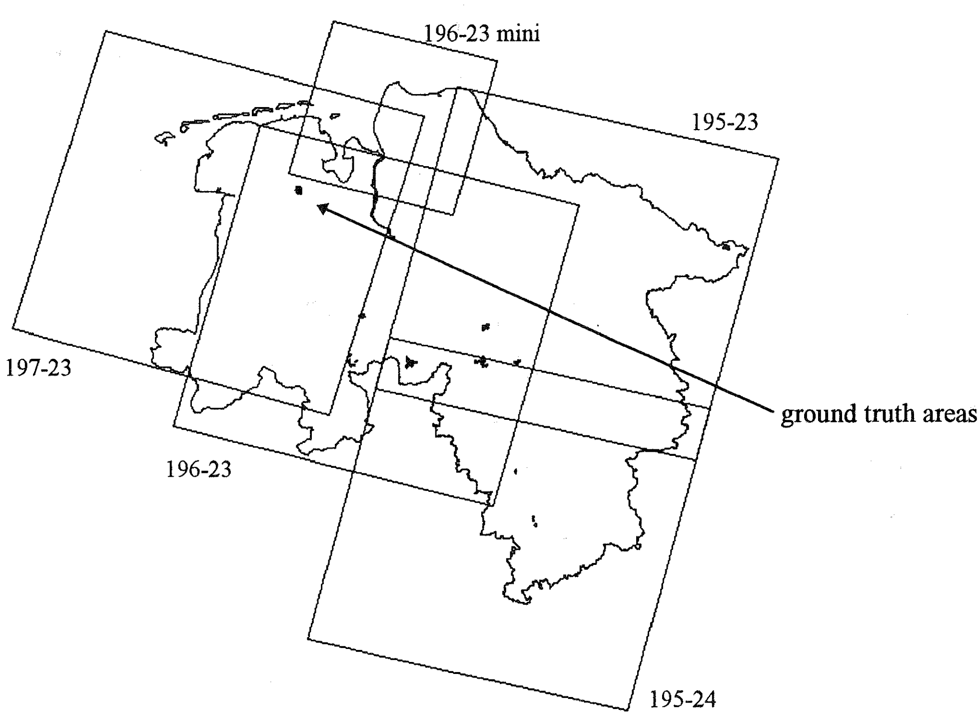

Figure 1 : Overview about the Landsat-Scene Cover

4. GROUND TRUTHING

To yield acceptable classification results, training data is needed. This means that the image analyst must develop training statistics for all spectral classes constituting each information class to be discriminated by the classifier. A supervised classification requires a thorough knowledge of the geographic area. Most importantly, the quality of the training process determines the success of the classification stage and, therefore, the value of the information generated from the entire classification effort. The overall objective of the training process is to assemble a set of statistics that describe the spectral response pattern for each land cover type to be classified in an image [Lillesand/Kiefer 1987].

An adjusted mapping key for ground truth measurements was generated together with the Agency for Ecology of Lower Saxony. This mapping key is adapted to the special mapping key for biotopes in Lower Saxony with respect to § 28a NNatG (Lower Saxonys Environmental Protection Statutes) [Drachenfels, 1992]. For selected queries and overlay analysis, these mapped test areas were transformed to separate GIS layer in ArcInfo® format. This procedure was facilitated by an adapted graphical user interface written in ArcInfo's macro language AML (Figure 2) [Schelling, 1995].

5. GEOMETRIC PRE-PROCESSING

To use remotely-sensed imagery and their classification results in geographic information systems, these image data have to be transformed to an uniform reference system. Using the polynomial correction techniques, an image can be registered to a map coordinate system allowing its pixels to be addressed in terms of map coordinates rather than pixel and line numbers [Richards, 1994]. Many applications of remote sensing image data require more than one scene of the same geographical area, acquired at different dates, to be processed together. Such a situation arises when, as in our monitoring project, changes are of interest, in which case registered images allow a pixel by pixel comparison to be made. There are two ways to register two images to each other. You can register two images to each other by registering each to a map coordinate base separately, or alternatively, one image can be chosen as a master image to which the other, known as the slave, is to be registered. We chose the second method for our study. In our case the master image was the Landsat-TM imagery database from 1990/91 covering the complete area of Lower Saxony. This imagery was georeferenced using 1st order polynomial procedures with a nearest neighbour resampling technique to a German topographic map with a Transverse Mercator projection based on a Bessel ellipsoid. As a result, the maximum residual error is 1.5 Pixel (45 meters). The scrutiny of residual errors was made on the one side by overlaying geometrically correct ATKIS-datasets and on the other side by measuring the same unequivocal radiometric pixels in both imagery (master to

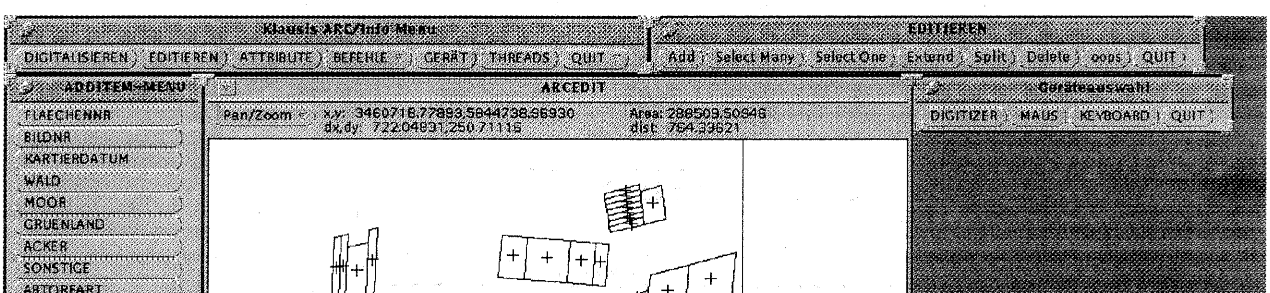

Figure 2: ArcInfo Menu for Information Input

slave). The colour infrared aerial photos have been geometrical corrected by registering them to the German base map (scale 1: 5000). By stitching the results together, the single scenes and images could be combined to a mosaic.

6. CLASSIFICATION AND RESULTS

Classification is the process of sorting pixels into a finite number of classes, or categories of data, based on their values. If a pixel satisfies a certain set of criteria, then the pixel is assigned to the class that corresponds to that criteria. The result is a (GIS) file whose values represent known thematic categories such as landcover or vegetation types. For the first part of the classification process, the computer system must be trained (supervised classification) to recognise patterns in the data. Training is the process of defining the criteria by which patterns are recognised. The result of the training process is a set of signatures (area of interest, abbreviated as AOI), which are statistical criteria for a set of proposed classes.

We used the maximum likelihood algorithm as the method for a supervised classification process. Figure 4 gives an overview of an ideal integrated GIS and remote sensing environment. It shows how various data sets can be integrated as layers in a GIS to start monitoring analyses over time.

A hierarchical method is used for extracting bogland classes with respect to the environmental protection goals. A highly accurate classification of the following classes was accomplished: deciduous- and mixed forest, coniferous forest, water, very wet areas, meadowland/farmland with vegetation, meadowland/farmland with partly vegetation, meadowland/ farmland without vegetation, peat quarrying with maximum of 50% vegetation, de- and regeneration stages. Statistical accuracy analysis shows an accuracy value of over 90% for the classification (accuracy assessment method with independent random points). An extended approach for fine tuning of 15 bogland classes gave an accuracy of about 79%. This approach assigned single bogland areas with good results. For a state-wide approach the first method is preferable with respect to the accuracy. An overview of the hierarchical method is shown in figure 3.

From the ground truth campaign and the classification results, the following lessons for an operational monitoring concept could be learned:

- Time variability differs for different areas (e.g., between forest and meadowland); therefore, different strategies have to be developed for each class;
- For a prolonged period monitoring concept, it makes sense to generate individual mask layers (for example with farmland, meadowland, forest, urban areas, peatland, de-/ regeneration stages, and water);
- These mask layers could be generated from a classification or vector data-sets with different data sources;
- A meadowland class could be generated or extracted by using the Normalised Difference Vegetation Index (NDVI) in several April scenes. Those areas which always show a high NDVI should indicate meadowland, whereas, due to crop rotation, arable land will be vegetated only in a limited number of years [Reinke, 1995].

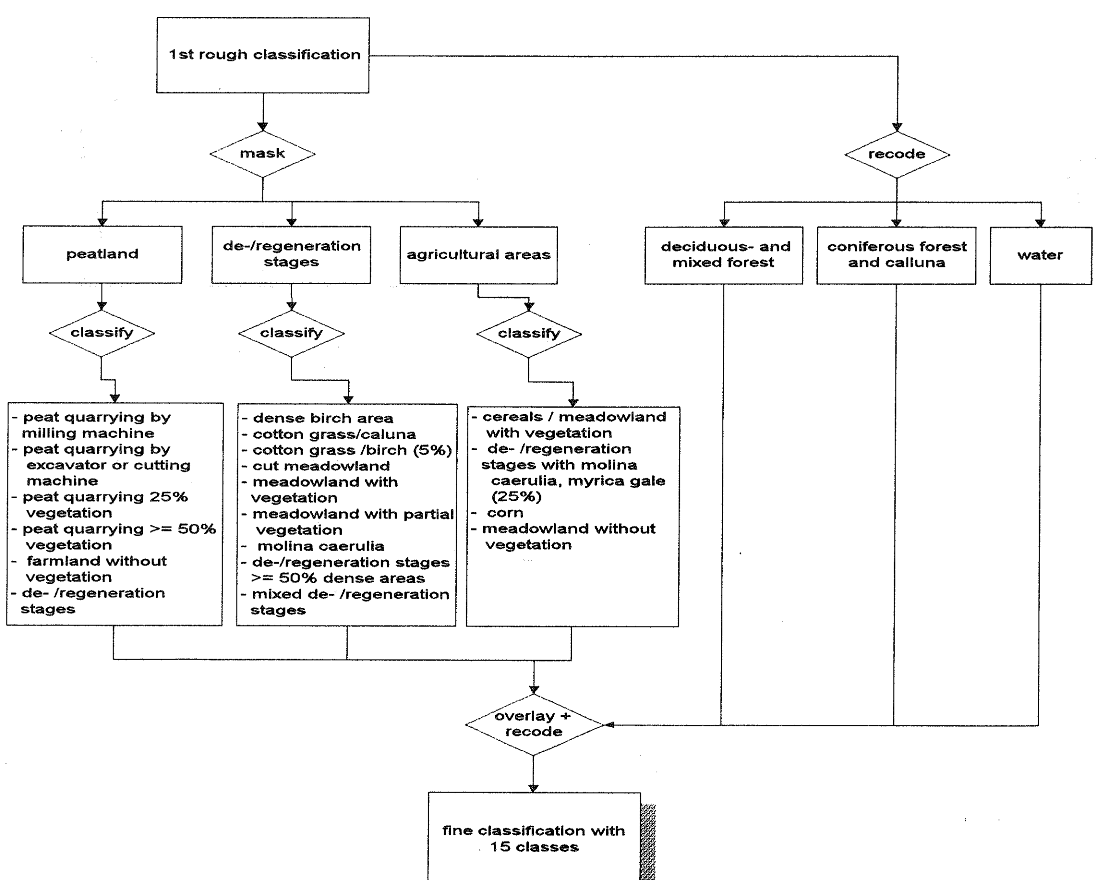

Figure 3: Hierarchical Classification Method

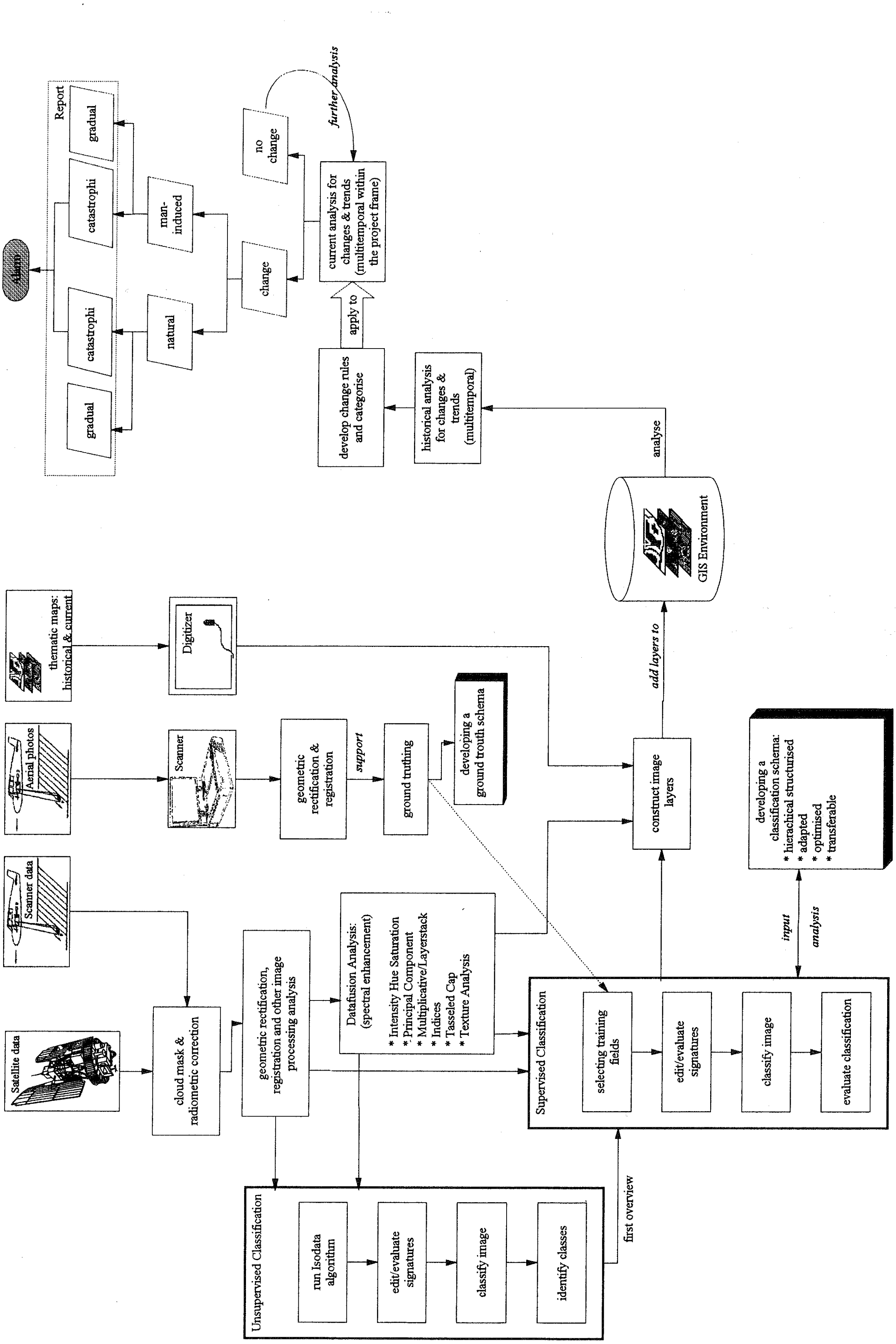

Figure 4: overview of an ideal integrated GIS and remote sensing environment

Comment	Low Variability	Moderate Variability	High Variability
example	forest/urban areas/water	de- and regeneration stages	farmland, meadowland, peatland
strategies	determination of a high number of reference areas	these areas are in most cases gradual stages (e.g. dense areas)	for every new classification new training- and test areas have to be mapped
	digitising and assigning of attributes (as a vector layer or area of interest)	determination of a high number of reference areas	
	1st vector layer (AOI) can be used for subsequent classification	only those areas have to be assessed	
	no new determination of training areas are necessary	new training sets have to be found if areas have changed due to gradual succession	
mapping time	it is not necessary to map these classes on the day of data acquisition	the mapping should be close to the day of data acquisition	the mapping should be on the day of data acquisition

Table 2: Time Variability of Areas and Strategies

Analyses for the transferability of signatures from one test area to another bogland within the same scene shows good results. These results have been inspected by a visual comparison with actual biotope mappings. The transferability of signatures from one scene to an other has been tested in the overlapping area of scenes 196-23, 195-23 and 195-24. It shows that only signatures with a low time variability (e.g. urban areas, airport) are transferable. The other signatures should not transferred because of different sunangles, haze and radiometric differences.

Results from multisensor analyses with different data fusion techniques, e.g., principle component and IHS-transformations, show no significant improvement in the differentiation of signatures (classes). Classification results from a combination of Landsat-TM imagery and SPOT-Pan or ERS-1 data indicate that there is no improvement compared to a classification using Landsat-TM imagery only. A presentation of the signatures in ellipsoid form in the important feature spaces (scatter diagram) confirms these results. It shows strong overlapping areas, that indicate a poor differentiation of some classes and a visual inspection shows the same negative results for those classes.

7. CONCLUSION

As final steps, all produced information and GIS layers will be included into the environmental information system of the Department of Environment, Lower Saxony (GEOSUM). This information will be provided to the various State Natural Protection Agencies. This project will support the meadowland and peatland protection programme.

REFERENCES

Drachenfels, O. v. (Bearb.), 1992. Kartierschlüssel für Biotoptypen in Niedersachsen unter besonderer Berücksichtigung der nach § 28a NNatG geschützten Biotope, Stand 1992. Naturschutz Lanschaftspflege Niedersachsen, Heft A4, Hrsg.: Niedersächsisches Landesamt für Ökologie - Naturschutz - Hannover.

Ehlers, M., 1992. Data Types and Data Structures for Integrated Geographic Information Systems. In: Star, J.L. (Ed.) The Integration of Remote Sensing and Geographic Information Systems, American Society for Photogrammetry and Remote Sensing, Bethesda, MD, pp. 51-73.

Ehlers, M., 1995. The Promise of Remote Sensing for Land Cover Monitoring and Modeling, Joint European Conference and Exhibition on Geographical Information, The Hague, The Netherlands, Vol. 2, pp. 426-432.

Ehlers, M. and U. Rhein, 1995. Environmental Monitoring - Statewide Comparative Landuse Classification in Lower Saxony Focusing on Moor and Pasture Areas. In: Proceedings, 9th International Symposium on Computer Science for Environmental Protection CSEP'95, Berlin, Vol. I, pp. 209-218.

Reinke, L., 1995. GIS-gestützte Analyse von Fernerkundungsdaten zur Bestimmung des Grünlandanteils im Bereich des Dümmers. (unveröffentlichte Magisterarbeit, Hochschule Vechta).

Richards, J. A., 1994. Remote Sensing Digital Image Analysis. Springer Verlag. Berlin.

Schelling, K., 1995. GIS-gestützte Auswertung von Fernerkundungsdaten zur Bestimmung von Moorzustand und -nutzung am Beispiel Goldenstedter Moor (unveröffentlichte Magisterarbeit, Hochschule Vechta).