A KNOWLEDGE-BASED APPROACH TO VEGETATION MONITORING WITH QUICKBIRD IMAGERY

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ABSTRACT:

Nature conservation authorities have to face the growing demand for environmental monitoring, especially in the context of *Natura 2000*. Immense amounts of data will have to be gathered to fulfill the EU-guidelines. The recent improvement in geometric resolution has brought satellite imagery into focus. In the presented study the main objective is to investigate the potential of very high resolution satellite data to support monitoring tasks following the Flora-Fauna-Habitat (FFH)-Guideline. Automated and visual image analysis methods for the derivation of parameters for the evaluation of habitat types are developed and tested in several study areas in the region of Brandenburg/Germany and in Poland. As Quickbird is the satellite with the highest resolution available at the moment and its spectral characteristics are suitable for environmental applications, our investigation is focused primarily on this satellite. The high geometric resolution requires advanced methods for classification. Thus, a hierarchical knowledge based approach is used. Since no generalization should occur, the classification process is pixel based. A new method for the automated extraction of signatures is developed. The first results show the capacity of Quickbird imagery to support monitoring and to derive indicators. Advantages and remaining problems are discussed.

1. INTRODUCTION

The new generation of very high resolution (VHR) satellites offers new possibilities for the monitoring of nature conservation areas and biotopes or habitats. Especially the detailed geometric resolution of up to 0.61 m and the digital multispectral nature of the data are important features for the development of time- and cost-effective monitoring procedures. Recent studies show the potentials of VHR imagery in conjunction with additional data for the detection of invasive plants (Tsai et al., 2004) and for habitat monitoring (Aplin, 2004). Still many difficulties have to be overcome. The high spatial resolution requires new methods of image processing and analysis. Investigation has focused for quite some time on automated classification methods. These studies used object oriented approaches as well as common pixel based image analysis techniques. For VHR imagery the object oriented methods seem to lead to more satisfying results, though the transferability of segmentation and classification rules is still a problem (Leser, 2002). Also a generalization of image objects occurs (Koch et al., 2003), which is desirable for many applications but not for the detailed derivation of quantitative parameters. The use of knowledge bases and additional data has proved to increase accuracy and number of separable classes (Pakzad, 2001; Hoffmann et al., 2000). Textural measures can be very helpful for the classification of urban areas (Steinnocher, 1997) as well as for forest parameters (Wezyk, 2004). Still visual image analysis is unrivalled for complex applications and the integration of both visual and automated methods has been applied successfully to environmental monitoring issues (Kenneweg et al., 2000). The importance of remote sensing for nature conservation is steadily increasing, especially with the new generation of VHR satellites, though nevertheless investigation has to focus on the development of application-oriented methods (Kenneweg, 2001; Ehlers, 2002).

The main objective of the presented study (SARA'04: satellite-based regional monitoring for environmental applications) is the development of both automated and visual methods to gain information from VHR satellite imagery for the monitoring of biotopes and habitats** on the large scale. A special focus lies on the evaluation of *Natura 2000* habitat types. For environmental monitoring a given object of interest has to be surveyed repeatedly with comparable standardized methods. The best way to evaluate change is to use valid quantitative or qualitative indicators and to compare them with thresholds or quality standards (Plachter, 1991). Hence the general approach of this study is indication based, whereas the indicators are mainly composed of vegetation or land-cover classes. All algorithms are developed and tested on several study areas in Brandenburg/Germany and Poland.

2. METHODS

Since the methods have to be transferable and repeatable to fulfill the requirements of monitoring issues (especially within the context of *Natura 2000*), they should be independent from image and data characteristics. Thus procedures depending on radiometrically standardized imagery and on absolute spectral reflectance values would not be feasible. Instead a more pragmatic approach of using relative values is preferred within

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** The terms 'biotope' and 'habitat' can be seen as synonyms, 'habitat' is used in context with the FFH-Guideline.

this study. As the transferability of those procedures is essential, the classification system is built upon a knowledge base and the overall classification scheme follows a hierarchical design. Pixel based methods are preferred to keep the very detailed information and to allow for the derivation of quantitative indicators.

2.1 Study areas and data

Six different study areas were chosen to investigate a large variety of biotope and habitat types and to evaluate the transferability of the knowledge based classification system (Table 1). Jüterbog, Lieberose, Potsdam, Schwedt and Falkensee are situated in the region of Brandenburg. The study area Warthe is located close to the German border in Poland. The study areas differ very much in structure and characteristic. Jüterbog and Lieberose are former military training areas with widespread open and dry biotopes as well as large forest areas. Potsdam and Falkensee are urban areas with a rich pattern of settlement, wood, agriculture, rivers and lakes. The Warthe estuary in Poland represents a large wetland area predominated by low-impact agriculture, while Schwedt is a wetland area characterized by intensive agriculture.
As Quickbird is the satellite with the highest geometric resolution available at the moment and its spectral characteristics are suitable for environmental applications, our investigation is focused primarily on this satellite. Quickbird has a geometric resolution ranging from 0.61 to 0.70 m in the panchromatic channel and 2.44 to 2.88 in the multispectral channels (depending on the view angle) and a radiometric resolution of 11 Bit. The delivered images for the study areas have a fair (Lieberose) to excellent quality (all others) and were delivered as sensor corrected standard product.

Study area	Area km²	Acquis. date	Cloud cover	View angle	Main charact.
Jüterbog	82	04.08.03	0%	14.6°	military training area
Lieberose	163	06.09.04	0%	20.5°	military training area
Potsdam	200	29.07.04	1%	5.6°	urban
Falkensee	94	29.07.04	1%	5.6°	urban
Schwedt	240	14.09.03	0%	8.9	wetland
Warthe	75	03.09.04	0%	12°	wetland

Table 1. Study areas and imagery

Furthermore topographic data, biotope types and land-use maps from CIR-interpretation and habitat type maps from terrestrial survey are used (Table 2).

Data source	Date	Application
Topographic data (ATKIS)	2004	Georeferencing
Area-wide biotope type/land-use data	1992/1993	Knowledge base
Biotope type/land-use data (Potsdam, Jüterbog)	1998	Knowledge base
Terrestrial survey	2003/2004	Accuracy assessment
CIR-airphotos	1998	Accuracy assessment

Table 2. Additional data sources

This information is integrated into the knowledge base or is respectively used for accuracy assessment. For Potsdam and Jüterbog a full set of stereoscopic CIR-airphotos is available and serves for the accuracy assessment.

2.2 Image analysis

The complex nature of imagery with a very high geometric resolution requires a hierarchical classification approach. After the image pre-processing (conversion to spectral radiance, georeferencing, resolution merge) first of all the satellite data need to be structured into semantic meaningful masks following a top-down process. This is done by using ratios and textural measures as well as additional data (biotope type maps) within a knowledge base, thus the valuable pixel based information will be kept throughout the whole action.

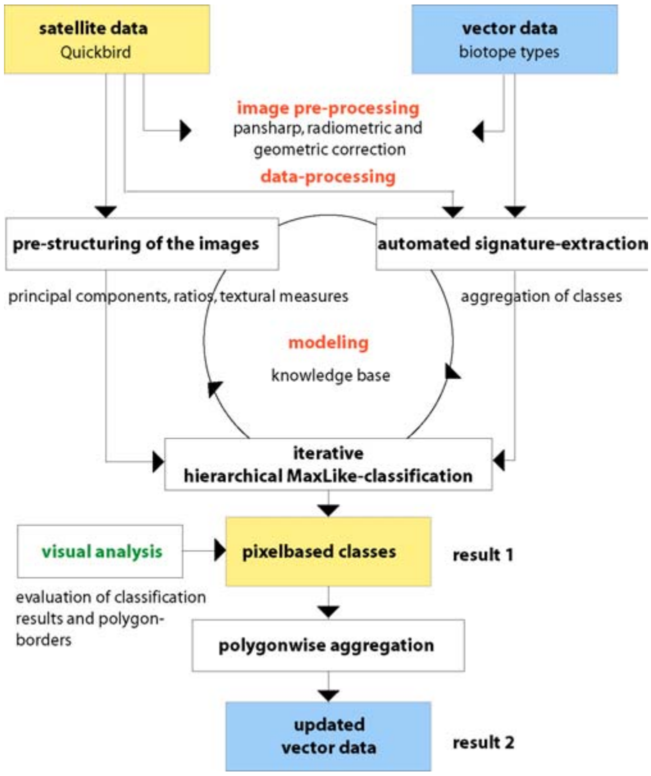


Figure 1. Processing scheme for the derivation of indicators, biotope types and land-use classes (Result 1 represents the pixelbased land-cover classes; Result 2 represents the biotope types and land-use classes after aggregation)

2.2.1 Knowledge based signature extraction

Supervised classification methods like the maximum likelihood algorithm require well defined training areas and pure signatures to lead to satisfying results. The very high spatial resolution of Quickbird imagery makes a manual delineation of spectrally pure areas almost impossible. Also the use of a large number of training pixels would be a big advantage for the classifier but cannot be supplied efficiently by manual digitizing. Thus the most part of the image should be employed as training information and automated ways must be found to provide them. In this study a knowledge based approach is followed. The basic biotope type and land-use data are used as an input for the knowledge base. Since biotope types and land-use classes can comprise a lot of different land-cover classes

and due to the high geometric resolution, these land-cover classes can comprise many different signatures, a way must be found that helps to determine appropriate signatures for all land-cover classes and to exclude changed areas with universal rules. Additional parameters like textural measures, different ratios and vegetation indices are calculated from the image and after a detailed signature analysis for all investigated land-cover classes general rules are established (realized with Erdas Imagine Expert Classifier).
These rules are set within the knowledge base as is exemplarily shown in Figure 2 to define the necessary training pixels.

	input data	rule/procedure
Hierarchical level 1		
shadow mask	PAN image	local minimum/filter
Hierarchical level 2		
	PAN image	high texture/Isodata cluster
tree mask	shadow mask	northwestern shadow/filter
	PS image	high NDVI/Isodata cluster
	biotoptype map	forest or no forest/query
Hierarchical level 3	PAN image	local minimum/filter
	shadow mask	no tree shadow/filter
moss	tree mask	no tree/query
	biotoptype map	open and dry/query
dry grassland > 10% on sand *e.g. Corynephorus*	shadow mask	no shadow/filter
	tree mask	no tree/query
	biotoptype map	open and dry/query
	PS image	ratio3/1 > 0.8/query
		NDVI < 0/query

Figure 2. Abbreviated example for the hierarchical levels used for the automated signature extraction and classification.

If, for instance, a rule is set for the correction of forest and non-forest polygons (within the forest polygons small gaps can occur, or trees can occur within the non-forest polygons) the hypothesis ‘trees’ can only be true if there is high texture and a high NDVI. The attribute ‘high’ is not filled with real numbers beforehand, only during the signature extraction process the texture-image and the NDVI-image are clustered with the Isodata algorithm into three clusters: high, medium and low values.

In Figure 3 the generation of training areas for dry open biotope types is shown. At this stage the single trees and woods are already masked out one step before, now signatures must be found for the land-cover classes occurring in dry open biotopes. The biotope type “heath” does not only comprise the class “heath” itself, but can include also “dry grassland” and “moss” covered spots with different densities and “open sand”. To delineate e.g. “moss” from “heath” a rule is set in the knowledge base that looks for extreme local minima – if a minimum is not nearby a tree and therewith a shadow it has to be “moss”.

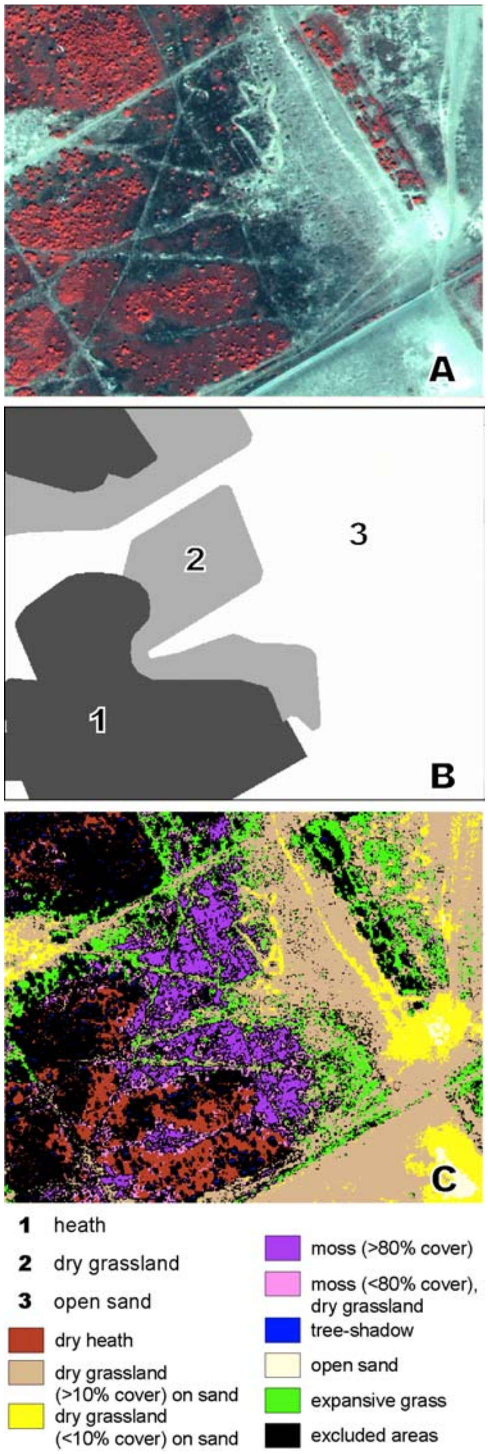


Figure 3. Example for the automated generation of signatures from old biotope type data through a knowledge base (A: Quickbird subset, pansharpened, RGB=4,3,2; B: biotope type map from 1992; C: generated training areas for signature extraction)

The automated extraction of training pixels leads to very pure signatures and because of the high number of training pixels a gaussian shape is approximated for most of the classes. In Figure 4 the difference between signatures extracted from manually digitized training areas and derived with the automated method is shown.

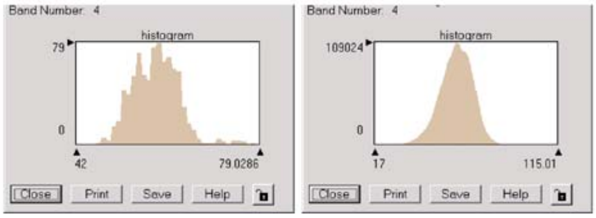


Figure 4. Signatures for the class 'dry grassland (>10% cover) on sand' extracted from manually digitized training areas (left) and from automated method (right).

2.2.2 Classification

With the signatures extracted according to the hierarchical level the single masks are classified either with the Maximum Likelihood or the Isodata algorithm. In Figure 5 the classification results for dry open biotope types are shown.

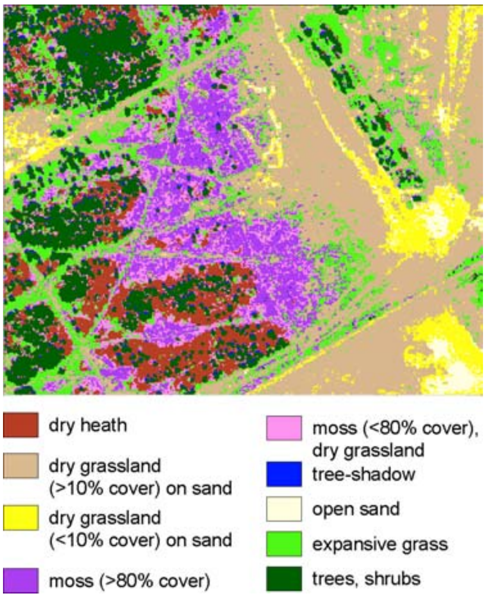


Figure 5. Example for the supervised classification with automatically extracted signatures (Maximum Likelihood). Trees and shrubs are added from classification level 2.

The knowledge base is also filled with neighborhood rules for the differentiation of spectral similar classes (e.g. for dark water and asphalt), which are separated in a post-classification step.

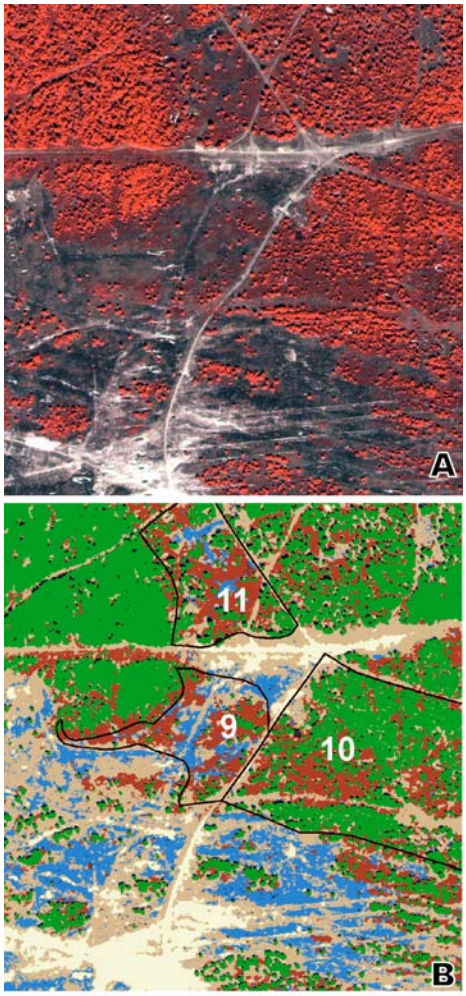
2.2.3 Visual image analysis

A drawback of the automated signature extraction is that certain classes not presented in the "old" maps cannot be detected. E.g. if there was no forest area with oak present in the "old" maps, no signatures would be extracted for the class oak. If there occurs now a new habitat with oaks, it would be rightly classified as broad-leaf forest but the tree species would be classified wrongly. Also extraordinary circumstances cannot be integrated into rules, because it would push the knowledge base and the processing time to infinity. If, for instance, a wetland area around a lake is flooded due to the temporarily risen water level, there will be no signatures extracted for the subdued and degenerating plants because no adequate rule exists.

Those drawbacks can be overcome by the integration of visual image analysis. Polygon-borders and therewith the area size of habitats are evaluated visually as well as the classification results. Hence obvious classification errors and abnormalities can be detected. The produced pixel based indicators can now be used for the evaluation of habitat types, because they can be linked to the individual reference habitats. The calculation of percentages is easily realized with standard GIS-operations (see Figure 6). The pixel based classes can then be grouped to biotope types or land-use classes according to general aggregation rules.

3. RESULTS

The described classification methods can be used for the evaluation of biotopes or habitats (Figure 6). According to the given quality standard or threshold the derived land-cover classes can be grouped to indicators.



	Nr. 9	Nr. 10	Nr. 11
wood	9.5%	48.8%	26.6%
dry heath	41.3%	27.0%	36.2%
moss	19.8%	0.7%	7.7%
open sand	1.0%	1.1%	0.3%
grass	26.2%	18.5%	23.2%
shadow	2.2%	3.9%	6.0%
area in m²	24 471.9	103 821.3	27 859.0

Figure 6. Classification results for the habitat type 'European dry heath' (4030) in Jüterbog. The area borders are taken from the first terrestrial inventory (A: Quickbird subset, pansharpened, RGB=4,3,2; B: classification result overlaid with habitat borders).

For the evaluation of the *Natura 2000* habitat type 'European dry heath' (as well as for 'inland dunes' and 'xeric sand calcareous grassland') the land-cover classes shown in Figure 5 are grouped to the following indicators: wood cover (all trees and shrubs), open sand (open sand, dry grassland on sand), moss (moss, moss mixed with dry grassland), grass (expansive grass) and heath (heath). Figure 6 shows the classification and aggregation results for three reference habitats on the study area Jüterbog.

The transferability of the classification procedure and the knowledge base was tested for the same habitat types on the study area Lieberose. The imagery has quite different characteristics than for Jüterbog, the viewing angle is larger and the resulting quality is only fair. The acquisition was made in September whereas Jüterbog was captured in August. The classification results (Figure 7) show the main ecological problem in Lieberose, the heath is repressed by the spreading grass covered areas.

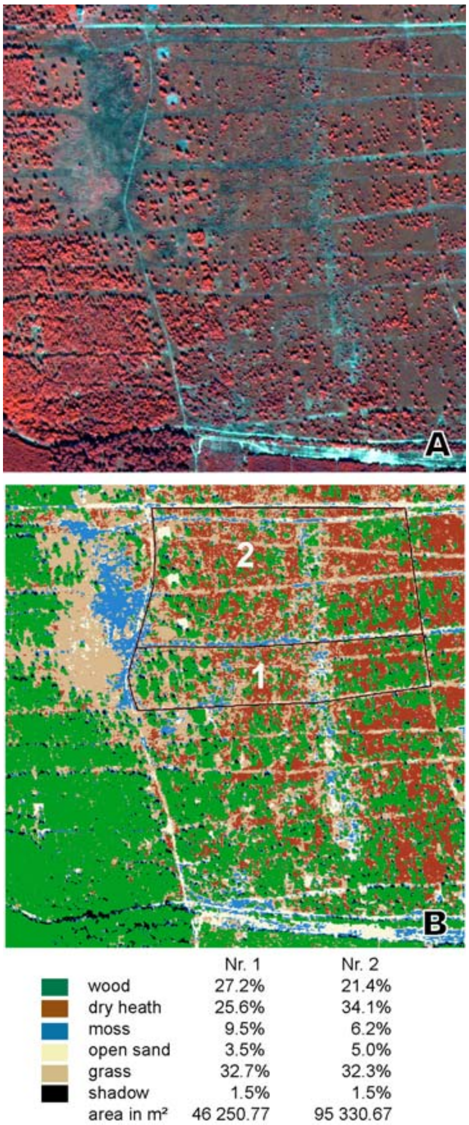


Figure 7. Classification results for the habitat type 'European dry heath' (4030) in Lieberose. The area borders are taken from the first terrestrial inventory (A: Quickbird subset, pansharpened, RGB=4,3,2; B: classification result overlaid with habitat borders).

The knowledge base proved to be transferable without manual adjustment. The accuracy assessment was realized with a random sample of 20 points for each class pro study area and a visual comparison with the pansharpened satellite images.

Class	Jüterbog Producers Accuracy	Jüterbog Users Accuracy	Lieberose Producers Accuracy	Lieberose Users Accuracy
dry heath	94.74%	90.00%	95.24%	100.00%
open sand	100.00%	90.00%	100.00%	90.00%
moss	95.00%	95.00%	89.47%	85.00%
grass	95.24%	100.00%	100.00%	95.00%
wood	100.00%	95.00%	100.00%	95.00%

Table 3. Accuracy assessment for the habitat type 'European dry heath' with 20 random samples per class and study area (visual comparison)

4. CONCLUSIONS

The potential of VHR satellite data for vegetation monitoring and especially for the evaluation of *Natura 2000* habitat types is high for the first investigated habitat types. Pixel based methods have delivered very good results and can be used to derive quantitative indicators. The knowledge base and the automated signature extraction procedure proved to be transferable without manual adjustment for the investigated dry habitat types and allow for a very quick automated processing of large areas. The derived indicator maps are a valuable support for the evaluation and if combined with terrestrial investigation on selected areas an effective monitoring procedure could be realized.

A remaining issue to discuss is the transferability of the method on imagery captured at the beginning of the vegetation period, because within the study only pictures from July, August and September were examined so far. It is to be expected that the knowledge base rules have to be adapted to spring conditions. Furthermore transferability of the method to be applied with airborne digital data sets (with similar spectral characteristics) can be expected but has to be tested by operational application experiments.

During the project SARA'04 (duration 10/2003 – 07/2005) more habitat types occurring in Brandenburg will be observed. Transferability of the knowledge base rules will be further tested in the six study areas. The use of additional data like digital terrain models and soil maps will be investigated. Furthermore the implementation of control functions is planned, so that classification results can be evaluated with automated methods. Rules for the assignment of shadow pixels to neighboring classes will be included in the knowledge base. Interesting objective for future investigation could be the use of change detection methods and stereo information.

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