

Automated Boundary Delineation and Spatial Change Assessment of Alpine Habitats (Berchtesgaden National Park, Germany)

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Abstract

The 16 km² sized study site Klausbachtal is situated in the Berchtesgaden National Park (NPB), which lies in the Alpine region of South Eastern Germany. The test site represents a mountainous area, characterized by a high bio- and habitat diversity and a cliffy relief. NPB participates in the European research project HABITALP (Alpine Habitat Diversity). One aim of this project is to monitor habitat diversity and environmental changes. Since 1980 habitat delineation in NPB was accomplished in an intuitive way by experienced interpreters using color infrared (CIR) aerial photographs. Due to vegetation and environmental changes caused by climate warming, and driven by ongoing loss of biodiversity as well as for reasons of time and economy, there is an increasing demand for updated image data in a high time rate and automated image analysis. In the described study we used pan-sharpened data from a QuickBird scene as segmentation basis. First, this paper presents an iterative, one-level representation (OLR) segmentation strategy and its potential for automated habitat delineation using very high spatial resolution (VHSR) optical QuickBird-satellite data. Second the virtual-overlay method is described for assessing either 'real' spatial object changes or differences in habitat delineation approaches between corresponding habitat geometries of the years 2003 and 2005.

KEY WORDS: Habitat extraction, iterative one-level representation, very high resolution satellite imagery, HABITALP-project, change assessment, virtual-overlay-approach, Klausbachtal, Berchtesgaden National Park

1. Introduction

The Berchtesgaden National Park, one out of eleven protected areas within the Alps, participates in the Interreg IIIb project HABITALP (Alpine Habitat Diversity). One aim of this project is to monitor habitats and long-term environmental changes on the basis of color-infrared (CIR) aerial photographs. Since 1980 in an interval of five years manual delineations of habitats have been accomplished by experienced interpreters on CIR-aerial photographs. CIR-aerial photographs are widely used for a variety of natural resource mapping, since the combination of green, red and near infrared spectral information has proven to be valuable for extracting vegetation. In the HABITALP project, based on previous experiences with CIR photos, a standardized habitat interpretation key (HIK) has been developed for land use types in protected alpine areas. The HIK-key is designed to be transferred to other high mountain landscapes outside the Alps in the future (HABITALP, 2003).

For reasons of time and economy, and in this context more specifically to meet the reporting obligations on the conservation status of habitats within the framework of Natura-2000, there is an increasing demand on frequently updated image data (Lang and Langanke, 2006). Satellite systems of the new generation with very high spatial resolution (~ 1m) strongly support this aim. Data originating from the QuickBird (QB) satellite system (launched 2001) which has a high repetition rate of three to seven days, depending on the latitude (DigitalGlobe, 2006). The QB-panchromatic sensor has a very high spatial resolution of approximately 0.61 m, whereas the four multispectral bands have a resolution of approximately 2.4 m. Both QB-sensors have a high radiometric resolution of 11 bit. Applying a resolution-merge process the spatial resolution of QB-imagery is close to the spatial resolution of some aerial-based sensors. Therefore, for particular tasks, satellite-based data are more and more qualified as an alternative to aerial-based data (Lang and Langanke, 2006).

Numerous image analysis systems for specific tasks have been developed in the past years, many of which include a segmentation- and a following classification process. The segmentation process is an important step for image analysis and after Gorte (1998): by forming the conceptual link to human perception, it is essential for image understanding (Lang and Langanke, 2006). Image segmentation subdivides an image into spatially correlated and spectral homogeneous regions with the aim of a high correlation of neighboring pixels and the reduction and aggregation of data without losing too much inherent information. Furthermore segmentation can be used to provide a consistent set of image primitives as landscape objects (Lang et al., in press; Burnett and Blaschke, 2003). A range

of segmentation strategies exists, among them pixel-, edge- and region-based segmentation approaches. In the domain of remote sensing and landscape analysis region-based and knowledge-based approaches are established. Image objects which result of region-based segmentation techniques have in comparison to single pixels, the advantage of being appraisable as meaningful or not. These approaches are based on aggregated spectral information, bearing a specific shape (Blaschke and Strobl, 2001); likewise topological characteristics of object arrangements are known (Preiner et al., 2006). Furthermore, approaches like this try to imitate the human perception capacity by hierarchical scalable segmentation and segment identification through semantic knowledge. The software eCognition 4.0 (Definiens, Munich) follows this approach and extracts hierarchical levels by multi-resolution region-based segmentation resulting in image objects of different scales (Baatz and Schäpe, 2000). In this study habitat geometries of two different time slots were compared, one produced by a human interpreter and the other by a digital image analysis system. These two geometries have non-congruent object outlines even when working in the same scale domain. An experienced interpreter of remote sensing imagery extracts image objects according to scale in a generalized manner. In comparison the software eCognition works on specific spectral and form parameter, but not generalized (Lang et al., in press).

2. Geographical setting

The study site comprises an area of about 16 km² in the Klausbachtal, situated in the south-western part of Berchtesgaden National Park (NPB), which lies in the Alpine region of South Eastern Germany (47°36'N, 13°00'E). The test site represents a mountainous area, characterized by high bio- and habitat diversity and a steep and rough terrain. The highest point is located on the western mountain flank of the Hochkalter massif with an elevation of 2460 m a.s.l.; the north-easternmost point of the Klausbach-river represents the lowest elevation of about 825 m a.s.l. The entire NPB has been mapped in eight main categories of HABITALP-mapping units (HABITALP Interpretation key, 2003), divided in several subclasses. The test site Klausbachtal comprises the following five main habitat types: (1) agricultural land and perennial forb communities, (2) immature soil sites and dwarf-shrub plant community, (3) trees, field trees or shrubs and groups of shrubs, (4) forest and (5) settlement and traffic. During this project, selected habitats of these five main mapping units were analyzed. In general, most of the National Park area belongs to the core zone in which natural processes and developments are not influenced by human interference. But there exists also a permanent and temporary transition zone which are anthropogenic used or are influenced

of human beings. In these two zones anthropogenic influenced forests of former times (like saline-spruce forests) are going to be transformed into nature-orientated mixed forests (Berchtesgaden National Park, 2005). The permanent and temporary transition zone together makes up about 49% of the test site. As a consequence the national park management is very interested in an automated habitat monitoring procedure of this test site because of its high changes in habitat dynamic.

3. Data and data pre-processing

Data used for habitat extraction and change assessment are a pan-sharpened QuickBird (QB) scene from August 2005 (0.6 m spatial resolution) and a CIR airphoto mosaic from 2003 (0.2 m spatial resolution). The ordered QB-scene is a Standard Ortho-ready bundle-product which consists of a panchromatic and a multispectral dataset, resulting of parallelly arranged multispectral and panchromatic QB-sensors. The Standard Ortho-ready imagery type is pre-projected in UTM-33 (WGS-84) but with a low spatial accuracy, accordingly it is necessary to post-orthorectify this QB-product. Because of the fact that the multispectral and the panchromatic sensors are offset from each other on the QB-focal plane, the same point on the ground is imaged at a slightly different time, which results in a slightly different view angle (Hitachi Software

Engineering, 2004). As a consequence both datasets were separately orthorectified using the rational polynomial coefficients (RPC) orthorectification model. Producing an orthorectified image with this model, each of the datasets, its rational polynomial coefficients and a DEM with a 10 m spatial resolution was used. The orthorectification result of the rough terrain study area can be improved with the additional usage of accurate, well-distributed ground control points (GCP's) (Smith, 2005). The entire study site consists of less anthropogenic objects like streets, rectangular places. As a consequence we used rooftops and crossroads as GCP's, which have a high recognisability and stability. A pan-sharpening-method according to Liu (2000) was performed to combine the high radiometric information from the multispectral dataset with the high spatial information from the panchromatic band. This process results in a multispectral dataset ground-resolution of 0.6 m. The pan-sharpening procedure is optimized to maintain the original spectral values to a large extent (> 90%), in comparison to methods based on principal component analysis (Lang and Langanke, 2006)

4. Segmentation strategy: iterative one-level representation (OLR)

Scenes of high spatial and spectral variability can be segmented using the one-level representation (OLR)

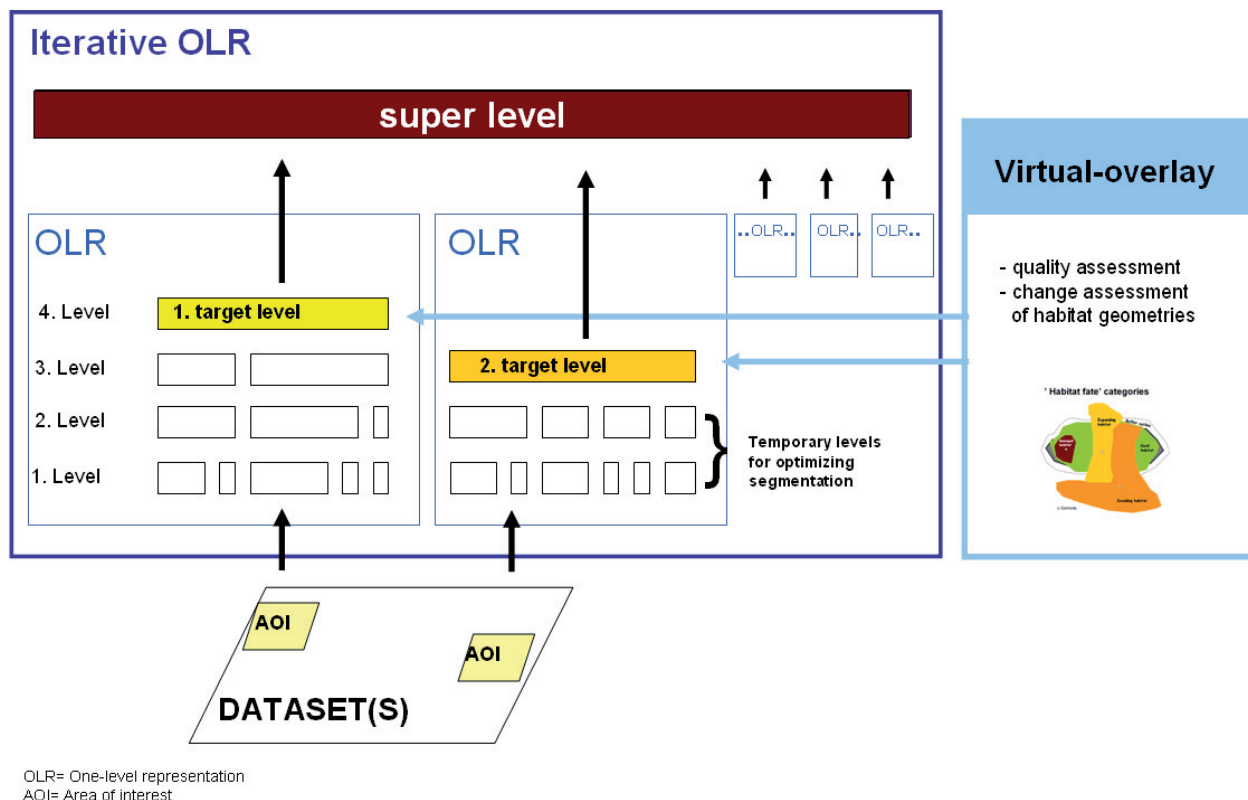


Figure 1: Scheme of iterative OLR in combination with the virtual-overlay approach (see chapter 5).

strategy (Lang and Langanke, 2006). This we applied for identifying image objects (like alpine habitats) of different scales and levels. For segmentation we used the software eCognition with its implemented region-based local mutual best fitting approach (Baatz and Schäpe, 2000). The result is controllable by user-specific assessment of color and shape homogeneity.

OLR means that through iterative segmentation entire habitats are delineated at one single target level which reflects the appropriate scale domain (Lang, 2002). Generating optimized target levels, the basic rule of image segmentation is not allowed to break. By this concept the image is divided into non-overlapping regions so that coarser levels are hierarchically structured in finer sub-levels and vice versa. Applying OLR, first a small area of interest (AOI) was selected and single habitats were segmented on specific target levels. The quality of the segmented geometries was compared with habitat boundaries visually delineated on CIR airphotos, using the virtual-overlay approach (described in chapter 5). Second, the detected target levels of the single habitats were applied to the whole test area. At some levels, habitats could be identified in the entire test site. These habitats are results of the same iteration steps and parameters. A user-specific number of target levels can be extracted from the entire test scene via iterative OLR. Habitat geometries of prior target levels should not be disregarded during the generation of the next habitat target level. At last these single levels can be reassembled on a super level (see Fig. 1; Preiner et al., 2006).

5. Change assessment: Virtual-overlay-approach

After the extraction of single habitat geometries via OLR, the segmented geometries of the QB-scene 2005 were compared with the visually delineated and digitized geometries derived by a human interpreter on the CIR imagery of 2003. The virtual-overlay approach includes enhancements in the context of investigating spatial relationships among corresponding objects. Object correspondence can be seen as a product of spatial object change over time or as a result of different object delineations (Schöpfer and Lang, 2006). In this project, two different systems, the visual human-perceptive system and the digital image analyses system have produced geometries with non-congruent object outlines even when working in the same scale domain. The virtual-overlay method was also used to compare these outlines of two different time slots. Furthermore change assessment of these habitats was proved. This approach is implemented in a tool called LIST (Landscape Interpretation Support Tool, Lang et al., in press), an extension for ESRI's ArcView 3 and ArcGIS 9. The authors introduced the term 'object fate' for determining object relationship and changes over time. Based on

the concept of parent-and-child themes, two vector layers represent the specific fate of corresponding objects (Schöpfer and Lang, 2006). In our case the analyzed objects are habitats and as a consequence we call this particular fate 'habitat fate'. Habitat fate of two comparable geometries was proved by setting a threshold value for 'spatial overlay strictness (SOS)' to accept overlaps of corresponding, but not fully congruent delineations. Through the applied threshold value a specific size of buffer zone is introduced. The buffer size controls the allowed spatial difference of two habitat geometries being compared; the SOS-threshold reflects the degree of overlap, expressed by a percentage value. Based on the virtual-overlay approach specific 'habitat fate' can be analyzed over time without modifying geometries (Schöpfer and Lang, 2006). 'Habitat fate' is then analyzed by overlaying geometries from habitat fate time t_0 and t_1 . In our project, habitat fate time t_0 is a reference habitat which reflects the digitized geometries of the air photo interpretation. On the other hand, habitat fate time t_1 provides the automatically segmented outlines of the software eCognition 4.0. A habitat in habitat fate time t_0 can change in time and as a consequence the same habitat at habitat fate time t_1 can be expressed by the following four possibilities (1) good habitat, i.e. habitat t_1 is falling completely in the buffered outline of a t_0 habitat, (2) expanding habitat, i.e. habitat t_1 is exceeding the buffered outline of a t_0 habitat but has its geometric centre within the delineated outline of habitat t_0 , (3) invading habitat, i.e. habitat t_1 has its geometric centre outside of the origin or buffered delineated object t_0 , therefore usually this object type is not directly related to object t_0 (Lang et al., in press). Finally (4) there is an emerged habitat, i.e. habitat t_1 which is falling completely in the origin outline of a t_0 habitat (see Fig. 2). A special case of habitat fate occurs when habitat t_1 behaves like an

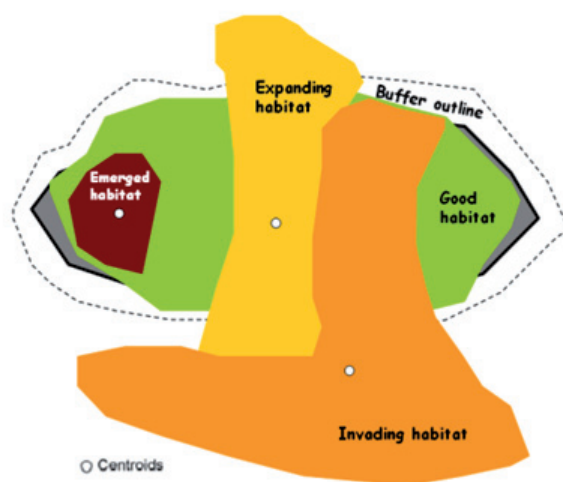


Figure 2: 'Habitat fate' categories implemented in LIST (Schöpfer and Lang, 2006, modified by E. Weinke).

expanding habitat but represents an area which is completely new developed (such as a clear-cut forest). In this case LIST will identify this habitat as an expanding habitat. In our project we only calculated habitat fate types 1, 2 and 4 because we determined the geometries of one habitat at two different times (t_1 and t_0). As a consequence the analyzed habitats only can be a good, an expanding or an emerged habitat.

6. Results

Based on the OLR-segmentation strategy, habitats could be segmented at single representation levels which produced similar habitat delineation as the geometries of a human interpreter (see Fig. 3). The quality of these habitats introduced at different target levels depends upon the defined iteration steps and parameters used in eCognition 4.0.

Altogether, 44 single habitats were extracted at eight target levels. At each representation level a specific number of habitats with different textural features, different habitat type and size were identified. These results are to be seen in the light of a high number of heterogeneously composed habitats and a high variation of habitat size in the entire test site. The extracted habitats represent five of the eight main habitat types of the standardized HABITALP key (HIK). Although different habitat types

were segmented at each target level, some target levels are more suitable to extract a specific habitat type (see Fig. 3 and HABITALP Interpretation key, 2003). As an example, in target class 4 most of the extracted habitats are of the type immature soil site (HIK: 5000) which consists of a combination of coniferous and debris areas. To reach this target class at the first iteration steps we selected a very high color and compactness factor. Only in the last iteration step finally the shape factor was weighted higher. These results show that by applying the iterative OLR segmentation strategy it is possible to get one habitat or more single habitats at a specific target level, which have a similar texture and represent a specific main HABITALP-mapping unit.

Due to the fact that in this project two different systems are compared, geometries have non-congruent object outlines. In Fig. 4, one example for each of the main HABITALP-mapping units is shown. This illustrates the mentioned non-congruent habitat outlines of these two systems. Applying the virtual-overlay approach, habitat fate of each habitat is identified. The habitat of the first example shows a meadow habitat with a very homogeneous texture and no changes between 2003 and 2005. As a consequence a small SOS-factor of 5% was used to identify this habitat as a good habitat. The second example consists of a heterogeneous texture of debris and coniferous areas.

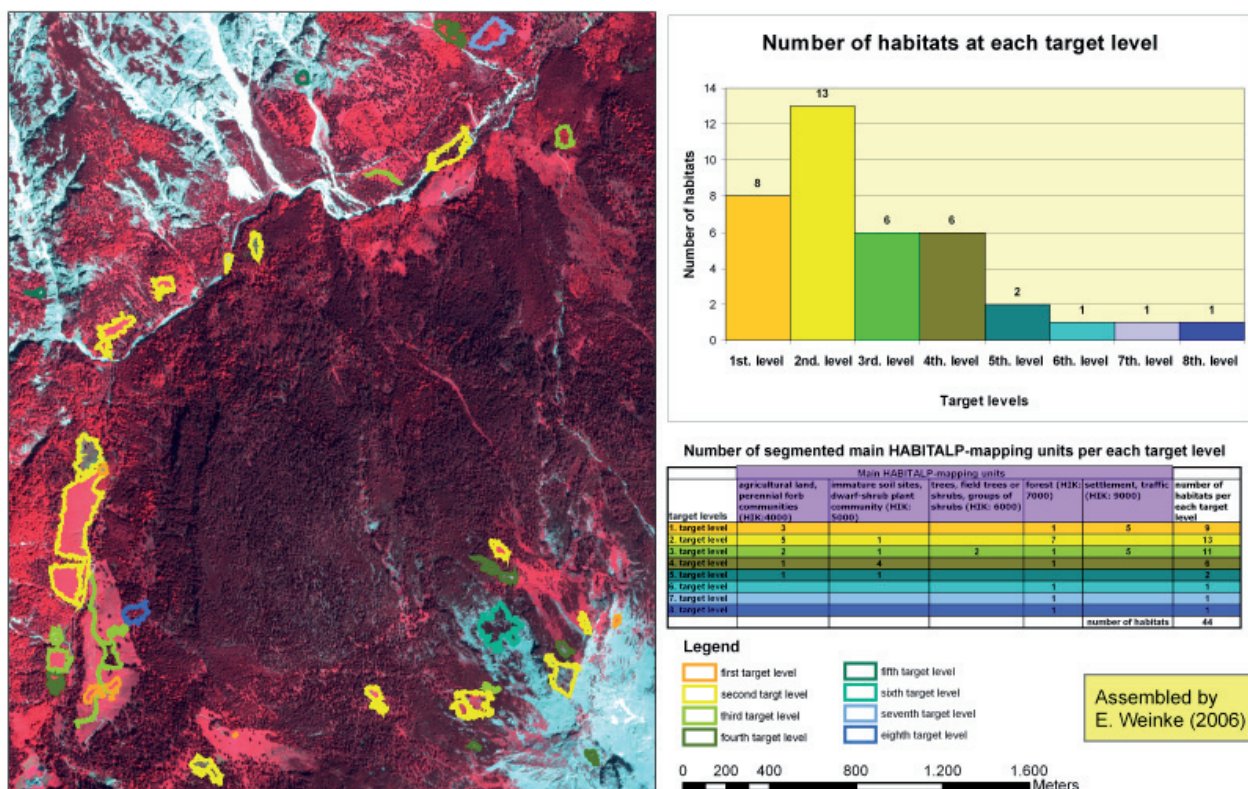
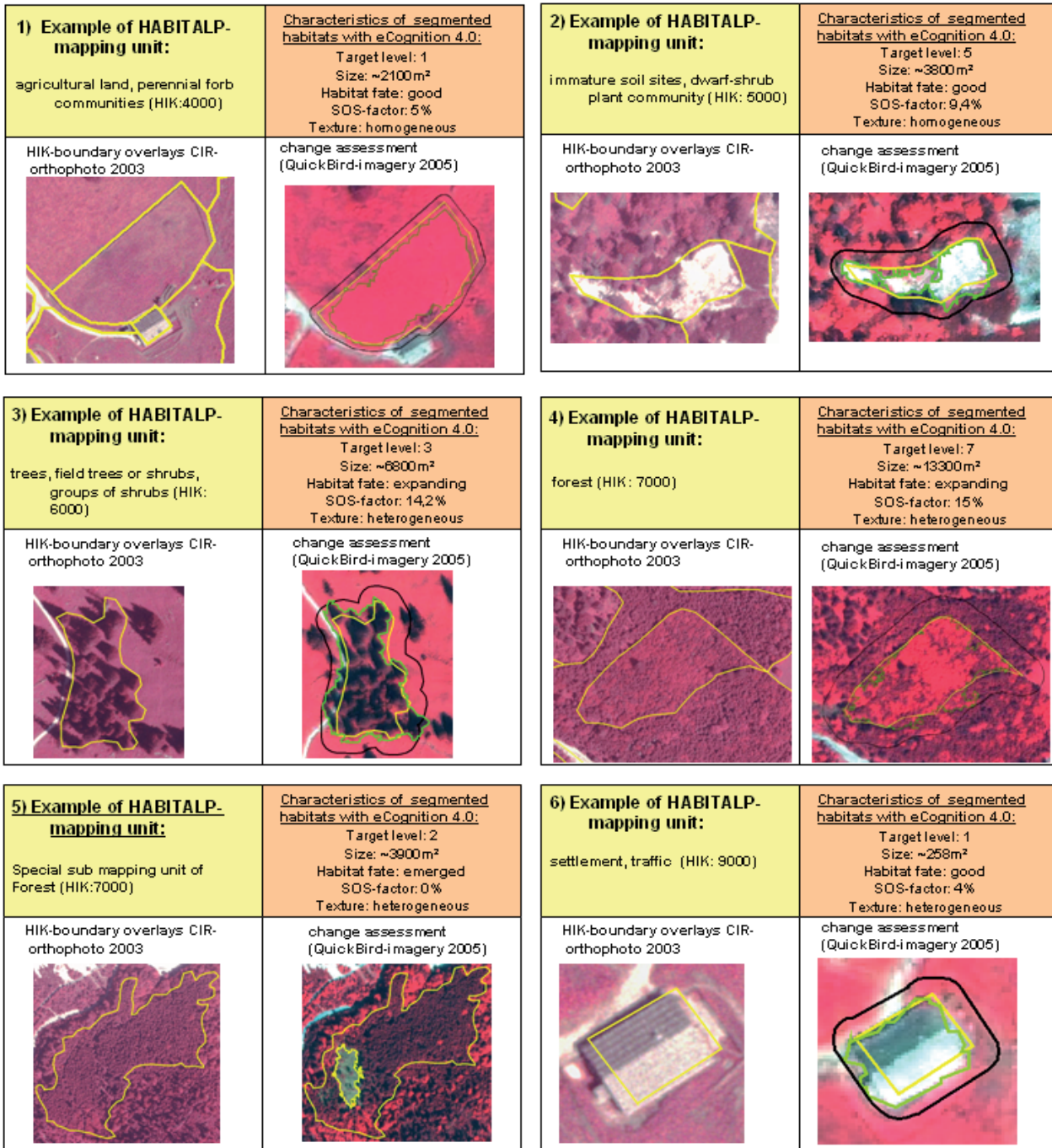


Figure 3: Extracted habitats and target levels originated from the iterative OLR segmentation strategy in the test site Klausbachtal.

A SOS-factor of 9.4% was used to identify good ‘habitat fate’ of this habitat. In this case the high buffer distance is justified because the interpreter perceptually included single features (like trees) in an otherwise homogeneous debris habitat matrix, whereas the software strictly seg-

ments the homogeneous debris area. At the sixth example an SOS-factor of 4% was applied to reach good habitat fate. This case shows that the software extracts the entire house because it works pixel-based, whereas the human interpreter works generalized. The habitat in the third ex-






-  Buffer zone
-  Visual border delineation of CIR-aerial photographs
-  Habitat border which results of a segmentation process

Figure 4: Examples for each main HABITALP-mapping unit which can be found in the Klausbachtal.

ample has a high SOS-factor of 14.2% and is an expanding habitat. It is shown that the software cannot differentiate between tree crown and tree shadow. As a consequence the expanding tree crown in the south-eastern part of the habitat could not be identified. The habitat in the fourth example also shows an expanding habitat with a high SOS-factor of 15%. This habitat is really expanding because spectral changes could be identified in the south-east of this habitat. About half of the test site is situated in the temporary and permanent transition zone. As a consequence many habitats like the habitat in the fifth example could be identified which represent a clear-cut forest and an emerged habitat.

7. Discussion

In this project it was shown that very high spatial resolution (VHSR) QuickBird imagery are suited for automated habitat delineation. QB satellite data, besides red, green and near infrared bands, also contain a blue and a panchromatic dataset, in comparison to CIR-aerial photographs. Using a suitable pan-sharpening-method, the spatial resolution of the multispectral dataset can be merged to the high spatial resolution of the panchromatic dataset, maintaining most of the high radiometric resolution of the multispectral bands. As a consequence the pan-sharpened QB-data has a similar spatial resolution as the CIR-aerial photographs. Furthermore, segmentation results will be more accurate, using the multispectral as well as the panchromatic dataset. We assume that satellite-based data which contain multispectral bands with a resolution of the QB-panchromatic dataset or higher will improve the segmentation results in the future. In general, to extract habitats with image analysis software, reference outlines are fundamental components from either ground truthing or an experienced aerial interpreter.

There are various possibilities to approaching automated change detection. One possibility would be to connect an existing segmentation tool (e.g. one of the routines implemented in eCognition) with a database to obtain automated segmentation through habitat specific parameters, which can be applied and adapted to identify changes.

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