PFG 2013 / 5, 0415–0426
Stuttgart, October 2013

Report

Image Analysis Methods to Monitor Natura 2000 Habitats at Regional Scales – the MS.MONINA State Service Example in Schleswig-Holstein, Germany

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Keywords: knowledge-based image classification, RapidEye, grassland habitats

Summary: The Natura 2000 network of protected sites is one of the means to address the issue of biodiversity conservation in Europe. Protected under the habitat directive, EU member states have to undertake surveillance of habitats and species of community interest and report every six years on habitat range and distribution, conservation status and the future prospects of the habitats within and outside of protected sites. Remote sensing techniques have been applied successfully to monitor habitat changes relevant for Natura 2000 monitoring using multi-temporal satellite image data, but many challenges remain especially outside protected sites to assess the development of habitats over time. A flexible information layer concept was developed within the FP7 project MS.MONINA to address the complex task of monitoring natural habitats. In this paper the new approach to classify grassland land cover classes in Schleswig-Holstein, Germany, will be presented. Based on ecological parameters experts defined simple description models, which were used by image analysts to extract corresponding image features for four different grassland types. Information layer operators were defined to extract image features for subsequent classifications.

Zusammenfassung: *Bildanalysemethoden zum Monitoring von Natura 2000 Lebensräumen auf regionaler Ebene – das MS.MONINA State Service Beispiel in Schleswig-Holstein.* Das Natura 2000 Schutzgebietsnetz ist eine der Europäischen Maßnahmen zum Erhalt der Biodiversität Europas. Ausgehend von der FFH Richtlinie müssen die EU Mitgliedsstaaten die geschützten Arten und Lebensräume beobachten und alle sechs Jahre über deren Zustand, Verbreitungsgebiet und Entwicklungsaussichten innerhalb und außerhalb von FFH-Gebieten berichten. Verfahren der Fernerkundung wurden schon erfolgreich im FFH Monitoring eingesetzt, um Veränderungen der Lebensräume auf Basis multitemporaler Satellitenbilder zu beobachten. Viele Herausforderungen bestehen vor allem außerhalb der bekannten Schutzgebiete, um die Entwicklung der Lebensräume zu bewerten. Innerhalb des FP7 Projekts MS.MONINA wurde ein flexibler „Information Layer" Ansatz entwickelt, um die komplexen Aufgaben im Monitoring von natürlichen Lebensräumen zu adressieren. In diesem Artikel wird der neue Ansatz zur Klassifizierung von Grünlandtypen in Schleswig-Holstein präsentiert. Auf Basis von ökologischen Parameter und Bildmerkmalen wurden Expertenmodelle erstellt und für die Klassifizierung der Grünlandklassen als Informationsbilder („Information layer") aufbereitet.

1 Introduction

The conservation of biodiversity is an international matter of high importance to mankind. This was recognized by the signing of the UN Convention on Biological Diversity, at the 1992 Earth Summit in Rio de Janeiro. Since then, many countries have set out national strategies and actions plans to halt the increasing loss of biodiversity, mainly caused by human activities, leading to a habitat loss and ultimately to an extinction of species. The Natura 2000 network of protected sites is one of the means to address the issue of biodiversity conservation in Europe. It represents sites of European interest with particular ecologi-

DOI: 10.1127/1432-8364/2013/0188 1432-8364/13/0188 $ 3.00

cal value and was formed on the legal base of the Council Directive 92/43/EEC on the conservation of natural habitats and wild fauna and flora, more widely known as the Habitats Directive, adopted in 1992 and the bird directive adopted in 1979 (79/409/EEC). The habitat directive requires EU member states to undertake surveillance of habitats and species of Community interest and report every six years on the habitat occurrence (range and distribution), the conservation status based on specific structures, functions and typical species, as well as the future prospects of the habitat. These parameters have to be evaluated over the complete biogeographical region defined as an ecologically coherent region within a member state.

Remote sensing has been successfully applied to monitor biodiversity aspects (Turner et al. 2003, Strand et al. 2007, Wang et al. 2010). Data from optical satellite sensors have shown to function as useful predictors of species richness in different vegetation types (Levin et al. 2007, Rocchini et al. 2010). Remote sensing techniques have also been used to monitor habitat changes in the context of Natura 2000 monitoring using multi-temporal satellite image data (Weiers et al. 2004, Bock

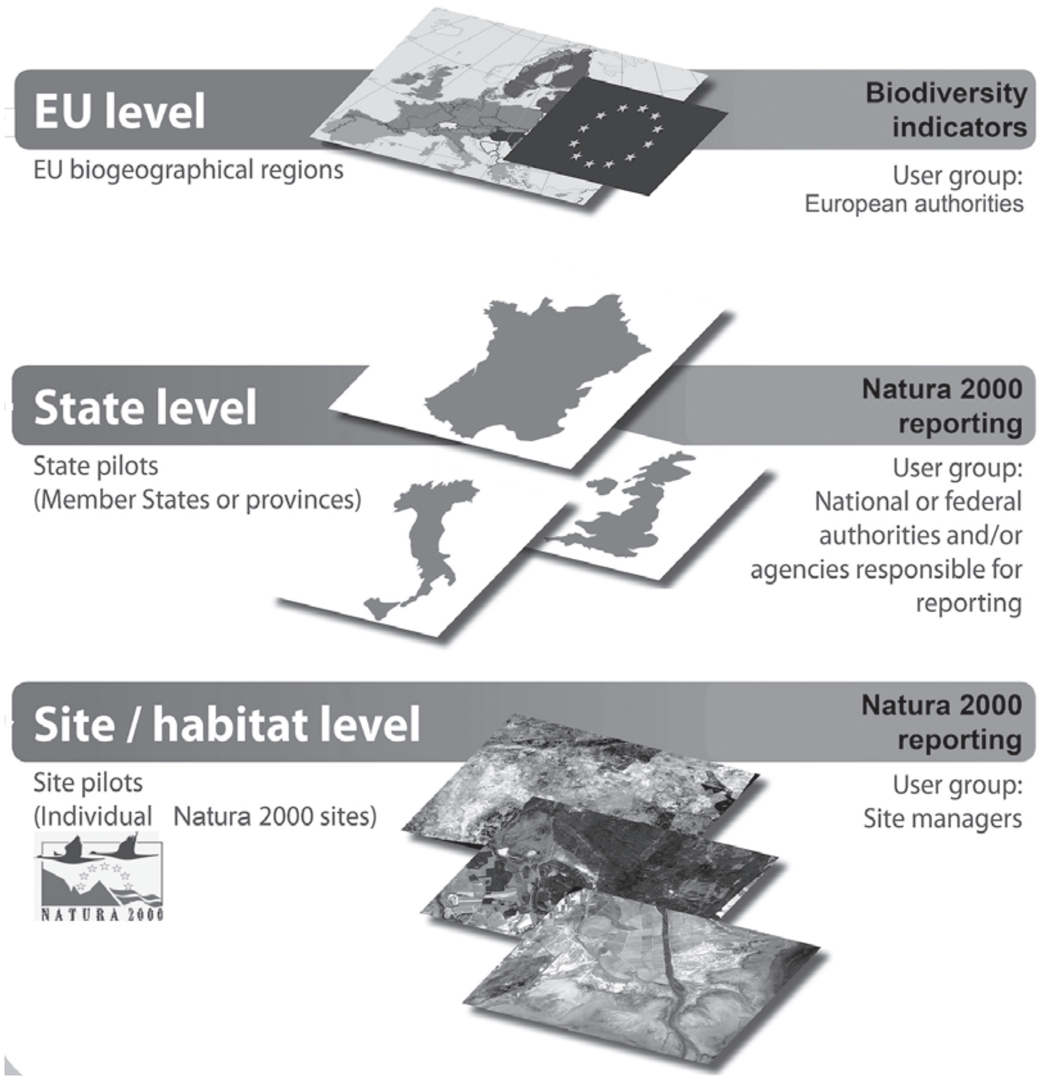

Fig. 1: The multi-scale approach in MS.MONINA to derive adapted remote sensing methods to support Natura 2000 monitoring (adapted from Lang et al. 2012).

et al. 2005, Buck et al. 2012). Especially very high resolution satellite data could support the monitoring of Natura 2000 sites (Förster et al. 2008, Hall et al. 2012).

The FP7 project MS.MONINA (Multi-Scale Service for Monitoring Natura 2000 Habitats of European Community Interest; MS.MONINA, 2013) was initiated to develop new concepts and remote sensing methods to support Natura 2000 monitoring. It is based on a multi-scale approach, to reflect and address the requirements and procedures to monitor and report the status of protected habitats and biodiversity of different user groups (Lang et al. 2011, Fig. 1). At the state level, national or regional agencies have the obligation to report habitat occurrence and condition for the entire state/province within their biogeographical regions. While there is often a good knowledge base for protected Natura 2000 sites, e.g. through field surveys and management plans, the information on habitat occurrence and status outside of this site network is often lacking. Here, the so called MS.MONINA state

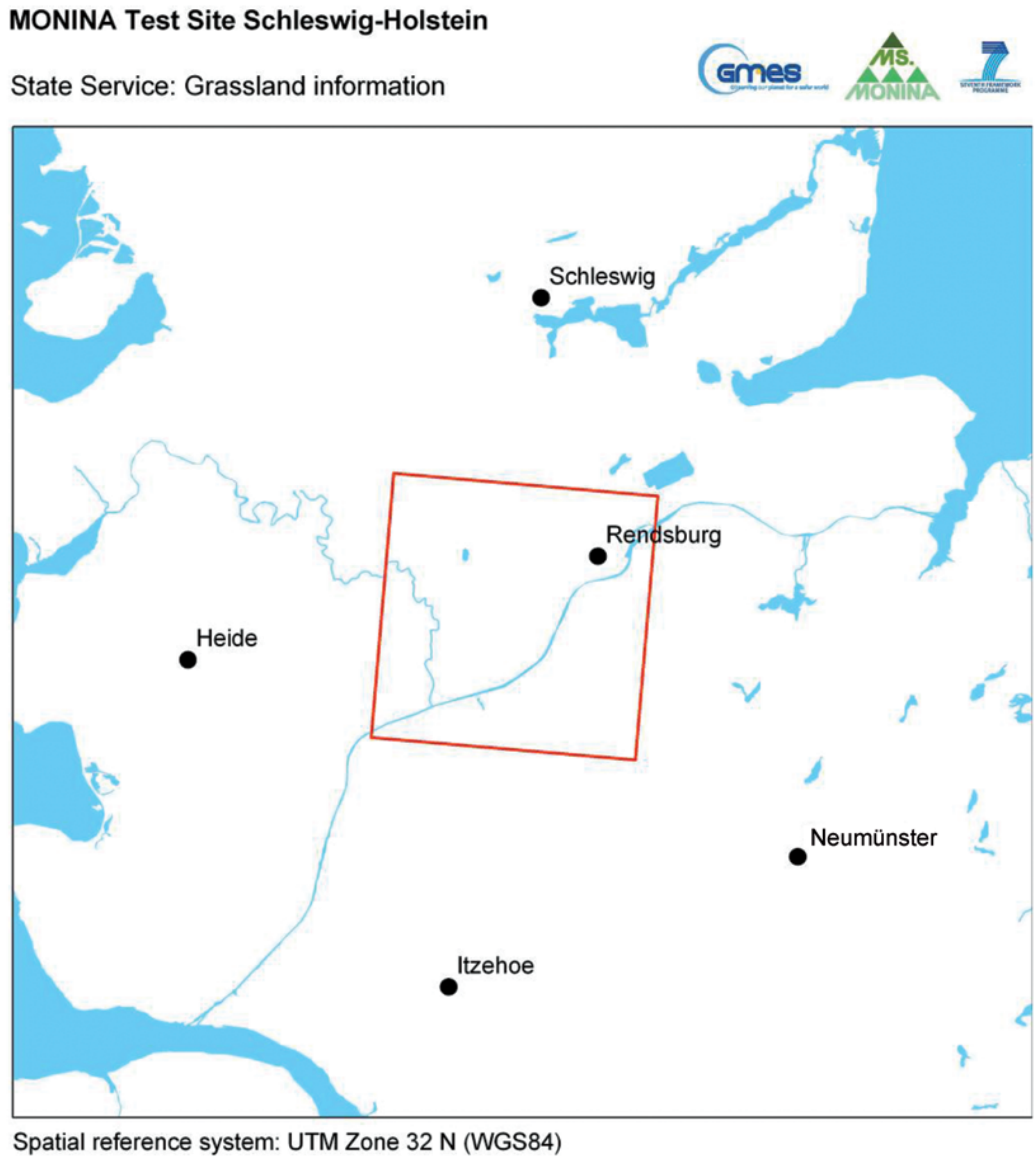

Fig. 2: Test site (red square) location in Schleswig-Holstein, Germany.

services shall provide support through two major project components:

- Expert models: Using a statistical modelling approach (maximum entropy model) the ecological niche of species and habitats is modelled based on abiotic factors such as soil information and digital elevation models. These models provide habitat potential maps which can be included into image classification methods either by weighting the class probability or excluding classes due to restricted natural potential of occurrence.
- Image analysis tools: Image classification is based on a variety of methods and tools. These tools are used to extract habitat relevant spectral, spatial or temporal information from remotely sensed images.

The state service developments are demonstrated in various state pilots across Europe. In this paper one of the state pilot cases is presented, based on the development of image analysis tools in Schleswig-Holstein, Germany, located in the Atlantic biogeographical zone. Through discussions with experts from the regional environmental protection agency (LLUR, Landesamt für Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein) the focus of this state pilot was set to the demand for spatially explicit data on grassland distribution and use intensity.

In this paper the developed information layer approach is presented. Here, the focus is set on the methodological description of the approach to setup expert models and produce information layers for grassland classification in Schleswig-Holstein, Germany.

2 Study Site

The test site lies within the Atlantic biogeographical region in the federal state of Schleswig-Holstein, Germany. It is characterized by the lowland rivers Eider, Treene and Sorge, and dominated by pastoral agricultural land use (Fig. 2). Relicts of wide-spread wetlands form some of the most valuable bog remnants. The following Natura 2000 grassland habitat types have been listed by the regional user (LLUR) as of special concern: Semi-natural dry grasslands and scrubland facies on calcareous substrates (*Festuco-Brometalia*) (habitat code 6210), Molinia meadows on calcareous, peaty or clayey-silt-laden soils (*Molinion caeruleae*) (habitat code 6410), and lowland hay meadows (habitat code 6510).

3 The Information Layer Approach

Vegetation scientists and experts in environmental monitoring often lack remote sensing expertise but already use image information to support their work. Used as background image in field mapping campaigns, they support the identification and delineation of different vegetation forms or landscape structures. Their experience and interpretation skills allow them to differentiate habitats from image components such as image colour, shadows, neighbouring features or proximities to other habitats. Often ancillary information such as soil type maps or digital elevations models are additionally used. Remote sensing experts on the other hand often use statistical approaches, e.g. maximum likelihood classifier, to classify natural habitats based on spectral image information pixel by pixel. With the recent advance of object-based classification approaches the use of spatially explicit and ancillary information is of increasing importance (Blaschke 2010). In some way these methods try to imitate the human perception and interpretation procedures (Lang & Langanke 2006).

This fact is also used in MS.MONINA to develop our so called information layer approach. However, the presented approach is not limited to pixel or object-based methods. It is more a methodological framework to prepare different data sources (image and ancillary information) in a structured manner, formalize expert knowledge and integrate ecological parameters in an image classification workflow. In short, expert knowledge about habitat interpretation is formalized and used within an image classification process. This requires a close communication between habitat experts, often vegetation scientist, and remote sensing experts, which is seen as a crucial aspect for the success of Natura 2000 studies using remote sensing techniques (Vanden Borre et al.

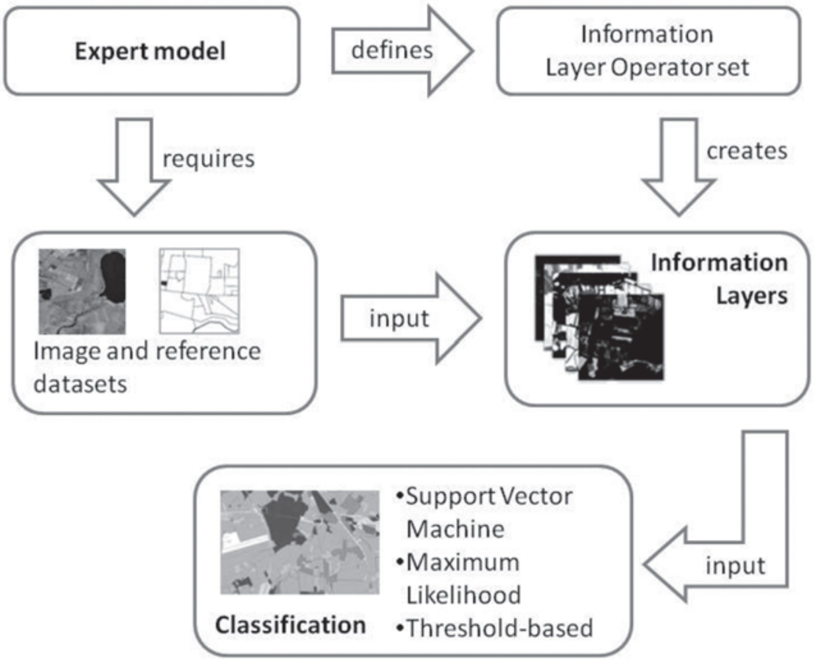

Fig. 3: Workflow logic of the developed information layer approach.

2011). Therefore, the developed approach has the potential to increase the acceptance and foster the use of remote sensing in environmental monitoring applications.

Our information layer approach consists of the following central components and processing steps, which will be explained in more detail in the following sections (Fig. 3):

- Definition of ecological parameters of each grassland type based on expert knowledge (**expert models**)
- Generation of relevant **information layers** that represent these ecological parameters
- **Classification** of grasslands using these information layers as input

3.1 *Definition of Grassland Types and Expert Models*

In the service case Schleswig-Holstein four different grassland types were identified: Intensively used grassland (GI), mesophilic grasslands (65xx), wet grasslands (64xx), and dry grasslands (62xx). These classes were defined in terms of ecological parameters and image interpretation features in close exchange between vegetation scientists of the regional monitoring agency (LLUR) and image analysis experts (Tab. 1). These expert models indicate on the one hand which information is relevant for experts to identify the correspondent habitat type, mostly through GIS

Tab. 1: The ecological parameters and image interpretation features used for the grassland types in Schleswig-Holstein.

Grassland type	Biomass	Mowing season	Homogeneity	Soil moisture	Slope orientation	Line structures
62xx	Low-medium	Non	Low-medium	Very low	Southern	Non
64xx	Low-medium	August	Low-medium	High	Not relevant	Low
65xx	Medium-high	June	Medium-high	Medium-high	Not relevant	Low
GI	Medium-high	2-4 times	High	Low- medium	Not relevant	Non-low

or visual image analysis. On the other hand they are based on an evaluation by image analysts, whether and how these features can be extracted from remote sensing images based on established image analysis techniques.

For example, according to the regional experts, different mowing practices are applied for different grassland types in Schleswig-Holstein. As deduced by the name, intensive grasslands are those that experience a higher number of mowing events over a given vegetation period. Dry grassland (62xx) and wet grassland (64xx) on the other hand are never or only once mowed in August (in the case of 64xx). Mesophilic grasslands (65xx) might be mowed once a year, in June. This fact can be adressed using multi-temporal image analysis techniques given a satellite time series over the vegetation period.

Field visits reveal, that dry grasslands (62xx) are often very patchy/heterogeneous, meaning that they do not form a homogeneous grassland layer, but also contain patches of open soil and should thus correspond to different spectral signatures within a dry grassland plot. Wet grassland (64xx) are moderate homogeneous, while mesophilic (65xx) and intensive grasslands (GI) are very homogeneous.

Abiotic factors such as soil type, soil condition and field exposition play a major role in grassland distribution in Schleswig-Holstein. Dry grasslands (62xx) are more concurrent on southern slopes and on nutrient-poor soil types with low water retention capacities. Vegetation scientist use this information to target their field work. While soil type and water rentention capacities can not be extracted from remote sensing images over vegetated areas, existing soil maps can be used and incorporated in the image analysis as ancillary information. Digital elevation models (DEM) can be used to calculate exposition.

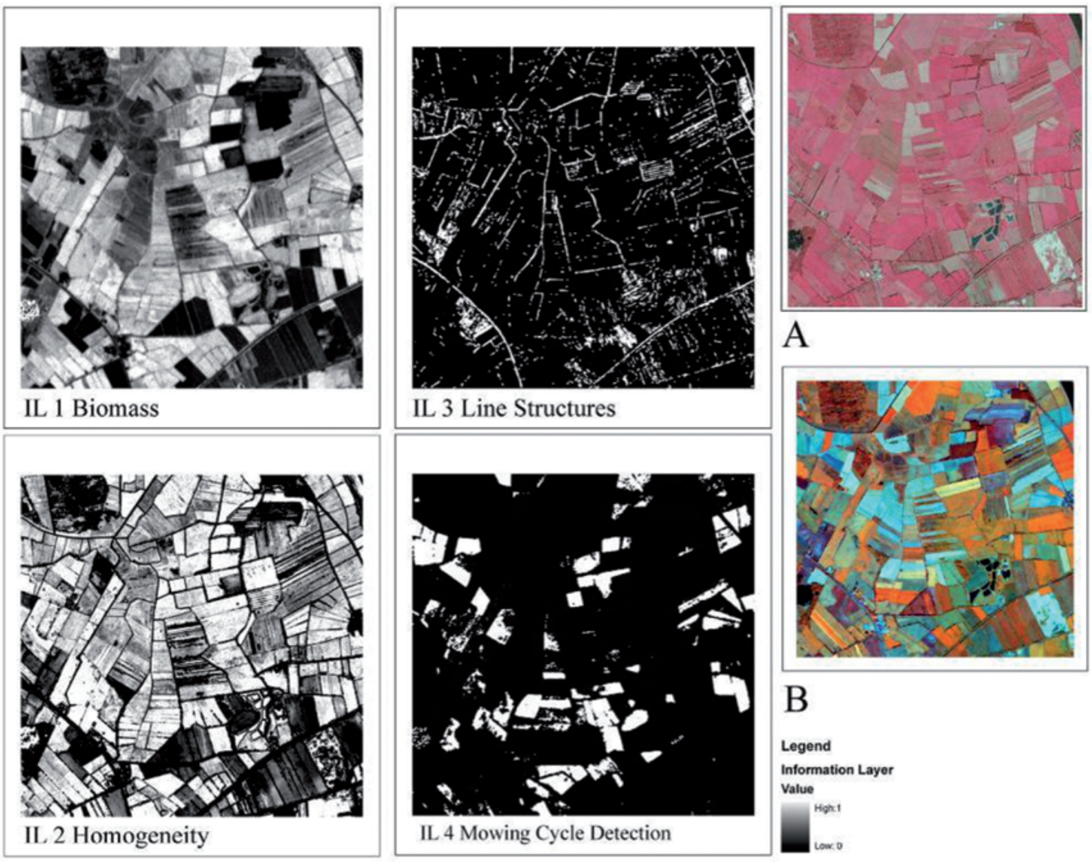

Fig. 4: Information layer (IL1-4) examples based on aerial orthophotos (A = DMC camera with 0.4 m ground sampling distance GSD and four channels) and satellite data (B = RapidEye, 5 m GSD, 5 channels).

3.2 *Information Layer Production*

These expert models define the set of corresponding information features relevant to differentiate the four grassland types. All image features are stored in so called information layers (IL) as standardized raster data (GeoTIFF). Only one image feature can be represented per IL (Fig. 4). The image features can be of very different nature:

- Spectral ILs: Original bands, derived vegetation indices, or alike (for an overview see Silleos et al. 2006).
- Temporal ILs: multi-temporal information based on an analysis of images from different dates, e.g. the mean spectral dynamic parameter proposed by Franke et al. (2012).
- Structural ILs: information about important structures within the image, e.g. linear line structures which give a hint at tracks from agricultural machines.
- Spatial ILs: Information on the 2D or 3D geometry of land surface elements, e.g. derived from digital elevation models.
- Additional data ILs: Information derived from non-image datasets, e.g. weather reports and soil characteristics vector maps.

Depending on the feature to be extracted, different image sources are needed, from very high to low resolution data, multispectral to hyperspectral, and single images to time series. For the production of each information layer a suitable image analysis algorithm (information layer operator, ILOP) is needed. The chosen algorithm, together with data requirements and constraints to produce the information layers are described in metadata documents (Fig. 5).

To produce the required information layers according to the grassland models in our study, a number of image analysis algorithms were implemented in the image analysis software Halcon. The spatial, structural, spectral, temporal and additional information layers were produced using RapidEye satellite image data or digital aerial orthophotos (Tab. 2). All RapidEye data, provided as L3 standard data, was atmospherically corrected (ATCOR-2)

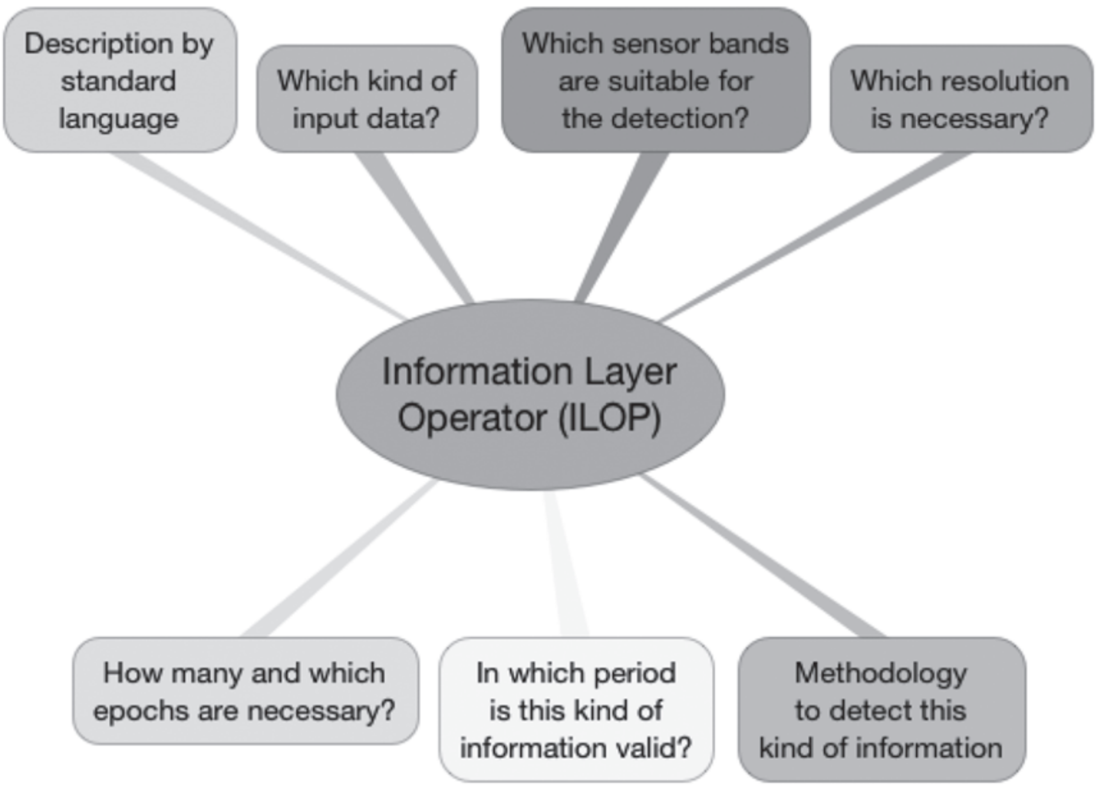

Fig. 5: Metadata information to describe the information layer operators.

Tab. 2: Applied datasets.

Input data	Original projection	Date	Description	Used for
RapidEye [1)]	UTM 32N WGS84 (EPSG 32632)	2009 – 2011	5 m GSD (ground sampling distance) 5 bands (B,G,R, RedEdge,NIR) Signed 16 bit GeoTIFF	Mowing IL Biomass IL
Orthophoto [2)]	UTM 32N GEM 10C (EPSG n/a)	2009 – 2011	0.15 m GSD 4 bands (R,G,B,NIR) Unsigned 8 bit GeoTIFF	Linear Features IL Homogeneity IL
Digital Elevation Model [3)]	UTM 32N GRS1980 ETRS 1989 (EPSG 25832)	2005 – 2007	Derived from airborne laser scanner data 1 m pixel size Float 32 bit ASCII Grid	Slope orientation IL
Soil map [3)]	Gauss-Krueger 3 DHDM (EPSG 31467)	Unknown (continuously compiled since the 1930s)	ESRI Shapefile Polygons	Soil moisture IL Soil quality IL Soil type IL
Training sets [2)]	UTM 32N WGS 84 (EPSG 32632)	2009 – 2012	ESRI Shapefile Polygons	Feature extraction validation

1) Provided by the European Space Agency via the GMES Space Component Data Access Portal
2) Provided by the Landesamt für Landwirtschaft, Umwelt und ländliche Räume Schleswig-Holstein (LLUR)
3) Provided by the Landesamt für Vermessung und Geoinformation Schleswig-Holstein (LVermGeo SH)

prior to analysis. All image data was re-projected to a common reference system (UTM 32N, WGS84).

The information layers were calculated using existing or adapted vegetation indices (Biomass), common image analysis techniques (standard deviation windows for homogeneity) or newly implemented algorithms (mowing time window comparison for the detection of mowing events) (Tab. 3). Ancillary vector information (soil maps) was converted to thematic raster images. All information layers were normalized to a value range from zero to one.

4 Discussion

Grassland habitats are an important component of biodiversity in Europe (Silva 2008). Almost 20% of the habitat types listed in the habitats directive are associated with extensively used grassland formations (Halada et al. 2011). Through intensification of land use and soil sealing for infrastructure development, or the abandonment of traditional management forms, these habitats are under increasing pressure (Henle et al. 2008, Navarro & Pereira 2012). Between 1975 and 1995, around 12% of the European grassland diminished (Poiret 1999). Protective measures such as the Cross Compliance regulations (EU regulation 73/2009) and the monitoring of high nature value farmland, a mandatory baseline indicator according to the EU Common Monitoring and Evaluation Framework, could not stop the decline of grassland (Nitsch et al. 2012, Schramek et al. 2012). The image analysis components developed in the state pilot Schleswig-Holstein can provide information

Tab. 3: List of ILOPs implemented in the state pilot Schleswig-Holstein (ILOP = Information layer operator).

Spectral ILs	
Biomass	The normalized difference vegetation index (NDVI) was defined as a proxy of the biomass (1) (Tucker et al. 1979). $$NDVI = \frac{(\mathrm{Rnir - Rred})}{(\mathrm{Rnir + Rred})} \quad (1)$$ For the study case, RapidEye images were used. For that reason, a modified version of NDVI was used: the red edge NDVI (2) (Gitelson et al. 1996). We substituted the near infrared by the red edge band: $$Red\ edge\quad NDVI = \frac{(\mathrm{Rred\ edge - Rred})}{(\mathrm{Rred\ edge + Rred})} \quad (2)$$
Homogeneity	Homogeneity is referred in the IL method to spectral variability. Orthophotos were used to calculate the homogeneity IL, based on the inverse standard deviation of all pixels within a 5x5 pixel mask.
Temporal IL	
Mowing cycle detection	For the detection of the mowing cycles several (up to 4) expected mowing time windows are compared each to a reference within the vegetation period before the first mowing. If a decrease in biomass matches a threshold, a mowing cycle has been detected for this particular time window. Depending on the grassland class different time windows are checked.
Structural IL	
Linear structures	This IL represents linear structures with long straight parallel lines. The first step to produce this IL is a line extraction using a Gaussian line model. After the extraction, the lines are converted into line segments. Then the line segments are analyzed for length and curvature. All short line segments and those with a higher curvature are deleted; the rest is used as linear structures. At the end of the process the line segments are converted back into a greyscale image. A Gaussian filtering increases the area of influence of the line structures.
Spatial IL	
Slope orientation	To build up this IL, a digital elevation model (DEM) of the area was used. An algorithm in Halcon has been implemented to create an exposition map.
Additional data ILs	
Soil type	For this IL, the soil map of Schleswig-Holstein provided by the LLUR was used. For our study, the information about soil type was extracted per pixel within the training sets. These values were analyzed in a histogram in order to know the preferential soil type per grassland class.
Soil moisture	To build up this IL, we proceeded similar to the soil type IL. The LLUR soil map was used again and information about water retention extracted within the training areas for each grassland types and analyzed in a histogram.
Soil quality	Soil quality refers here to the conservation state regarding soil erosion and depth. This information was also retrieved from the LLUR soil map and analyzed accordingly in a histogram, based on the training areas for each grassland type.

to protect biodiversity. Indicators about the trends and changes in grassland habitats distribution can be provided, if a grassland classification is repeated in time, and information about agricultural management changes are evident, e.g. through an increased number of mowing cycles.

The grassland model features were identified in a close exchange dialog between the regional monitoring agency and image analysis experts. This evaluation of user needs is one key issue to successfully incorporate remote sensing approaches into habitat monitoring (Vanden Borre et al. 2011). Existing grassland nomenclatures formed the framework for the definition of these classes. During the initial user dialog, it became evident that the very high user expectations to directly address grassland habitats as defined in the Natura 2000 process are very challenging. According to the Natura 2000 guidelines, grassland types are defined mostly from a vegetation science perspective with key grass species differentiating the grassland types (European Commission 2007). Recent advances in hyperspectral remote sensing have successfully tried to identify these complex vegetation communities (Schmidtlein & Sassin 2004) or plant indicators (Schmidtlein 2005) using remote sensing. However, so far no hyperspectral satellite image sensors are available to deliver regular image data needed to monitor environmental developments according to the Natura 2000 requirements over large regions in an operational manner. Therefore, the applied grassland classes (GI, 62xx, 64xx, 65xx) in this project were defined on selected ecological conditions and image features that can be extracted from aerial photos and multi-spectral images. While these classes do not represent the Natura 2000 habitats, they can be used as an indicator on habitat existence and in general on grassland status and trends in Schleswig-Holstein.

Capturing these image features in standardized information raster layers allows an easy data exchange and a multiple use of only once produced image information for various purposes. Several ILs were created to represent grassland parameters using remotely sensed and field data. In the next steps these ILs will be used as input in different classifiers, e.g. threshold-based, support vector machine, and maximum likelihood, to compare classifier performance and map the grassland distribution of the Schleswig-Holstein test site.

The developed IL approach is flexible to new models and target land cover classes. In the context of Natura 2000 this could be the application of the presented information layers to other Natura 2000 habitats of relevance in Schleswig-Holstein (Tab. 4). For example, increasing biomass in a heath habitat could indicate increasing grass cover, an indicator of deteriorating habitat quality according to the national guidelines for the assessment of habi-

Tab. 4: Examples to apply IL to additional Natura 2000 habitats.

Information layer	Used for grassland type in this study	Potential relevance for other Natura 2000 habitats (code)
Biomass	62xx, 64xx, 65xx	Dry sand heaths with *Calluna* and *Genista* (2310), Dry sand heaths with *Calluna* and *Empetrum nigrum* (2320), Inland dunes with open *Corynephorus* and *Agrostis* grasslands (2330), Northern Atlantic wet heaths with *Erica tetralix* (4010), European dry heaths (4030), degraded raised bogs still capable of natural regeneration (7120), transition mires and quaking bogs (7140)
Homogeneity	62xx, 64xx, 65xx	Inland dunes with open *Corynephorus* and *Agrostis* grasslands (2330), Northern Atlantic wet heaths with *Erica tetralix* (4010), European dry heaths (4030)
Linear structures	62xx, 64xx, 65xx	Degraded raised bogs still capable of natural regeneration (7120)

tat condition (Schnitter et al. 2006). Future work should address the application of this IL approach in a wider context.

Acknowledgement

The research leading to these results has received funding from the European Community‘s Seventh Framework Programme (FP7/2007-2013) under grant agreement No. 263479. We would also like to thank the European Space Agency for the provision of the RapidEye satellite data via the GMES Space Component (GSC) Data Access Portal (DAP). Additionally we would like to kindly thank the Landesamt für Landwirtschaft, Umwelt und ländliche Räume Schleswig-Holstein (LLUR) for providing their expert knowledge and field reference data, as well as the Landesamt für Vermessung und Geoinformation Schleswig-Holstein (LVermGeo SH) for delivering their digital aerial image data.

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