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Detecting Land Use And Land Cover Changes In Northern German Agricultural Landscapes To Assess Ecosystem Service Dynamics

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Abstract

Land use and land cover (LULC) and their changes in share and number of classes can be documented by remote sensing techniques. Information on LULC is needed for the assessment of ecosystem services and is used as input data for mapping and modelling. This information is important for decision-making and management of ecosystems and landscapes. In this study, LULC were analysed in two agricultural areas in Northern Germany by means of a pixel-based maximum likelihood classification approach of 11 Landsat TM 5 scenes between 1987 and 2011 followed by a post-classification refinement using the tool IRSeL. In this time period, grassland declined by about 50 % in both case study areas. This loss in grassland area can be associated with changes in provisioning ecosystem services as the supply of fodder and crops and the number of livestock declined from 1987 to 2007. Furthermore, an on-going increase in maize cultivation area, which is nowadays more and more used as biomass for biogas production, documents the addition of another provisioning service, i.e., biomass for energy. Combining remote sensing and research on ecosystem services supports the assessment and monitoring of ecosystem services on different temporal, spatial, and semantic scales.

Keywords:

provisioning services, quantification, crop rotation, remote sensing, agricultural management practice

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1 Introduction

The detection and monitoring of changes in land use / land cover (LULC) and thus in the supply of ecosystem services at various spatial scales are important research tasks. Ecosystem services contribute to human well-being in various ways, and can be subdivided into provisioning, regulating and cultural services (Kandziora et al. 2013a). The ecosystem services concept needs to be incorporated in management and decision-making, even though there are still challenges in the spatially explicit quantification, mapping and modelling of ecosystem service supply and demand (Crossman et al. 2012), and in the classification and valuation (de Groot et al. 2010).

In recent times, mapping and modelling of ecosystem services has gained increasing relevance and several approaches have been developed to expedite these methods. The assessment of ecosystem services based on LULC has been documented in several case studies (e.g., Koschke et al. 2013; Kroll et al. 2012). As detailed LULC maps are lacking for several countries or regions, remote sensing data is considered a valuable source for LULC data (Kennedy et al. 2009). Some studies have combined remote sensing techniques to examine e.g., potential impacts of land use changes to urban ecosystem services (Estoque and Murayama 2012). The use of models such as InVEST (Polasky et al. 2011) requires LULC maps as input data to model and map multiple ecosystem services (Leh et al. 2013). Many of these studies emphasize the need to include the gained knowledge of LULC change and ecosystem service change in decision-making and management (Estoque and Murayama 2012) as well as to understand past changes (Lautenbach et al. 2011) and predict future impacts on ecosystem services and human well-being (Lorencová et al. 2013; Sexton et al. 2013).

Deforestation and growing urbanisation have been often found to be the most severe LULC changes in the past decades (MEA 2005). However, changes in agricultural areas due to intensification and changes in crop rotation are present as well. Many studies focus on the assessment of ecosystem services of agricultural areas with little consideration of crop rotation and management practices (Koschke et al. 2013). Agricultural ecosystems generate an ample range of ecosystem services and interactions between the single ecosystem services, such as crop production or erosion and nutrient regulation, which in turn influence crop production (Dale and Polasky 2007; Lorencová et al. 2013). As agricultural land use accounts for a large area globally, the focus of research questions should also be placed on gaining detailed information on crop rotation, management practices and shares of arable land and grassland (Koschke et al. 2013; Lorenz et al. 2013).

Thus, this study was conducted in two case study areas (Bornhöved Lakes District and Kielstau Basin) in Northern Germany that are not influenced by deforestation or urban sprawl but are important supply areas of multiple ecosystem services due to their large extent of agroecosystems. The two case study areas are considered representative landscapes for Northern Germany (Fränzle et al. 2008; Fohrer and Schmalz 2012) and are good examples for the development in agriculture and the supply and changes in ecosystem services over the past decades.

Remote sensing techniques (here: classification of Landsat images) were used to derive land cover information in both case study areas for several time steps. In combination with crop rotation information, land cover data provides information on land use. Here, land cover and land use are used as synonyms in the term land use / land cover (LULC).

Therefore, the objectives of the study are:

(i) identifying the LULC changes in the available Landsat time series;

(ii) using this information to derive crop rotation practices and

(iii) identifying the influence of LULC changes on ecosystem service supply and the changes in selected provisioning services over two decades in both case study areas.

After the methodological explanations and the presentation of the results, the approach is discussed regarding the advantages and disadvantages of combining remote sensing techniques and ecosystem service assessments.

2 Study areas

Both case study areas are situated in the eastern part of the northern German state Schleswig-Holstein and feature similar climatic conditions (8.2°C average temperature and 919 mm/a precipitation in the Kielstau Basin (Fohrer & Schmalz 2012) and 8.1°C average temperature and 697 mm/a precipitation in the Bornhöved Lakes District (Fränzle et al. 2008)). LULC are predominantly agroecosystems with small shares of settlements and forest areas.

The Bornhöved Lakes District is located 30 km south of the capital Kiel (Figure 1). The study area was delimited to a size of 60 km² and lies partly within ten municipalities in the two districts of Plön and Segeberg. Located on the outskirts of the Weichselian glaciation, the northern part of the Bornhöved Lakes Districts belongs to the moraine area of the “Ostholsteinisches Hügelland” with its diversified relief. The southern part, the so-called “Trappenkamper Sander” contains mostly fluvioglacial deposits. Six glacially formed lakes (between 0.27-1.4 km²) are predominate features, which are surrounded by forest areas (Fränzle et al. 2008). The lakes have been landscape protection areas since 1962 and partly conservation areas since 1983 (LLUR 2012; Figure 1). Predominant soils are luvisols, cambic arenosols, and histosols (Fränzle et al. 2008). The Bornhöved Lakes District was the focus of an interdisciplinary ecosystem research project, which has been conducted from 1988 to 2001 (Müller et al. 2006).

The Kielstau Basin is located further north, close to the Danish border (Figure 1) in the district of Schleswig-Flensburg and lies partly within eight municipalities. The Kielstau Basin (50 km²) is a subbasin of the River Treene and a typical lowland basin with high river groundwater levels and low gradients. The river Kielstau is 17 km long and has several tributaries (Fohrer and Schmalz 2012). Haplic luvisols are the predominant soil type in the eastern part of the basin, while stagnic luvisols occur in the west. Sapric histosols are found along the Kielstau and its tributaries (Kiesel et al. 2009). The main river passes Lake Winderatt, which has been protected since 1972 (LLUR 2012; Figure 1). Since 1989 the former agricultural areas around the lake have been protected; nowadays they are used as extensive pastures in combination with a recreational area for hiking, nature protection, and environmental education. Since 2005 the basin is monitored and modelled intensively regarding water quality, sediment yield, water level, and hydrobiology (Fohrer and Schmalz 2012).

Based on the characteristics and peculiarities of both case study areas and the available data from past and recent monitoring and research programmes, the case study areas are considered suitable for the assessment and quantification of changes in LULC and ecosystem service dynamics.

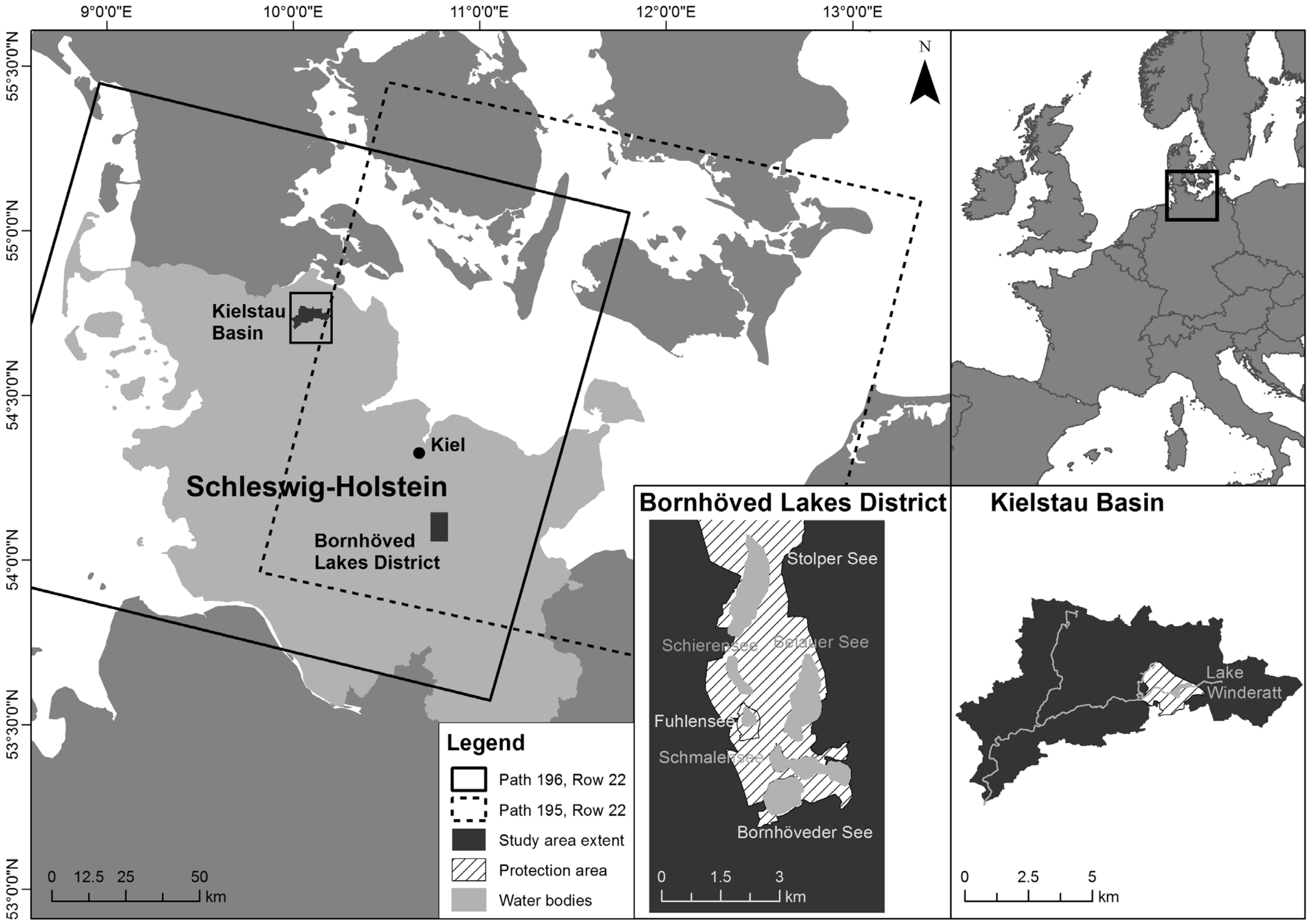

Figure 1: The Kielstau Basin and the Bornhöved Lakes District study areas and the location of the Landsat scenes

3 Methods

Figure 2 schematically illustrates the workflow to retrieve LULC maps, LULC changes, and crop rotations for assessing ecosystem services and their changes. The first step was the classification of available remote sensing data (Landsat TM). Based on the derived LULC classes and available data for quantification, assessments for selected ecosystem services were conducted. The focus was on provisioning services (crops, fodder, biomass for energy, livestock, and mineral resources) (Kandziora et al. 2013a) because they are the group of ecosystem services that can be directly deduced from LULC data, whereas regulating and cultural services strongly depend on the interaction of several ecosystem services and other factors like geological material, climate, topography, management measures and human perceptions. In this study regulating services and cultural services are not considered because respective modelling results for the quantification of regulating services and further quantification approaches on cultural services will be included in the next methodological assessment.

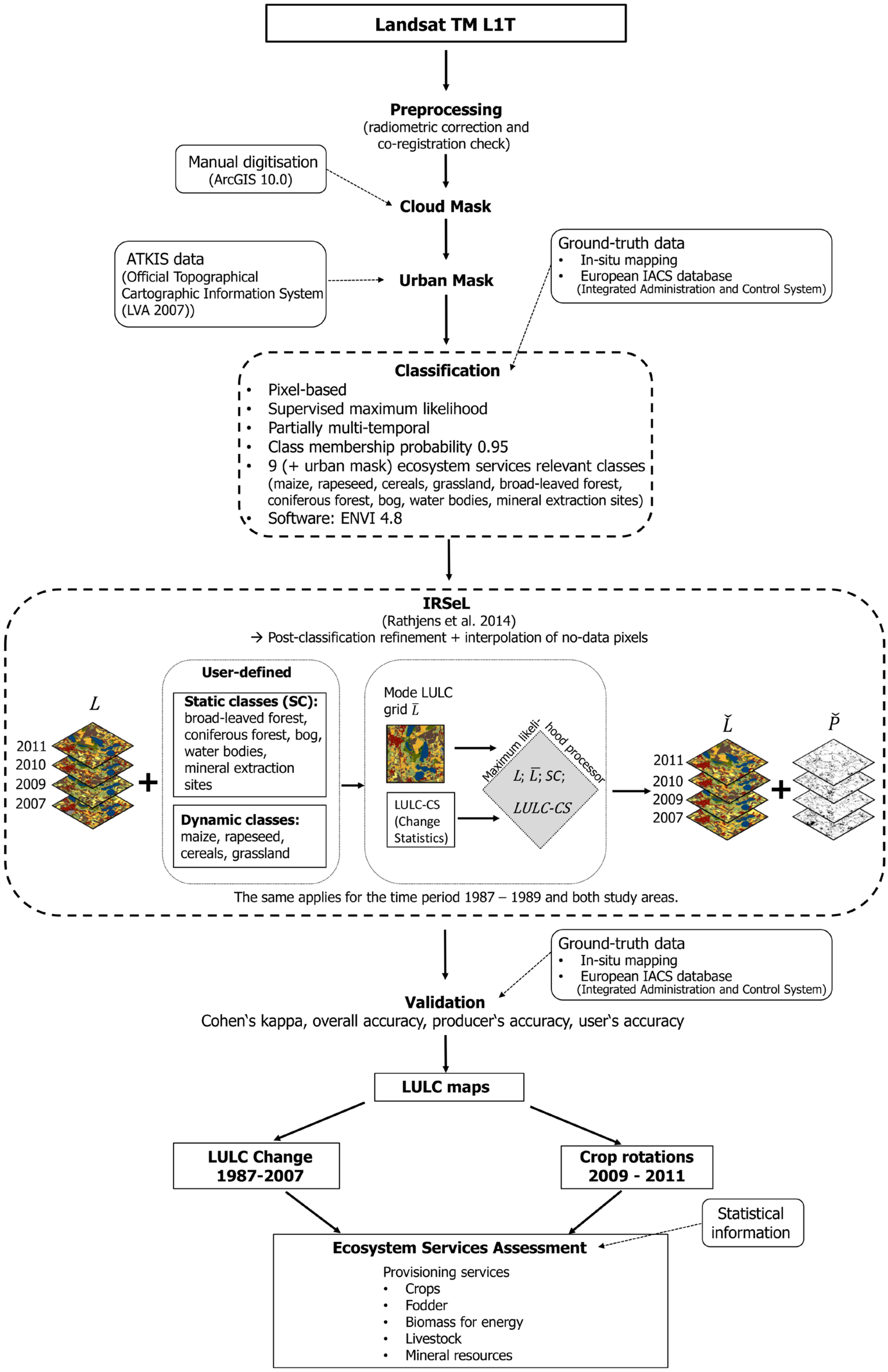

Figure 2: Methodological procedure for the assessments in the case study areas

3.1 Remote sensing preprocessing and land cover classification

For both study areas, eleven Landsat TM images were available to derive LULC maps. Table 1 provides a detailed list of the acquisition dates. Landsat path 196, row 22 entirely covers both study areas. Additionally, the Bornhöved Lakes District is located within Landsat path 195, row 22 (Figure 1); scene subsets were used to classify the study areas (Kielstau Basin: 702 x 502 pixels; Bornhöved Lakes District: 597 x 524 pixels). The United States Geological Survey Earth Resources Observation and Science Center provided L1T data (level-one-terrain-corrected). For both study areas high cloud coverage was the main limiting factor for image availability. Images were geo-referenced on Transverse Mercator UTM zone 32N (WGS84) and showed highly accurate co-registration with Rout-mean-squared errors (RMSE) < 1 pixel (Table 1). Landsat TM has a spatial resolution of 30 m in the optical wavebands and 120 m in the thermal waveband (USGS 2013), whereas only the reflective bands with a pixel resolution of 30 m were used in this study. Conducted radiometric correction encompassed the conversion of the original grey values [*Digital Number*] into radiances [*W/(m² µm)*] according to the equations suggested by Chander et al. (2009). Referring to the discussion of Song et al. (2001) atmospheric correction was considered unnecessary. The green (band 2), red (band 3), near-infrared (band 4) and mid-infrared (band 5 and 7) wavelengths formed the spectral input for the classification; the blue wavelengths (band 1) were not included due to their sensitivity to atmospheric influences. In the case where more than one suitable data set per year was available all scenes were merged and used as one dataset for a multi-temporal classification of the respective year (Table 1). Thus, class separability benefited from phenological or seasonal characteristics of land cover types (Pax-Lenney and Woodcock 1997). Clouded areas were manually digitised and masked

Table 1: Landsat TM acquired for the period 1987 – 2011 (path 195, 196, row 22), co-registration accuracy and available ground truth data

Year	Path 195	Path 196	Kielstau Basin		Bornhöved Lakes District		Co-Registration Accuracy		Ground truth data
			Usage	Cloud coverage [%]	Usage	Cloud coverage [%]	RMSE-Y	RMSE-X	
1987		18th April	x	0	x	0	0.7017	0.6851	Field mapping Bornhöved Lakes District
	27th April			-	x	0	0.6022	0.6425	
		7th July	x	0	x	0	0.7154	0.6574	
1989		25th May	x	0	x	0	0.8124	0.7094	Field mapping Bornhöved Lakes District
	5th July			-	x	0	0.6719	0.6875	
2007		25th April	x	1.8	x	0	0.6853	0.6578	ATKIS*, IACS**
2009		3rd July	x	0	x	0	0.7018	0.6295	ATKIS, IACS, field mapping
		20th August	x	0		0	0.8063	0.9315	
2010		4th June	x	0	x	9.4	0.7350	0.6581	ATKIS, IACS, field mapping
		7th August	x	2.2	x	0	0.6243	0.5223	
2011		6th May	x	0	x	0	0.6527	0.5176	ATKIS, IACS, field mapping

*Official Topographical Cartographic Information System, ** Integrated Administration and Control System prior to the classification. Pixels with sealed land cover often show a wide spectral variability (mixed pixel problem) resulting in an overestimation of sealed areas (Yuan et al. 2005). Therefore, a sealed area mask retrieved from the ATKIS 2007 database (Official Topographical Cartographic Information System; LVA 2007) was used to extract sealed areas from all data sets preventing erroneous extents. Actual land cover, as well as their relevance for ecosystem service supply, determined the definition of nine spectral classes, i.e., maize, rapeseed, cereals, grassland, broad-leaved forest, coniferous forest, bog, water bodies, and mineral extraction sites (the last class only in the Bornhöved Lakes District). Supervised image classification requires ground truth data to both train and validate the classifier (Campbell and Wynne 2011). High quality ground truth data originated from different sources (Table 1) including detailed field mappings, ATKIS database (LVA 2007), and annual agricultural data on field block level of the European IACS (Integrated Administration and Control System) database (MELUR 2010). The ground truth dataset was randomly divided into two datasets: one intended to train the maximum likelihood classifier and the second one for accuracy assessment. After selecting training pixels, their class histograms were checked for normality before applying a maximum likelihood classification implemented in the image processing software ENVI 4.8 (ITTVIS 2010). Using the statistics of the training pixels, the maximum likelihood classifier calculates probability density functions for each class. The pixels were then allocated to the class that showed the highest probability considering all spectral bands. A pixel remained unclassified, i.e., was not assigned to any class if all probabilities were below a user-defined threshold which was constantly set to 0.95 (Campbell and Wynne 2011).

3.2. Post-classification refinement with IRSeL and validation

Post-classification refinements performed with IRSeL (Improvement of Remotely Sensed Land Cover) (Rathjens et al. 2014) interpolated “no data pixels” (unclassified or cloud masked) and reduced potential classification errors. IRSeL is a tool that derives crop rotation or land use change statistics from remotely sensed LULC data sets L (Figure 2). Furthermore, IRSeL generates a map of average LULC $\bar{L}$ retrieved from the classification data set. The user defines LULC classes that are expected to be temporally static. In this study, the classes broad-leaved forest, coniferous forest, water bodies, bog, and mineral extraction sites were separately considered static for the 1980es and 2000es periods. IRSeL then integrated the user-defined static classes, crop rotation statistics, and spatial neighbourhoods of a pixel to allocate a LULC class to “no data pixels” or to re-allocate pixels with potential classification errors, i.e., pixels assigned to a static class according to the average LULC map received the respective static LULC class even if they were classified differently. Pixels that were correctly classified as a dynamic, i.e. agricultural class, retained the original LULC class. IRSeL also interpolated no data, i.e. unclassified or cloud masked pixels, according to the LULC of a pixel’s spatial neighbourhood and LULC in the previous/following year (crop rotation statistics). Pixels that were classified as a static class, however, which did not match the static classes in the average map, were revised. The resulting maps $\hat{L}$ showed a land cover without “no data pixels“ (Rathjens et al. 2014).

Accuracy assessment following Congalton (1991) was carried out on the IRSeL modified LULC maps. The second data set of the ground truth data served as input to generate error matrices as cross-tabulations of ground truth versus classified pixels. The validation was carried out for each data set, consisting of about 2600 (Bornhöved Lakes District) and 1900 (Kielstau Basin) validation pixels. In 1987 and 1989 accuracy measures of the Kielstau Basin were adopted from the Bornhöved Lakes District for maize, rapeseed, cereals, and grassland since the Kielstau Basin lacked field mapping data. Overall accuracy (OA) and kappa coefficient are accuracy measures addressing the entire classification. Overall accuracy is the share of correctly classified pixels (diagonal elements of error matrix) to all reference pixels. The kappa coefficient includes the off-diagonal elements, i.e., erroneous classification, and allows for agreement by chance (Congalton 1991). Values range between 0 and 1. Values close to 1 indicate a high accuracy; values close to 0 point towards poor agreement between classification and ground truth pixels (Foody 2008).

Producer's (PA) and user's (UA) accuracy represent per-class accuracy measures. The user's accuracy is the share of correctly allocated pixels of a class and the sum of all pixels classified as that class. The percentage of all correctly classified pixels to all reference pixels of the class is the producer's accuracy (Campbell and Wynne 2011). A high value close to 1 means higher accuracies and lower errors of commission (1-UA) and errors of omission (1-PA), respectively. A widely reported, but highly discussed, accuracy target for remotely sensed land cover is 85 % correct allocation (Foody 2008).

3.3 Producing land cover maps, land use / land cover change, and crop rotation maps

The validated data sets represented the final LULC maps. LULC change was assessed by calculating the percentage change between 1987 and 2007 with respect to the area of 1987 (Eq. 1).

$$x_i = \frac{A_2 - A_1}{A_1} * 100, \tag{1}$$

Where represents the rate of change [%] while A_1 and A_2 denote the area of LULC class i at time t_1 (1987) resp. t_2 (2007). Generating a difference map of the 1987 and 2007 LULC information emphasised spatial changes. Changes between agricultural classes (maize, rapeseed, and cereals) were considered as differences due to crop rotations. Combining field mapping data from 1987 and the IACS (Integrated Administration and Control System) data from 2007 enabled accuracy assessment of the LULC change map as previously described. In the Kielstau Basin the lack of ground truth data prevented validation of the LULC changes for the 1980s. Combining the classification results from 2009-2011 revealed 3-years of crop rotation pattern for both study areas.

3.4 Quantification of provisioning services by statistical data

The focus of this study was on provisioning services, which were subdivided into crops, fodder, biomass for energy, livestock, and mineral resources. Table 2 provides definitions for the single ecosystem services, their indicators, and data sources for quantification. All ecosystem services were quantified for the years 1987 and 2007 with official statistical data sets to show changes within two decades.

Table 2: Assessed provisioning services with definition, indicator description, units, spatial scale, and data sources

Ecosystem service and definition	Indicator/unit	Spatial scale	Data source(s)
Crops: harvested biomass used as food for human nutrition	Rapeseed yield (dt/ha/a)	Average data for whole district	Statistikamt Nord (2012)
	Winter wheat yield (dt/ha/a)	Average data for whole district	Statistikamt Nord (2012)
Fodder: harvested biomass used for livestock production	Maize yield (dt/ha/a)	Average data for whole district	Statistikamt Nord (2012)
	Rapeseed yield (dt/ha/a)	Average data for whole district	Statistikamt Nord (2012)
	Hay meadow yield (dt/ha/a)	Average data for whole district	Statistikamt Nord (2012)
Biomass for energy: biomass used to generate energy	Maize yield (dt/ha/a)	Average data for whole district	Statistikamt Nord (2012)
Livestock: here only cattle is quantified which is used for human nutrition	Number of cattle in the municipalities	Number applies to the whole area of the municipalities which are part of the study areas	Statistisches Landesamt Schleswig-Holstein (1989) Statistikamt Nord (2012)
Mineral extraction sites: minerals (here: sand and gravel) excavated from under the surface, e.g. for construction purposes	Number of sites (n)	Study area	Expert valuation

Crops were defined as harvest of plants contributing directly to human nutrition. The indicator for quantification is the annual average yield (dt/ha/a) in the administrative district for winter wheat. Winter wheat covers the largest area of cereals (MELUR 2010) and was therefore used as a proxy because no spectral distinction of cereals into barley and rye, e.g., was possible.

Fodder was calculated by the average yield (dt/ha/a) from maize and rapeseed harvest and the harvested grassland (hay meadow yield (dt/ha/a)) (Statistikamt Nord 2012).

Biomass for energy applied to the harvested maize that is used in biogas plants as primary substrate due to its efficiency in generating energy (MELUR 2011).

Agricultural statistical data were used to quantify the provisioning ecosystem services crops and fodder for the years 1987 and 2007 by multiplying the annual yield with the cultivated area.

Livestock was calculated by the number of cattle in the municipalities which the two study areas are located in. Livestock data was available for 1988 and 2007.

Statistical data for quantification were available at different spatial scales: annual average yield data was available at the district level, whereas data on the number of livestock exist at municipality level but only for selected years. Both case study areas are not identical with the borders of the municipalities. They cover up to approx. 2/3 of the area of some of the municipalities; others account for only a very small part of the case study area. Therefore, the whole areas of the related municipalities were used. As a result, the number of livestock applies to a larger area than the respective case study areas.

Mineral extraction is not considered an ecosystem service in most definitions and studies (Haines-Young and Potschin 2010) but can be of importance in environmental management and decision-making. Depending on the size of the extraction sites, other ecosystem services like landscape aesthetics and also biodiversity can be affected. Here it is considered owing to the development of the mineral extraction sites over the analysed time scale. As no information was available on the amount of excavated material, only the number of mineral extraction sites was used as an indicator for LULC change.

The years 1987 and 2007 were compared and it was investigated whether there was an increase in the selected ecosystem service, a decrease, or a new emergence, which obviously is in relation to changes in LULC.

4 Results

4. 1 Land use / land cover classification

Nine LULC classes, grouped as near-natural classes, agricultural, and artificial classes, could be distinguished from the Landsat TM images and sealed areas (from the urban mask). For each year (1987, 1989, 2007, 2009, 2010 and 2011), a LULC map was generated together with a change map. They show the LULC changes between the Landsat acquisitions from 1987 to 2007. Additionally a crop rotation map was created for the years 2009-2011. Figure 3 and 4 show the maps for the Bornhöved Lakes District and the Kielstau Basin, respectively. For both study areas the distinction of agricultural crops performed well and field structures appeared clearly in all classification results. In the Bornhöved Lakes District, mineral extraction sites and bogs were classified with high accuracy. In both areas, the small forested areas showed high accuracy measures. Due to the six lakes in the Bornhöved Lakes District the water class showed a higher number of pixels than in the Kielstau Basin; nevertheless, high accuracy measures were obtained for both study areas.

After post-classification refinements, the LULC maps showed very high correspondence with the ground truth data. Overall accuracy and kappa exceeded 0.9 for both study areas, except for the Kielstau Basin in 1989 (Table 3 and 4). Agricultural classes (maize, rapeseed, and cereals) exhibited tendencies towards accurate performance exceeding producer's and user's accuracies of 0.9 in most years and for both study areas. Grassland performed slightly better in the Bornhöved Lakes District but presented lower accuracies than agricultural classes. Broad-leaved forest, sealed areas and water bodies were on a very high accuracy level. Coniferous forest and bogs were more accurate for the Bornhöved Lakes District while both classes tended to show strong differences between user's and producer's accuracies. The low producer's accuracies resulted from an overestimation of pixels classified as coniferous forest or bog.

Table 3: Accuracy assessment for the Bornhöved Lakes District land use / and cover maps. Upper part of the table presents per class accuracies (PA and UA); the part below the line contains aggregated (kappa and overall) accuracies

	Accuracy assessment Bornhöved Lakes District											
	1987		1989		2007		2009		2010		2011	
Class	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA
Maize	0.91	0.99	0.93	1.00	1.00	0.84	0.73	0.96	1.00	1.00	1.00	0.88
Rapeseed	0.92	0.98	0.93	0.86	1.00	1.00	1.00	1.00	1.00	1.00	0.80	0.96
Cereals	0.98	0.85	0.75	0.89	1.00	0.90	1.00	0.86	1.00	0.92	0.97	0.89
Grassland	0.94	0.89	0.83	0.63	0.94	0.94	0.99	0.87	1.00	0.98	0.96	0.94
Broad-leaved forest	1.00	0.94	1.00	0.94	0.98	0.96	1.00	0.96	1.00	0.96	1.00	0.96
Coniferous forest	0.89	0.97	0.87	0.97	0.94	1.00	0.94	1.00	0.96	1.00	0.96	1.00
Bog	0.91	1.00	0.85	1.00	0.71	1.00	0.61	1.00	0.56	1.00	0.70	1.00
Sealed area	0.97	0.99	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	0.91	1.00
Water bodies	1.00	1.00	1.00	0.99	1.00	0.95	1.00	0.95	1.00	0.95	1.00	0.95
Mineral extraction sites	1.00	1.00	0.94	1.00	0.80	1.00	0.89	1.00	0.91	1.00	0.88	1.00
Kappa coefficient	0.9509		0.9199		0.9568		0.9405		0.9735		0.9374	
Overall accuracy	0.9569		0.9309		0.9620		0.9472		0.9765		0.9445	

Table 4: Accuracy assessment for the Kielstau Basin land use / land cover maps. Upper part of the table presents per class accuracies (PA and UA); the part below the line contains aggregated (kappa and overall) accuracies

	Accuracy assessment Kielstau Basin											
	1987		1989		2007		2009		2010		2011	
Class	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA	PA	UA
Maize	0.91	0.98	0.93	0.99	1.00	0.94	1.00	0.78	1.00	0.98	1.00	0.98
Rapeseed	0.92	0.98	0.93	0.87	1.00	0.97	1.00	1.00	1.00	1.00	1.00	0.99
Cereals	0.98	0.79	0.75	0.92	0.97	0.93	1.00	1.00	1.00	0.94	0.97	0.97
Grassland	0.94	0.86	0.83	0.66	0.96	0.91	0.78	0.89	0.95	0.85	0.88	0.85
Broad-leaved forest	0.98	0.88	0.99	0.96	0.99	0.88	0.99	0.90	0.99	0.91	0.99	0.86
Coniferous forest	0.46	1.00	0.84	0.95	0.48	0.95	0.76	0.95	0.52	0.98	0.95	0.45
Bog	0.87	1.00	0.76	1.00	0.59	1.00	0.98	0.98	0.57	1.00	0.53	1.00
Sealed area	0.99	0.99	1.00	0.94	0.99	1.00	0.92	1.00	0.99	1.00	0.96	1.00
Water bodies	1.00	1.00	1.00	0.98	1.00	1.00	0.91	1.00	1.00	1.00	0.82	1.00
Kappa coefficient	0.9231		0.8817		0.9293		0.9187		0.9404		0.9168	
Overall accuracy	0.9342		0.8963		0.9389		0.9291		0.9483		0.9282	

4.2 Land use / land cover changes from 1987-2007

Regarding the distribution of LULC classes (Figure 3 and 4) grassland was the dominant land cover in both study areas in the late 1980s. Cereals represented the most often cultivated crop type, followed by rapeseed. Maize made up about 5.6% in the Bornhöved Lakes District and 9.3 % in the Kielstau Basin in 1987. The Kielstau Basin showed small patches of forest area (< 100 ha) where broad-leaved forest prevailed. Larger broad-leaved and coniferous forests were present in the Bornhöved Lakes District. Only small bog sites existed in both study areas. The lakes formed a water area of about 440 ha (7.4 %) in the Bornhöved Lakes District, whereas Lake Winderatt is the only water body in the Kielstau Basin.

Two decades later, forest cover has increased in both study areas, especially the broad-leaved forest of the Bornhöved Lakes District. Slight reductions occurred in the LULC classes bog and water bodies. Mineral extraction sites extended about 60 ha (2007) in the Bornhöved Lakes District and were only marginally present on one site in 1987. One of the three mineral extraction sites which have been visible in the LULC since 2007, started excavating sand and gravel in 1996 (Wandhoff 2013).

With respect to agricultural classes and grassland, strong changes occurred in both case study areas. By 2007 the grassland area decreased by approx. 50 % compared to its extent in 1987 and cereals replaced grassland as the dominant land use. The cultivation of maize increased by 249 % in the Bornhöved Lakes District and increased by 83 % in the Kielstau Basin. The change maps in Figure 3 and 4 emphasize the spatial dimension of changes with an obvious conversion from grassland to agricultural classes. Re-cultivation from agricultural land to grassland partially occurred. Minor changes within near-natural classes were mainly delineated at the lake borders (Bornhöved Lakes District). Figure 5 highlights the retreat of grassland area as well as the shift towards the predominance of crop cultivation. Table 5 shows the share of crops which were cultivated in 2007 on former grassland area. With respect to the accuracy of detected spatial LULC changes (Figure 3 change map) overall accuracy (0.71) and kappa (0.63) were distinctly lower

Table 5: Percentage of agricultural classes in 2007 with respect to former grassland (1987)

	Agricultural classes in 2007		
Grassland in 1987	Maize	Rapeseed	Cereals
Kielstau Basin	26.9	15.8	57.4
Bornhöved Lakes District	44.5	17.0	38.5

Table 6: Overall accuracy (OA), kappa and per class accuracies (PA and UA) for the LULC change map (1987-2007) of Bornhöved Lakes District

Change class	**PA**	**UA**
No change	0.74	0.46
Changes due to crop rotations	0.83	0.84
From grassland to agricultural	0.76	0.67
From agricultural to grassland	0.59	0.92
Changes within near-natural classes	0.35	0.51
From agricultural to mineral extraction sites	0.44	0.97
Kappa coefficient	0.6271	
Overall accuracy	0.7128	

compared to the accuracies of individual LULC maps (Table 3, 4 and 6). Per-class accuracies varied strongly, i.e., changes from agricultural classes to grassland (user's and producer's accuracy > 0.83) performed better than changes in near-natural classes (user's and producer's accuracy < 0.51). According to user 's accuracy (> 0.92) changes from grassland into agricultural classes and from agricultural classes to mineral extraction sites performed best.

Depending on the year, the changes were calculated with regard to the reference year (here 1987), the increase or decrease in the agricultural classes varied. 1987 was chosen due to the higher accuracy compared to 1989. Table 7 shows the changes of all LULC classes for the years 2007, 2009, 2010, and 2011 compared to the reference year. Standard deviation was higher in the Bornhöved Lakes District. The increase in maize cultivation areas in both study areas was largest in 2011 compared to 1987.

4.3. Changes in crop rotation from 2009-2011

Crop rotation could only be assessed for the years 2009-2011 as no continuous time series of Landsat images were available for other years. Both study areas exhibited similar tendencies for both cultivated crops and land cover change (Figure 3 and 4, crop rotation). A mix of cereals and rapeseed represented the most important crop rotation followed by a combination of permanent grassland, maize and cereals because of relatively fertile soils, as shown by Schleuß (1992). Mono-cropping of maize between 2009-2011 was observable but showed a low share of 5-6 %; however, including maize in shorter crop rotations was the second most important practice (mixture of maize and cereals).

Table 7: Change of area [%] of LULC classes in the years 2007, 2009-2011 compared to 1987 and standard deviation (Stdev)

LULC class	Bornhöved Lakes District					Kielstau Basin				
	2007	2009	2010	2011	Stdev	2007	2009	2010	2011	Stdev
Maize	249	89	142	304	85	83	62	57	113	22
Rapeseed	113	110	24	12	47	47	19	41	28	11
Cereals	-24	-11	10	-3	12	28	33	11	26	8
Grassland	-46	-31	-42	-54	8	-51	-44	-32	-52	8
Broad-leaved forest	37	37	37	37	0	14	14	14	14	0
Coniferous forest	-28	-28	-28	-28	0	169	169	169	169	0
Bog	11	11	11	11	0	-75	-75	-75	-75	0
Sealed area	0	0	0	0	0	0	0	0	0	0
Water bodies	-3	-3	-3	-3	0	9	9	9	9	0
Mineral extraction sites	188	188	188	188	0	-	-	-	-	-

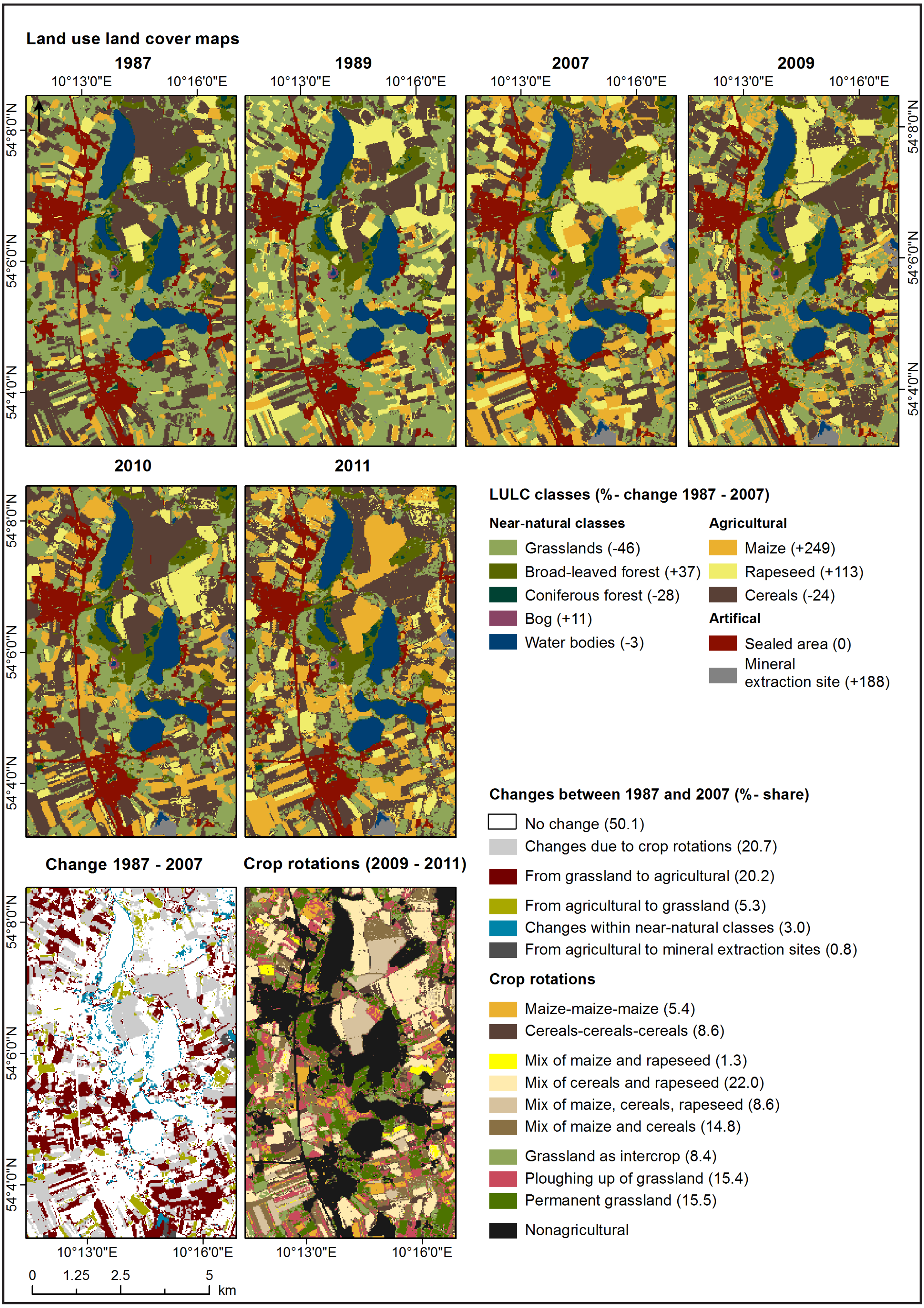

Figure 3: Land use / land cover maps for the Bornhöved Lakes District. Changes [%] in area between 1987 and 2007 are listed in parentheses (see legend) and illustrated spatially in the third row. The third row presents retrieved crop rotations from 2009 – 2011. Share [%] is shown in parentheses (see legend)

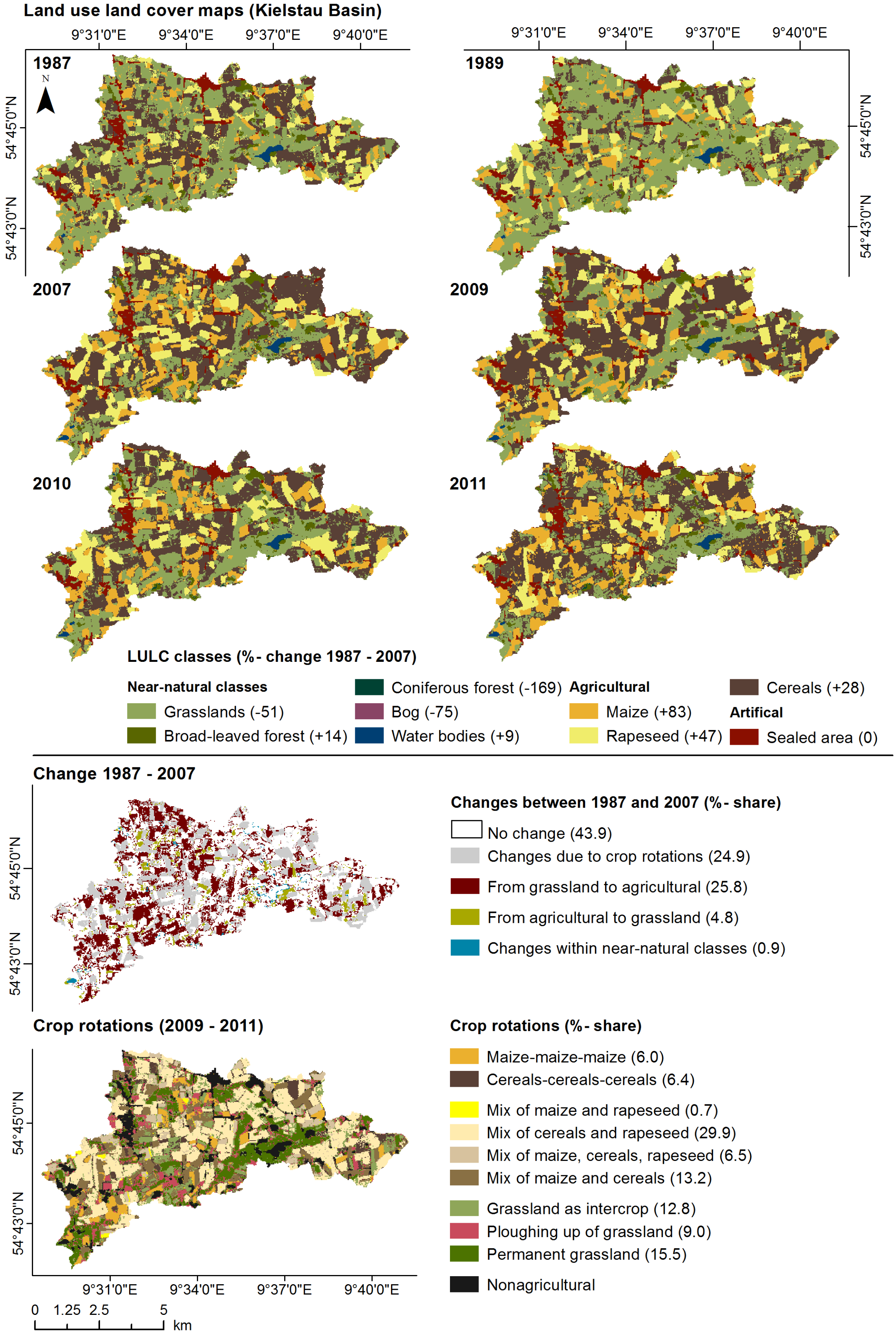

Figure 4: Land use / land cover maps for the Kielstau Basin. Changes [%] in area between 1987 and 2007 are listed in parentheses (see legend) and illustrated spatially in the fourth row. The fifth row presents retrieved crop rotations from 2009 – 2011. Share [%] is shown in parentheses (see legend)

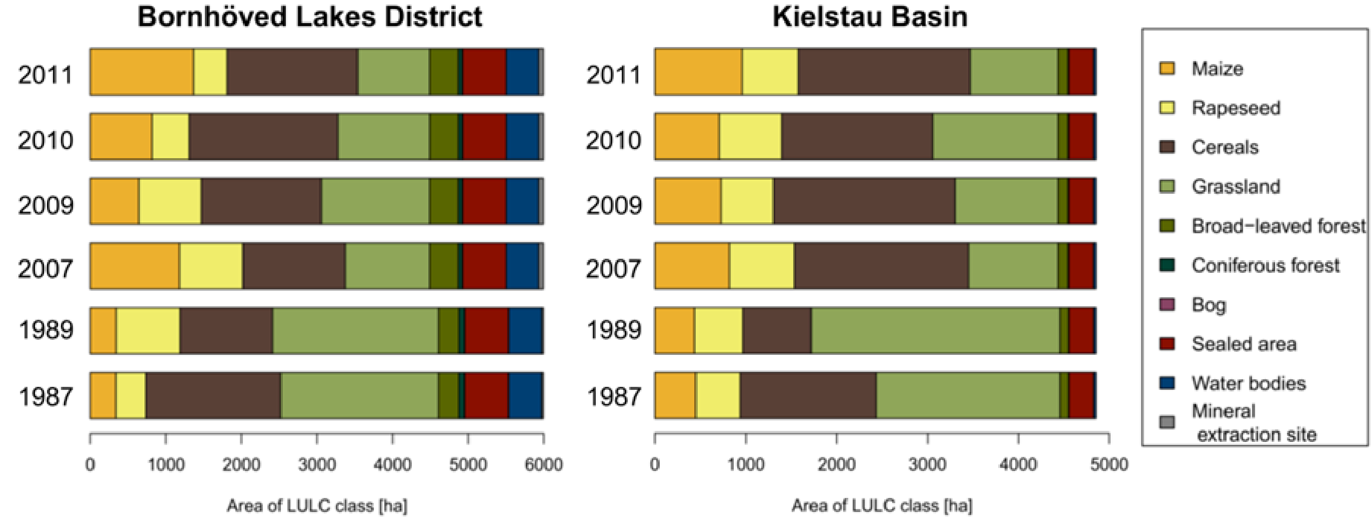

Figure 5: Land use / land cover class areas [ha] of the Bornhöved Lakes District (left) and the Kielstau Basin (right) for the investigated years (1987, 1989, 2007, 2009, 2010, and 2011)

4.4 Changes in ecosystem service supply from 1987-2007

Due to the clear changes in LULC shares for the agricultural areas in both case study areas from 1987 to 2007, several changes in provisioning ecosystem services could be detected. First of all, the decrease in grassland areas was changing the supply of fodder for livestock. This is also connected to the decrease in livestock (Table 8) as the number of cattle has decreased by about one third in both case study areas during 20 years. The harvested fodder from grassland has decreased by about 50 % due to the reduced area as well as lower average yields in 2007 in the districts Plön and Schleswig-Flensburg (Statistikamt Nord 2012).

Second, the increase in maize cultivation is connected to the installation of two biogas plants in each study area (Steen 2013; Hirschberg and Hirschberg n. d.), resulting in a shift in provisioning services from fodder and food supply to the addition of biomass for energy (Table 9). The average harvest for crops differed in 2007 due to a larger share of cereal cultivation in the Kielstau Basin (Table 8).

The LULC maps reveal an addition of two mineral extraction sites in the Bornhöved area due to suitable geological conditions since the beginning of the 1990s.

Table 9 sums up the changes in ecosystem services from 1987 to 2007. The Bornhöved Lakes District shifted the provisioning services supply from fodder, crops, and livestock to biomass for energy, fodder, crops, and livestock production. Mineral extraction was increased by two additional sites in the Bornhöved Lakes District. The LULC changes in the Kielstau Basin resulted in a decrease in the supply of fodder and livestock as well and added biomass for energy supply. Mineral extraction sites are not present in this area.

Table 8: Changes in provisioning services in both study sites from 1987-2007

	Bornhöved Lakes District		Kielstau Basin	
	1987	**2007**	**1987**	**2007**
Maize (dt/a yield)	95860	461108	96826	318345
Rapeseed (dt/a yield)	10602	31438	14480	27145
Cereals (dt/a yield)	133660	98574	105264	144889
Grassland (dt/a yield)	171472	89389	155110	85976
Livestock (number of cattle) *	11624	7692	15264	9468
Mineral extraction sites	1	3	0	0

* data for 1988

Table 9: Changes in selected provisioning ecosystem services from 1987 to 2007. o = ecosystem service was available in this year; / = ecosystem service did not exist in this year; + or – represent an increase / decrease compared to 1987 (based on data from Statistikamt Nord 2012; Statistisches Landesamt SH 1989; expert valuation)

Ecosystem Services	Bornhöved Lakes District		Kielstau Basin	
	1987	**2007**	**1987**	**2007**
Maize (fodder)	o	-	o	-
Maize (biomass for energy)	/	+	/	+
Rapeseed (fodder, crops)	o	+	o	+
Cereals (crops)	o	-	o	+
Grassland (fodder)	o	-	o	-
Livestock (cattle)	o	-	o	-
Mineral extraction sites	o	+	/	/

5 Discussion

Classifying both study areas with a pixel-based maximum likelihood classification approach resulted in highly accurate LULC maps for six years as a basis for delineating LULC changes and assessing ecosystem service dynamics. Nevertheless, the remote sensing approach involves uncertainties which have to be considered for the assessment of ecosystem services together with the uncertainties of the used indicators for quantification of ecosystem services dynamics.

5.1 Remote sensing data set and approach: LULC maps, LULC changes and crop rotation maps

Obtained LULC maps showed very high accuracies that strongly exceeded the 85 % benchmark for thematic mapping in remote sensing applications (Foody 2008). Both study areas were relatively small; detailed, high quality ground truth data sets and partially multi-temporal classification facilitated accurate classification explaining the very high accuracies. Using more than one image of the growing season incorporates phenological characteristics in the classification, which is essential for differentiating grassland and crop types accurately (Pax-Lenney and Woodcock 1997; Franke et al. 2012). Thus, per class accuracies (producer's and user's accuracy) for agricultural classes and grassland exceeded 0.75 throughout. The user's accuracy thus expresses that, e.g., over 86 % (grassland 1987, Kielstau Basin) of the respective LULC class could be located in nature by the end-user. Producer's accuracy means that the analyst correctly classified 94 % (grassland 1987, Kielstau Basin) of the respective LULC class. Clearly visible field structures further underpinned a plausible classification. Moreover, applying a sealed area mask and performing post-classification refinement with the tool IRSeL improved the results, e.g., reduced salt-and-pepper effect of pixel-based classification approaches. With respect to the detection of LULC changes, retrofitting with IRSeL allowed for temporal consistency so that changes resulted rather from LULC changes than classification errors (Rathjens et al. 2014).

Nevertheless, the validation of the Bornhöved Lakes District change map revealed lower accuracies. Post-classification comparison of individual LULC maps to detect changes is subject to spatial inaccuracies and classification errors (Foody 2002). Applying IRSeL on the classification results reduced introduced errors by classification. However, the often disregarded positional accuracy of satellite imagery plays an important role (RMSE in Table 1). The less accurate performance of changes within near-natural LULC classes which depicted small or narrow shapes (Figure 3) underpinned potential errors owing to positional differences. Changes within near-natural classes mainly occurred at lake shores. Mixed spectral signals of water and land in one pixel pose a problem of coarse spatial resolution in classifying the land water interface (Campbell and Wynne 2011). In contrast, changes of LULC in large fields showed higher accuracies; the larger area superimposed positional errors and is not as affected by mixed land covers. Nevertheless, classifying a heterogeneous landscape into 9 or 10 semantic classes on the basis of 30 m spatial resolution always represents a model of reality and involves errors, for instance the explained mixed land covers in one pixel (Boyd and Foody 2011).

Using remote sensing techniques and Landsat imagery, however, enabled the differentiation between agricultural crops, i.e., maize, rapeseed, and cereals which is an important advantage in the assessment and mapping of ecosystem services (Kandziora et al. 2013b). Because they provide different ecosystem services, the distinction between these crop types represents a valuable database for a detailed ecosystem service assessment as different crops account for different provisioning services and influence regulating services, such as erosion control, and cultural services differently (de Vries et al. 2010). Depending on the availability of imagery and ground truth data remote sensing presents a further advantage to obtain LULC data over long time series (Boyd and Foody 2011). Therefore, this study benefited from the long data archive of Landsat TM imagery (Cohen and Goward 2004). Thus, LULC changes could be analysed in both study areas for the time period of two decades. Selecting the year 1987 as change reference was reasonable due to the higher accuracies compared to the 1989 maps. Furthermore, the LULC map of 2007 is the first data set after the commencement (2000) and first amendment (2004) of the German Renewable Energies Act (EEG) (UBA 2011). Since biogas plants were subsidised in the EEG, distinct changes in the agricultural landscape were expected between the two time steps as agricultural statistics showed tendencies towards increased cultivation of maize in Schleswig-Holstein (Statistikamt Nord 2012), which is also noticeable in the further increased area until 2011 (Figure 5). Regarding land cover patterns, both study areas exhibited similar tendencies and were chosen to prove the changes in agricultural landscapes in Schleswig-Holstein. The statistical agricultural data for whole Schleswig-Holstein matched the detected LULC change dynamics: a reduction of grassland area was going along with increased maize and cereal cultivation (Statistikamt Nord 2012; UBA 2011). The strong increase of maize is founded on the more profitable cultivation related to the EEG as has been confirmed by previous studies in nearby locations (Oppelt et al. 2012; MELUR (2011).

Statistical information on cultivated crops revealed that further crops, such as sugar beets and potatoes, were cultivated in Schleswig-Holstein but to a smaller extent (Statistikamt Nord 2013;

MELUR 2010). Deriving separated information from these crops based on Landsat in this region was problematic; depending on image acquisition dates, the spectral behaviour of these crops resolved by Landsat represented a mixture of bare ground and green vegetation. For the sake of similar spectral behaviour and the difficult differentiation from maize in a classification, a separate class was not considered. Therefore, agricultural classes contained a bias, however, constant within the time series.

The LULC grassland included several types of grassland related land use practices, e.g., permanent unused grassland, meadows, or grassland for fodder production. With the data used in this study, conclusions on the practices of the more extended grasslands in the 1980es could be solely drawn by incorporating additional agricultural data. Further information on intensity of use, fertilizer use, and animal distribution must be included when analysing, e.g., regulating ecosystem services and biodiversity. The indicator yield from hay meadows is also only a proxy indicator due to the limited distinction of grassland types. The same applies to the use of winter wheat as a proxy for cereals because other crops, such as rye and barley, could not be distinguished by the applied remote sensing method.

Considering the analysis of the data of three consecutive years, 2009-2011, with regard to crop rotations, information on current grassland use practices was gathered. In both study areas, 15.5 % of the arable land was grassland throughout the three years indicating that this is permanent grassland or meadows. Grassland as intercrop indicated the utilization for fodder. The change class of “ploughed up grassland” were pixels that were grassland in 2009 (and 2010) and a crop fruit in 2010 and/or 2011. The shares of this practice were higher in the Bornhöved Lakes District and a considerable area of grassland conversion within that short period can be deduced. However, the analysis of three consecutive years may lead to a biased view. As explained previously the exact former usage of the grassland areas cannot be derived solely from the LULC maps. Thus, a definite conversion from unused grassland to arable land cannot be deduced. Even though the exact usage is not known, the LULC grassland retreated while the area of arable land increased. With respect to crop rotation practices on arable land, high energy yields per area (Rode 2005) and the self-compatibility of maize lead to tendencies of short crop rotations or even maize mono-cropping (Schultze and Köppel 2007) in parts of Schleswig-Holstein. Due to the discontinued time series of the remote sensing data, no long-term crop rotation practices could be detected. This problem has already been described by Meyer (2000) for the Bornhöved Lakes District. MELUR (2011) recommends, in general, a site-specific crop rotation.

5.2. Ecosystem services assessment: quantification by statistical data

The subgrouping of the provisioning services gives the opportunity to analyse the changes in the supply of the individual ecosystem services. However, the quantification of the individual ecosystem services raises the problem of assigning them indicators. Some data of the agricultural statistics can be assigned to several ecosystem services (e.g., winter wheat for crops and fodder, maize for fodder and biomass for energy). The use of rapeseed for biodiesel production is not considered in this assessment because it applies to another spatial scale since further processing of the biomass is needed, whereas a local relation between the production of maize and the installation of biogas plants can be assumed. Approximately 50 % of the maize yield is used for fodder and 50 % for energy production in biogas plants (MELUR 2011). Other substrates, such as manure and slurry, are used in biogas plants as well. Though the tracking of the substrates to a specific location is difficult (Hirschberg and Hirschberg n. d.; Steen 2013). The correlation between the increase in biogas plants due to energy laws and subsidies and the increase in maize cultivation areas is evident. A further increase in maize area and number of biogas plants in Schleswig-Holstein in the near future is expected (MELUR 2011). For instance, a third biogas plant is planned in the Kielstau Basin (Steen 2013).

The increase in maize cultivation area and the decrease in grassland area are influencing other ecosystem services negatively, especially regulating ecosystem services: e.g., erosion and nutrient loss is increasing because of the low plant cover during most of the year. Negative consequences for the protection of water bodies due to changes in the water and nutrient balance, loss of biodiversity, and abiotic diversity (BfN 2009; MELUR 2012) are expected. The loss of grassland implicates a decrease in the multifunctionality of landscapes. Grasslands contribute notably to landscape aesthetics and landscape beauty, which are cultural ecosystem services. Loss of grassland area in recent years has occurred in other regions in Germany as well (UBA 2011). For that reason, a further analysis of the changes in regulating and cultural services is needed by means of additional data sets and quantification methods (e.g., modelling) compared to the LULC-based quantification method applied here.

Agricultural production area and yields are sensitive to climatic variations (Lorencová et al. 2013), which results in fluctuations of harvest yields and cultivation area. Crop rotation is highly influenced by weather conditions during the sowing periods, such as late sowing due to wet or cold conditions, with a possible shift in future crop rotations. This must be considered when assessing time series. Statistical data have exposed an additional decline in permanent grassland area and an increase in maize cultivation area until 2010 (Statistikamt Nord 2013).

A further increase in the population of wild boars is expected by MELUR (2011), however, in different intensities in the districts in Schleswig-Holstein. The expansion of wild boar is favoured by good food and habitat conditions, which is given by the increase in maize cultivation areas. The main habitats can be found in the southern districts of Schleswig-Holstein. Therefore, the number of hunted animals (which could be used as a quantification indicator for the provisioning service “wild food”; Kandziora et al. 2013a) in 2007 varies largely between the case study areas. The Kielstau Basin is located in a region with a smaller amount of game; especially the number of wild boars is much lower in comparison. An expansion to the north is expected (MELUR 2008; 2012), as well as the further increase in population due to favourable food and habitat conditions.

Mineral resources were analysed in this assessment although they are not a provisioning ecosystem service in its classical meaning. The CICES classification excluded them because they depend more on ‘geodiverstiy’ than on biodiversity and the prevailing processes operating on the long time scale of ecosystem development (Haines-Young and Potschin 2010). But other authors (Brown et al. 2007; Kandziora et al. 2013a) argue for their inclusion. In the case of the Bornhöved Lakes District they provide an example of how other human activities can influence LULC and indirectly the supply of ecosystem services through the decline of agricultural area. There are several mineral extraction sites to the south and east of the study area because of the geological settings of the Kalübber and Trappenkamper Sander (Fischbock and Venebrügge 1990). Thus, this LULC class plays a major role in this research area. On the other hand, this land use might be of limited temporal scale, as the recent development in the Bornhöved Lakes District shows a partial conversion from one of the mineral extraction sites to fallow/agricultural land and the opening of a new one on former agricultural land in 2012.

In general, there is need for further development of suitable indicators for quantifying all existing ecosystem services in a case study area with spatial and temporal explicitness. Derived LULC maps reveal high potential for the application in LULC-based ecosystem services modelling. This information must be included in decision-making and environmental management.

6 Conclusion

The combined remote sensing and ecosystem services quantification approach enabled the detection of LULC changes and resulting shifts in the supply of ecosystem services in both case study areas in Northern Germany. The outcome of this study can be summarised by clear changes in the shares of agricultural and near-natural LULC classes: a decrease in grassland and a change in crop cultivation from 1987 to 2007 revealed a shift from fodder and crop production to the production of biomass for energy generation and a decrease in the supply of fodder and livestock. The crop rotation maps from 2009-2011 exposed further ploughing of grassland in combination with starting maize mono-cropping. In order to draw detailed conclusions for decision-making and management of agroecosystems a further analysis of the effects of these supply changes in provisioning ecosystem services on regulating and cultural ecosystem services is necessary.

The study demonstrated the potential of LULC classifications for the assessment of ecosystem services and their dynamics in more detail. This fact is often neglected. Remote sensing techniques can provide further methodological opportunities for integrated approaches in the assessment of ecosystem services at various spatial and temporal resolutions (e.g., Blaschke 2010; Kennedy et al. 2009). Combining remote sensing and ecosystem services research in interdisciplinary studies may enhance the assessment and monitoring of ecosystem services at different temporal, spatial, and semantic scales.

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