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Mapping provisioning ecosystem services at the local scale using data of varying spatial and temporal resolution

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ABSTRACT

Spatial data on land use and land cover (LULC) are broadly available on different scales and are used widely for mapping ecosystem services as LULC and their changes impact on the provision of multiple ecosystem services. Here four spatial data sets were compared for their practicability as input data for the LULC based assessment method in the Bornhöved Lakes study area. The results for this 60 km² study area are that more detailed land use information (ATKIS and a combined ATKIS/InVeKoS/Landsat data set) is preferred to CORINE land cover data due to the possibility of including spatial details (e.g. number of LULC classes and crop information) in the assessment of provisioning ecosystem services. The CORINE data set overestimated the supply of the two analyzed provisioning services crops and fodder in comparison to the combined data set which revealed information on the specific crops, making quantification with statistical information on yields easier. Spatial input data quality has an effect on the resulting provisioning service maps and quantifications of ecosystem services in the study area due to the identification/omission of ecosystem services, their extent and change. Consequently they also influence decision-making and the development of the ecosystem services concept in the future.

1. Introduction

Mapping of ecosystem services is an arising and significant topic in the scientific community, which is evident in the amount of publications and special issues on the topic in recent time (Crossman et al., 2012). Burkhard et al. (2012a, p.2) define ecosystem services as "the contributions of ecosystem structure and function—in combination with other inputs—to human well-being". This definition includes the highly managed and human-influenced agroecosystems, which are extensively spread globally and provide bundles of ecosystem services (Raudsepp-Hearne et al., 2010) or "agrosystem services" (Papendiek et al., 2012). Maximizing only selected ecosystem services (e.g. agricultural production) causes effects and trade-offs concerning other ecosystem services, ecosystem functions and human well-being (Tallis and Polasky, 2009). Since the concept of ecosystem services has the potential to be brought widely into decision-making and planning (de Groot et al., 2010), the use of maps to visualize ecosystem services and their spatio-temporal distribution in local (Troy and Wilson, 2006), regional (Cheng et al., 2006; Koschke et al., 2012; Kroll et al., 2012; Vihervaara et al., 2010), national (Egoh et al., 2008), continental (Haines-Young et al., 2012; Maes et al., 2011) and global case studies (Costanza et al., 1997) are recognized as a key element. Being spatially explicit is a focal requirement for ecosystem service maps and models which is commonly considered to be of great importance (e.g. Nelson et al., 2009; Tallis and Polasky, 2009; Troy and Wilson, 2006). As a map can only communicate a limited amount of information, most mapping studies focus on selected ecosystem services (e.g. Cheng et al., 2006; Egoh et al., 2008; Eigenbrod et al., 2010; Gulickx et al., 2013; Kroll et al., 2012; Naidoo et al., 2008; Nedkov and Burkhard, 2012; Schulp et al., 2012; Turner et al., 2007; van Oudenhoven et al., 2012). These maps are a prerequisite for ecosystem or urban planning, management and the sustainable use of resources and ecosystem services (Burkhard et al., 2009; Caspersen and Olafsson, 2010; Cheng et al., 2006; Koschke et al., 2012; Schulp and Alkemade, 2011; Tallis and Polasky, 2009) and they also explicitly link ecosystem conservation to human well-being (Fisher et al., 2009; Krishnaswamy et al., 2009).

There are several approaches and methods to quantify, map and evaluate ecosystem services as the following short review reveals. Fagerholm and Käyhkö (2009) give the example of participatory mapping of ecosystem/landscape service indicators in rural environments for a bottom-up management. Social and community values were mapped by Bryan et al. (2010) and Raymond et al. (2009) in the Murray–Darling basin as a counterpart to economic and biophysical mapping. A GIS-based mapping approach for social values of ecosystem services was compiled by

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Sherrouse et al. (2011). For management and policy decisions, ecosystem service distributions and capacities also need to be assessed in scenario comparisons (Nelson et al., 2009; Troy and Wilson, 2006) or comparison of historic land use changes (Lautenbach et al., 2011) and trade-offs (Haines-Young et al., 2012). Metzger et al. (2008) quantify and map spatial vulnerability of ecosystem services in Europe linked to global change. Models like InVEST (Tallis and Polasky, 2009) claim to incorporate both supply and demand, which can differ greatly depending on the case study areas (Burkhard et al., 2012b). There are several other models available for mapping ecosystem service distribution, illustrating an increase in model-based mapping methods (Haines-Young et al., 2012). However, Schulp et al., (2012) state that until recently, there have been no studies which apply the whole function-services framework in the required spatially explicit manner.

Many mapping examples are carried out for economic valuation of ecosystem services based on value-transfer (Cheng et al., 2006; Costanza et al., 1997; Troy and Wilson, 2006). Eigenbrod et al. (2010) discuss the problems resulting from value or benefit transfer methods by extrapolating data to different scales. When modeling and mapping ecosystem services, the input data and spatio-temporal scales of ecosystem service supply should be in comparable scales and resolutions (Burkhard et al., 2012b; Schulp and Alkemade, 2011; Tallis and Polasky, 2009). Konarska et al. (2002) compare two spatial scales (1 km and 30 m resolution of remote sensing data) for economic valuation of ecosystem services for each US state, concluding that there is an increase of ecosystem service values based on the finer resolution data. Wegehenkel et al. (2006) point out the influence of spatial distribution and extent of LULC classes on hydrological model parameters such as runoff and ground water recharge, which are regulating ecosystem services.

Temporal resolution is often low compared to spatial resolution, limiting data sets to 1–2 years. For Europe, the CORINE data sets exist for three time steps until now (1990, 2000 and 2006). Global and continental land cover data sets are derived from remote sensing data, which has been shown by Krishnaswamy et al. (2009) as an appropriate method for e.g. large-area mapping of hydrological and carbon services in combination with habitat and forest variability and biodiversity. However, some ecosystem services act on a rather local scale, with annual variations, for example due to crop rotation in agricultural areas, which need to be explored in more detail.

Though there are a number of approaches, case studies and results, there are still several unanswered questions about the technique of mapping ecosystem services, like data availability as a limiting factor (Troy and Wilson, 2006) combined with limits in user rights of spatial data and methodological uncertainties (Crossman et al., in press).

Here, an assessment method is applied in a case study area in Northern Germany in light of the on-going development of the land cover-based assessment method introduced by Burkhard et al. (2009, 2012b), where CORINE land cover classes were assessed for their capacity to provide ecosystem services. Based on these publications, the following research questions will be discussed:

(i) Are CORINE land cover data suitable as land cover input data for a local scale ecosystem services assessment case study?
(ii) What are the advantages and limitations of other available official land use/land cover data sets for assessing ecosystem services on the local scale?
(iii) For the quantification of ecosystem services, the question is if the available official statistics give enough information to quantify ecosystem services in a sufficient amount for mapping provisioning services in this local case study.

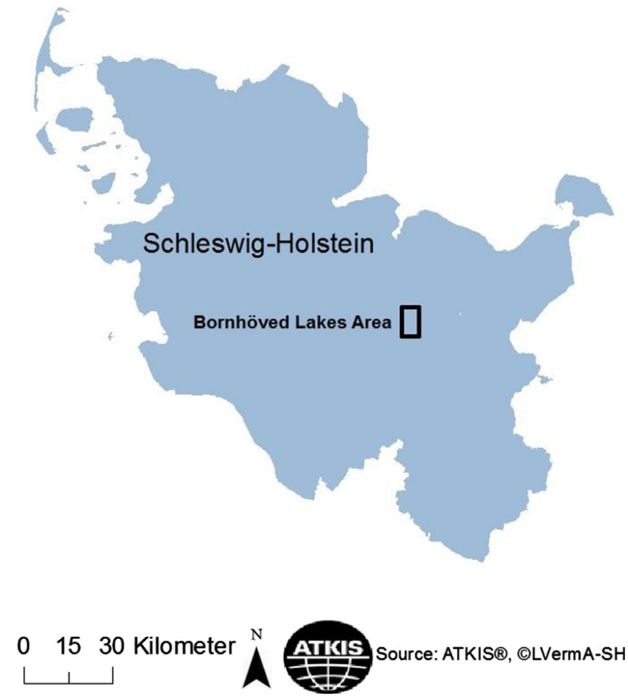

Fig. 1. Study area location in Schleswig-Holstein, Northern Germany.

First, four spatial datasets are introduced: CORINE, ATKIS, InVeKoS and a Landsat classification data set. These data sets are partly aggregated to three, which are used to generate LULC maps and their information content is compared. Then two provisioning services are quantified and mapped for the years 1990, 2000, 2006 (CORINE) and 2010 (ATKIS and the combined data set ATKIS/InVeKoS/Landsat). Based on the quantification and the resulting ecosystem services maps, the advantages and disadvantages of the data sets and LULC-based maps, together with further questions on mapping ecosystem services, are discussed.

2. Materials and methods

2.1. Study area and selection of provisioning ecosystem services

The study area is the Bornhöved Lakes Area, located in Northern Germany in the state of Schleswig-Holstein, approximately 30 km southwest of Kiel (Fig. 1). This study area was the focus of a 12-year integrative ecological study project (Fränzle et al., 2008) and is today part of the LTER network (LTER: Long-term ecological research; Müller et al., 2010).

Six glacially formed lakes (surface area ranging between 1.13 and 0.27 km²) and agroecosystems are the dominating landscape features. Forested areas, primarily around the lakes, and small settlements, which are larger in the west, are part of the study area as well (Fränzle et al., 2008; see Figs. 2–4).

For this analysis, the borders of the study area are defined by official topographic map sheets (German DGK scale 1:5000) resulting in a case study area of 60 km². The northern part of the case study area belongs to the administrative district of Plön, whereas the southern area is part of the district Segeberg.

As large parts of the case study area are used for agricultural production, the focus of this study is on provisioning ecosystem services. In this case, the provisioning ecosystem services were subdivided into “crops” for human nutrition and “fodder” for livestock breeding. Table 1 gives short definitions and potential indicators for the quantification of the two provisioning services.

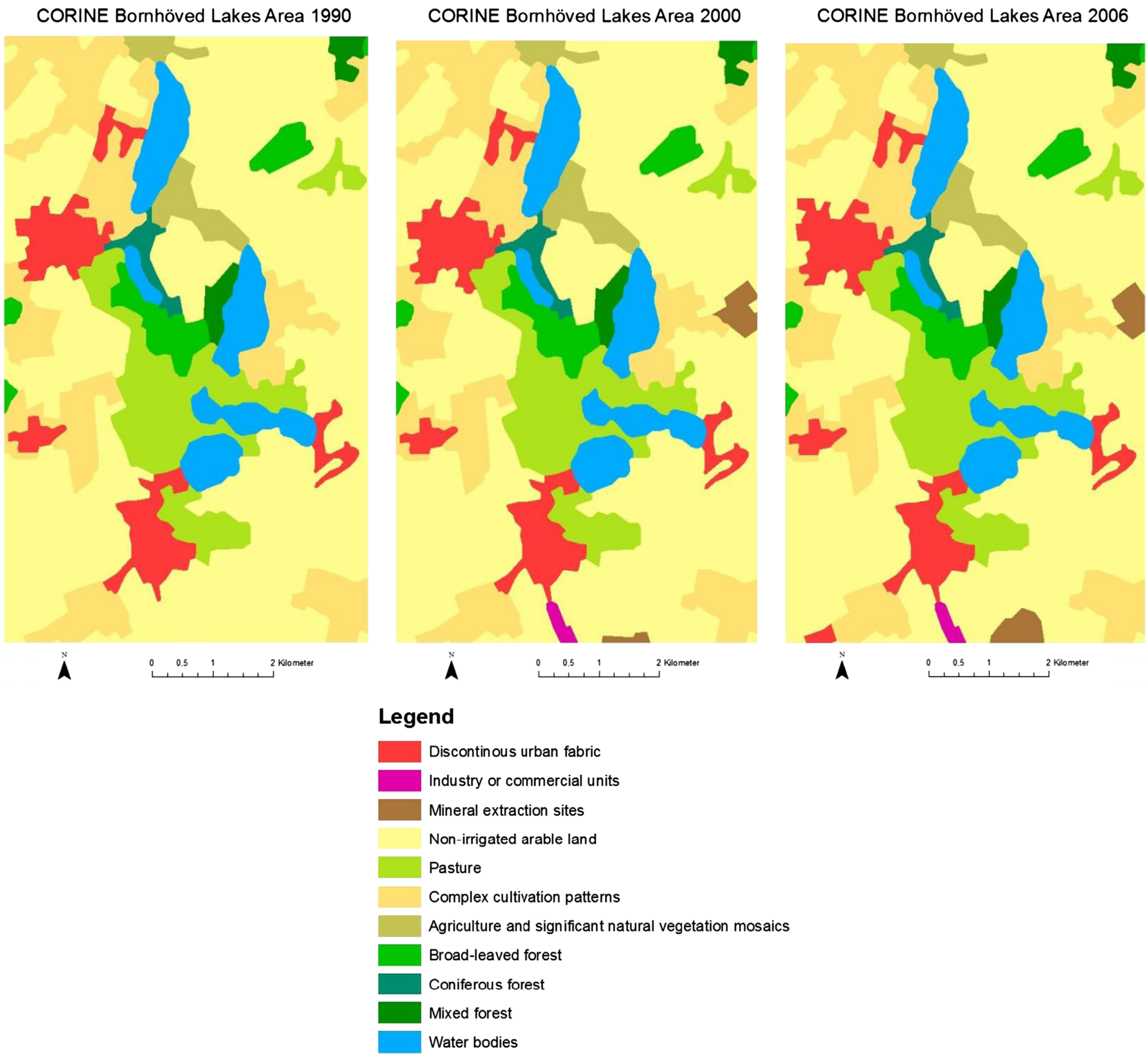

Fig. 2. Land cover changes in the Bornhöved Lakes Area based on CORINE from 1990 (left), 2000 (middle) and 2006 (right).

A further possible subdivision of ecosystem service is given in Kandziora et al. (2013).

2.2. *Input data for land use/land cover maps and mapping provisioning ecosystem services*

Four spatial data sets, CORINE land cover, ATKIS topographic data, InVeKoS agricultural data and a Landsat TM 5 maximum likelihood classification, were investigated to distinguish differences in LULC (e.g. number of classes) as well as their spatial and temporal resolution and the attributes of each class (for a summary see also Table 2):

2.2.1. *CORINE land cover*

CORINE land cover (CLC) is based on remote sensing data and has a minimum mapping unit of 25 ha. The data are available for the European Union member states for the years 1990, 2000 and 2006 for standardised comparisons of land cover. Datasets are available for download as 100 m grids, 250 m grids and 1 km grids from the European Environmental Agency, containing 44 land cover classes (Level 3) for Europe (Bach et al., 2006; Burkhard et al., 2009; Wegehenkel et al., 2006). For this study, the vector data sets for the case study's land cover classes for the three available years were used, which include the changes in land cover compared with the previous year. These data sets were also used to visualize the land cover changes in the Bornhöved Lakes area from 1990 to 2006 by comparing the maps generated with a Geographic Information System (GIS; ArcGIS 10) and analyzing the areas (%) of the land cover classes.

2.2.2. *ATKIS (Amtliches Topographisch–Kartographisches Informationssystem; Official Topographic–Cartographic Information System)*

ATKIS (Landesvermessungsamt SH) is the official German topographic information system for all federal states, which is updated on a regular basis by orthophotos and topographic surveys. The vector data set contains polygons (e.g. agricultural areas, lakes), linear features (e.g. rivers, streets) and points (e.g. towers, single trees).

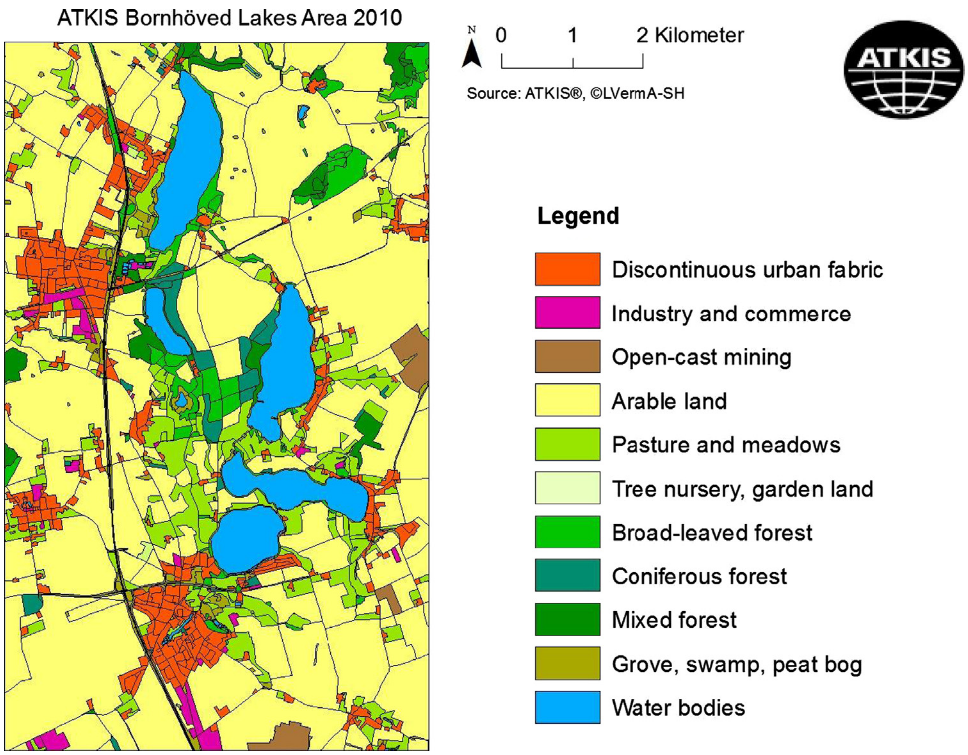

Fig. 3. Land use/land cover map based on ATKIS data for the Bornhöved Lakes Area for the year 2010.

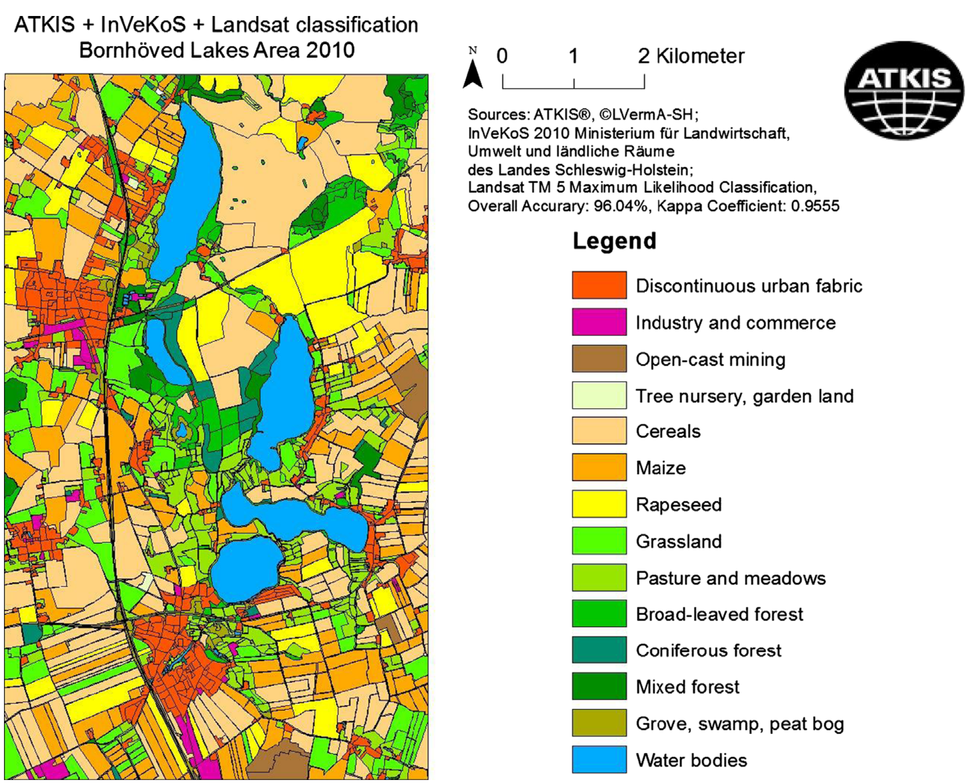

Fig. 4. Combined land use/land cover map for the Bornhöved Lakes Area in the year 2010 based on ATKIS, InVeKoS and the multiseasonal Landsat TM 5 maximum likelihood classification.

The minimum object sizes and the positional accuracy vary for each feature class (Bach et al., 2006). The detailed supplementary object catalog contains a semantic description for each object, enabling the user to obtain more detailed information (Wegehenkel et al., 2006; Weis et al., 2005). Only the polygon features were considered in this analysis because of the need to analyze provisioning service areas.

2.2.3. InVeKoS (Integriertes Verwaltungs- und Kontrollsystem; Integrated Administration and Control System (IACS))

InVeKoS is a control system established by the European Commission for institutional applications. It is a GIS-based system to identify agricultural areas in the European Union member states with a spatial GIS-geometry based on orthophotos. In order to

Table 1
Selected provisioning ecosystem services with definitions and potential indicators for quantification (based on Burkhard et al., 2009; Kandziora et al., 2013).

Provisioning service	Definition	Potential indicators
Crops	Cultivation of edible plants and harvest of these plants on agricultural fields and gardens which are used for human nutrition.	Harvested crops (t/ha a, kJ/ha a) Net primary production (tC/ha a; kJ/ha a) Yield (€/ha a)
Fodder	Cultivation and harvest of fodder for domestic animals.	Fodder plant harvest (t/ha, kJ/ha a) Net primary production (tC/ha a, kJ/ha a) Yield (€/ha a) Area used for harvesting fodder (ha)

Table 2
Summary of data set properties (after Wegehenkel et al., 2006).

	CORINE	ATKIS	InVeKoS	Landsat classification
Availability	Download for free (website of the European Environment Agency)	Official data; Permission required (Landesvermessungsamt Schleswig-Holstein)	Official data; Permission required (Ministerium für Landwirtschaft, Umwelt und ländliche Räume des Landes Schleswig-Holstein)	Satellite images for free (U.S. Geological Survey); classification requires further ground truth data and software
Temporal Resolution	1990 2000 2006	2010	2010	2010 (on request)
Scale/spatial Resolution	Minimum mapping unit 25 ha EU-member states	1:5000 Germany	EU-member states	30×30 m Global (on request)
Information content	Land cover	LULC (points, lines, polygons)	Agricultural areas and their use	Based on available ground truth data

receive funding from the EU, agricultural land owners are required to declare annually what kind of crops are grown and how other farm land is used (e.g. agricultural buildings, fallow land). The available digital spatial geometry is provided on a small scale (field block), whereas land use information is given for individual parcels/fields (each crop and land use receives an individual code). A field block is a continuous agricultural area that is bordered by clearly defined objects like streets, settlements, or forests. One field block can contain several smaller parcels or fields managed by one or several farmers. Therefore, a direct backtracking of cultivated crops on each field is not possible due to privacy protection (Backhaus and Beule, 2005). Due to the anonymization problem and the impossible location of crops on the agricultural area, the data set was here only used to split the large agricultural polygons from the ATKIS data set as landscape elements like hedgerows are included in the InVeKoS data set. So the agricultural areas are representing the individual fields, rather than the larger field blocks in the combined data set. These merged agricultural land use polygons receive the semantic description of the spectral results of the Landsat image classification.

2.2.4. Landsat maximum likelihood classification

Two Landsat TM 5 images were used for the distinction of arable land in the case study area (days of acquisition: June 4, 2010 and August 7, 2010; spatial resolution 30×30 m). A supervised, multitemporal, pixel-based maximum likelihood classification with the software Envi 4.2 (channels 2, 3, 4, 5, 7) has been executed for the study area. Training areas and validation areas were defined with ground truth data (e.g. from field mapping), resulting in a high overall classification accuracy of 96.04%. 10 different LULC classes could be distinguished based on the spectral information. The data set was only considered in combination with the other data sets, as it is the only raster data set, which makes it difficult to continue the comparison with the vector data sets. Therefore only the four LULC classes containing information on arable land were used for this analysis. The classified pixels of cereals, rapeseed, maize and grassland were combined with the agricultural polygons of the ATKIS/InVeKoS data set. As permanent grassland is not distinguishable from non-permanent grassland by the spectral reflection, the area of permanent grassland from the ATKIS set was used to create the maps.

LULC maps were generated for the years 1990, 2000 and 2006 with the CORINE data sets and for the year 2010 with the ATKIS data set and a second time supplemented by the combined ATKIS/InVeKoS/Landsat data set for the year 2010 using ArcGIS 10. The combined LULC map was generated by the ArcGIS tool “union” to avoid overlapping LULC layers.

2.3. Quantification of provisioning ecosystem services using statistical information

Statistical information provided by the Statistics Office of Northern Germany (Statistikamt Nord, 2012) on annual average yields (in dt $ha^{-1}\,a^{-1}$) for 1987–2011 in the two districts of Plön and Segeberg were used for the quantification of crops and fodder provisioning services. The indicators used to quantify crop supply are rapeseed yield and winter wheat yield. Winter wheat was considered as providing the largest share of cereals, as individual species (e.g. barley, rye) could not be identified with the spatial data sets. Maize and grassland yields were used as proxy indicators to quantify fodder supply.

To value the supply capacities of provisioning services in the Bornhöved Lakes Area, a scale from 0 (no relevant capacity) to 5 (very high relevant capacity) was employed (cp. Burkhard et al., 2009, 2012b). For quantification two approaches are possible: assessment of the potential supply of ecosystem services (Haines-Young et al., 2012) and the actual supply capacity for ecosystem services by a specific area (Burkhard et al., 2012b). Here the actual supply capacities are assessed by using the statistical information on average yields in the districts for the respective year. The official statistical information on yields is considered as the best possibility to quantify the final goods of crops and fodder.

The maximum yield (1987–2011) received “very high relevant capacity” (5) with the possibility to increase yields in the future. No relevant capacity (0) refers to the LULC which did not provide any of the crops or fodder (e.g. forest areas and discontinuous urban fabric). The classes from 1 to 5 were equally distributed among the lowest possible yield of 1 (dt ha^{-1} a^{-1}) and the highest yield in the years 1987–2011 (Table 3). As the yields differ in some years in the two districts, an average of the 0–5 scale was calculated, so only whole numbers are given as valuation.

The LULC areas in the three different provisioning service maps receive, based on their actual supply capacities in the specific year, a value from 0 to 5, which results in different provisioning service maps.

As CORINE and ATKIS do not distinguish crops (for human nutrition) from animal fodder plants, the agricultural areas receive the 0–5 value for the whole area. Therefore, the agricultural areas are considered once for the supply map of provision of crops and once for the provision of fodder map.

3. Results

The different LULC maps for the different years are presented first. Then the differences in provisioning service maps are depicted and discussed.

3.1. Differences in land use/land cover maps based on different data sets

The four considered data sets are considerably different in terms of spatio-temporal resolution and information content as described above (Table 2).

The CORINE data sets give a temporal resolution of three individual time steps, spanning over 16 years, while both ATKIS and InVeKoS (geometry) were only available for 2010 for this study. The Landsat TM 5 classification was only carried out for 2010, though more Landsat images are available for classification.

The CORINE-based land cover maps for 1990, 2000 and 2006 are depicted in Fig. 2, distinguishing 9 land cover classes for 1990 and 11 land cover classes for the other years.

Fig. 3 represents the more detailed LULC map which is based on the ATKIS data set. Here also 11 LULC classes can be distinguished, but they are different than the CORINE classes (see Table 4 for a more detailed description). The ATKIS data set contains less agricultural areas than the CORINE data set (see Figs. 2 and 3 and Table 5) for the study area. Agricultural areas in the Bornhöved Lakes Area are divided into pastures, arable land and tree nurseries/garden in ATKIS.

The second map for the year 2010 (Fig. 4) contains the spectral information from the Landsat TM 5 supervised classification for the agricultural areas together with the other LULC classes from ATKIS and the field geometry from InVeKoS. Therefore it is possible to distinguish the share of wheat, maize and rapeseed as well as grassland areas (permanent and non-permanent), increasing the number of LULC classes to 14. The sizes of fields are much larger in the northern part of the case study area, whereas the southern fields are smaller and more fragmented, which cannot be observed in the CORINE data.

Differences in area extent for selected classes are provided in Table 5, which demonstrate the larger extent of agricultural areas in the CORINE data set and a smaller extent in discontinuous urban fabric, forest and water areas. The pasture area is only by 0.2 km^2 smaller in the CORINE data set but the arable land is 5.3 km^2 larger in comparison to ATKIS. The small variations of 0.4 km^2 between the ATKIS data set and the combined ATKIS/InVeKoS/Landsat data set occurs due to minor spatial accuracy problems in the data sets sources. The CORINE class “Complex cultivation patterns” contains pasture areas and arable land, where the spatial location of crops and fodder supply areas cannot be explicitly placed. “Agriculture and significant natural vegetation mosaics” is a mixed class of not only agricultural use, but also natural areas, which provide different ecosystem services.

The combined LULC map for the year 2010 shows only relevant variations for the agricultural areas, as only the agricultural classes of the Landsat classification were applied. The distribution and share of the detected crops (cereals—16.8 km^2, maize—9.1 km^2, rapeseed—6.3 km^2) is clearly visible in the LULC map in Fig. 4. As the spectral information for permanent (pastures) and non-permanent grasslands (annual field grass) reveal no difference, a distinction cannot be made. Therefore the spatial information of pastures and meadows from the ATKIS data set were used for the combined LULC map. Grassland refers to the non-permanent grasslands which were additionally detected by the spectral signature.

3.2. Land cover changes in the Bornhöved Lakes Area

The CORINE data set is the only data set presented here, which gives the opportunity to characterize the changes in land cover as a base for the analysis of changes in ecosystem service supply.

Table 3
Quantification scheme for the provisioning ecosystem services crops and fodder (yield data source: Statistikamt Nord, 2012).

	Crops (average yield of winter wheat in the districts of Segeberg and Plön (dt ha^{-1} a^{-1}))	Crops (average yield of rapeseed in the districts of Segeberg and Plön (dt ha^{-1} a^{-1}))	Fodder (average yield of maize in the districts of Segeberg and Plön (dt ha^{-1} a^{-1}))	Fodder (average yield of grass in the districts of Segeberg and Plön (dt ha^{-1} a^{-1}))
0=no relevant capacity	0	0	0	0
1=low relevant capacity	1–19	1–9	1–87	1–22
2=relevant capacity	20–39	10–19	88–175	23–45
3=medium relevant capacity	40–59	20–29	176–266	46–68
4=high relevant capacity	60–79	30–39	267–353	69–91
5=very high relevant capacity	>80	>40	>354	>92
Average (1987–2011)	*82.5*	*35.5*	*351.9*	*87.9*
1990	79.2	32.9	366.8	94.0
2000	92.3	39.4	346.1	98.7
2006	84.6	37.5	314.2	80.1
2010	86.7	41.9	313.6	73.0

Table 4
LULC classes for the study area for the three spatial data sets as a comparison (based on Burkhard et al., 2009; supplemented by ATKIS object catalog file information).

CORINE land cover class and code	ATKIS land cover/land use class	Landsat TM 5 maximum-likelihood classification
112 Discontinuous Fabric Buildings, roads and artificial surfaced area cover between 50 and 80 % of the total surface area; they are associated with vegetated areas and bare soil. **121 Industrial or commercial units** Entire industrial or commercial complexes, including access roads, landscape areas, car parks, wasteland etc. (e.g. sanatoriums, spa facilities, hospitals, rest homes, military bases, educational establishments, university sites, commercial centers, waste water treatment plants).	**Discontinuous urban fabric** contains in ATKIS for Bornhöved parking lots, residential and public buildings, cemeteries and public open space and green areas for leisure/tourism. Streets are included as being part of the discontinuous urban fabric class. **Industrial and commerce units** can be subgrouped into nursery, waste water treatment and water works for this case study.	Sealed areas (buildings and streets) (not considered here)
131 Mineral Extraction Sites Area with open-pit extraction of construction material (sandpits, quarries) or other minerals (open-cast mines). Includes flooded gravel pits, except for river-bed extraction. This heading includes buildings and associated industrial infrastructure (e.g. cement factories) and small water bodies of less than 25 ha created by mining.	**Open cast mining** can be specified for Bornhöved as only being gravel and gravel-sand mines.	Open-cast mining (not considered here)
211 Non-irrigated arable land Cereals, legumes, fodder crops, root crops and fallow land. Includes flowers and tree nurseries, vegetables in green houses, aromatic, medical and culinary plants. **231 Pastures** Dense grass cover, of floral composition, dominated by graminacea, not under a rotation system. Mainly for grazing, but the fodder may be harvested mechanically. Includes areas with hedges (bocage). **242 Complex Cultivation Patterns** Juxtaposition of small parcels of diverse annual crops, pasture and/or permanent crops, provided that none of these three categories cover an identical surface unit of more than 25 ha within a single land unit. Arable land, pasture and orchards each occupy less than 75% of the total surface area of the unit. City gardens are included in this category.	**Agricultural areas** are divided into cropland, pasture and tree nurseries/garden land for the Bornhöved case study area.	Cereals Maize Rapeseed Grassland
243 Agriculture and significant natural vegetation mosaics Areas principally occupied by agriculture, interspersed with significant natural areas. Agricultural land occupies between 25 and 75% of the total surface of the unit. Hedge (bocage) areas are excluded from this category.	**Grove, swamp and peat bogs** including nature-near areas.	Pet bogs (not considered here)
311 Broad-leaved forest Vegetation formation composed principally of trees, including shrub and bush understoreys, where broad-leaved species predominate. Broad-leaved trees must represent more than three-quarters of the surface unit in this category. Young coppices and young plantations belong to this category.	**Broad-leaved forest**	Broad-leaved forest (not considered here)
312 Coniferous forest Vegetation formation composed principally of trees, including shrub and bush understoreys, where coniferous species predominate. Surface planted with conifers must represent at least 75% of the total surface of the unit; otherwise the unit is one of mixed forest.	**Coniferous forest**	
313 Mixed forest Vegetation formation composed principally of trees, including shrub and bush understoreys, where neither broad-leaved nor coniferous forest in the strict silvicultural sense (single tree or clump mixtures), but also complex forest parcels comprising an intricate mosaic of broadleaved and softwood species where no homogenous stand of more than 25 ha can be distinguished.	**Mixed forest**	Mixed forest (not considered here)
512 Water Bodies Natural or artificial stretches of water. Includes the water surface of dams.	Here all **water bodies** (lakes, ponds and artificial water bodies, also in the discontinuous urban fabric areas) are included for the study area.	Water bodies (not considered here)

Comparing the CORINE land cover maps in Fig. 2 for the years 1990, 2000 and 2006, only small changes in land cover in this area are detectable. For 1990, only nine land cover classes can be distinguished in Bornhöved. For 2000, changes occurred with the addition of the classes "mineral extraction site" and "industrial and commerce" due to economic development in the case study area.

However, the area has been dominated by agriculture for decades which comprises of the largest share of the case study area. From 1990 to 2000, "non-irrigated arable land" (CORINE code 211) was converted to "discontinuous urban fabric" (112), "industrial and commerce units" (121) and "mineral extraction sites" (131), pointing out human-induced economic pressures in this area.

During the years 2000–2006, human settlement sprawl continued, resulting in a continuous increase in "discontinuous urban fabric" from 6.4% to 6.8%. The most significant change occurs in the "mineral extraction site" extent (increase from 0 to 1.2% land cover from 1990 to 2006) and location, as the "mineral extraction site" in the east of the study area was changing its location with "non-irrigated arable land".

Table 5
Areas (km²) for selected LULC classes for the Bornhöved Lakes Area.

	CORINE 2006	ATKIS 2010	ATKIS+InVeKoS +Landsat 2010
Area in km²			
Agricultural area (arable land +pasture)	47.8	42.7	43.2
Arable land	*42.4*	*37.1*	*Rapeseed 6.3* *Cereals 16.8* *Maize 9.1* *Grassland 5.0* *Other 0.4*
Pasture	*5.4*	*5.6*	*5.6*
Discontinuous urban fabric	4.1	4.7	4.7
Mixed forest	0.7	1.3	1.3
Broad-leaved forest	1.7	2.1	2.1
Coniferous forest	0.5	0.9	0.9
Water bodies	4.2	4.5	4.5

Table 6
Changes in land cover (%) from 1990-2006 in the Bornhöved Lakes Area.

CORINE Land cover	Bornhöved Lakes Area (60 km²)		
	% in 1990	% in 2000	% in 2006
Discontinuous urban fabric	6.4	6.5	6.8
Industrial or commercial units	0.0	0.3	0.3
Mineral extraction sites	0.0	0.8	1.2
Non-irrigated arable land	54.5	53.3	52.8
Pastures	9.0	9.0	9.0
Complex cultivation pattern	15.9	15.9	15.7
Agriculture and significant vegetation mosaics	2.2	2.2	2.2
Broad-leaved forest	2.9	2.9	2.9
Coniferous forest	0.8	0.8	0.8
Mixed forest	1.2	1.2	1.2
Water bodies	7.1	7.1	7.1

The overall decrease in agricultural area is only minor with 1.7%. Over the course of 16 years, there has been no change in the land cover proportions of “pasture”, all three forest types, “agriculture and significant natural vegetation mosaics” and “water bodies”. The land cover changes in % are summarized in Table 6.

3.3. Differences in maps of selected provisioning services based on different land use/land cover data

Based on the average yields for the years 1987–2011, the crop and fodder yields for the years 1990, 2000, 2006 (for CORINE) and 2010 (ATKIS and ATKIS/InVeKoS/Landsat) were evaluated using the 0–5 scale. The resulting maps (Figs. 5–8) reveal the variations in supply capacities of crops and fodder for the investigated years. Yields of agricultural products are affected mostly by changes in temperature and precipitation, resulting in different supply capacities for the individual years (Landwirtschaftskammer, 2011).

The temporal changes show a decreasing supply capacity for fodder and an increasing supply for crops (Figs. 5,6). Due to the highly human-influenced agroecosystems (especially by fertilizer application) the actual supply capacities for crops and fodder are high (4) to very high (5) for all years. Fig. 5 shows the differences in fodder supply the LULC classes “pasture” and “non-irrigated arable land”, “complex cultivation pattern” and “agriculture and significant vegetation mosaics” for the year 2000. The CORINE-based maps are more general in the share of crops and fodder, leading to an assumed overestimation of crops and fodder supply and their distribution. The applied indicators for fodder differ in yields for this year (grass yield for pasture and maize yield for the arable areas) (cp. Table 3). For the other indicators the average in the evaluation values, results in a “very high capacity” value of 5 for the years 2000 and 2006.

The significant difference in comparison to the CORINE-based maps is visible in the maps for the year 2010 (Figs. 7,8), where the share of crops and fodder are smaller when including the spectral information derived from the Landsat classification to distinguish cereals, rapeseed, maize and grassland because their share can then be allocated to a specific agricultural parcel. The comparison of these maps to CORINE reveals less supply of fodder and crops in the year 2010. Hence, including more detailed data allows for a more accurate picture of the distribution of crops and fodder provisioning areas, which is a valuable increase of information for stakeholders and decision-makers.

4. Discussion

Using land cover as a proxy for ecosystem service assessments has both positive and negative effects, but the use of maps for visualization and as a communication tool is widely recognized (Burkhard et al., 2009; Willemen et al., 2012). Comparing the LULC maps (Figs. 2–4) for this Northern German case study area reveals the differences in output when using different spatial data for ecosystem service maps (Figs. 5–8). The more detailed combined ATKIS/InVeKoS/Landsat map in Fig. 4 clearly shows the landscape fragmentation at this local scale. This gives a better idea of the distribution of ecosystem service supply capacities in comparison to the more general CORINE data set. The numbers of LULC classes, which can be identified from the input data set, influence the resulting ecosystem service assessments. When only using LULC, relevant ecosystem services cannot be detected as certain spatial or temporal aspects or LULC classes are not represented in the input data set.

Though being of coarser resolution and information content, the CORINE data set has the advantages of easy and free access as well as Europe-wide coverage for three time steps within a 16-years period giving the chance to compare and transfer ecosystem service assessments to and between regions. Kroll et al. (2012) clearly show the possibility to map changes in selected provisioning ecosystem services due to policy decisions in a regional case study area in Eastern Germany by applying the CORINE data set.

The German-wide ATKIS data set has the advantage of more detailed and higher number of classes and information content for the local scale via the object catalog (e.g. type of mineral extraction site). This fosters specific investigations on the local scale on other ecosystem services.

The most important information for assessing provisioning services from agricultural areas, are related to the individual cultivation, which is available from InVeKoS without the required spatial explicitness. The InVeKoS data set is only applicable in this case as one of the sources for the spatial geometry. The semantic description for the polygons needs to be derived from the ATKIS and the Landsat classification data sets.

The Landsat classification locates the individual crops and gives the opportunity to reduce crop rotations and other factors influencing and interacting with other ecosystem services when several years of classification are available. Knowledge on crop rotation and further cultivation techniques for a longer time period leads to enhanced assessments of further ecosystem services, e.g. erosion regulation, that differs tremendously for various crops, as included in the C-factor of the Universal Soil Loss Equation (e.g. factor 0.50 for silage maize, beans and rape, 0.35 for winter and summer

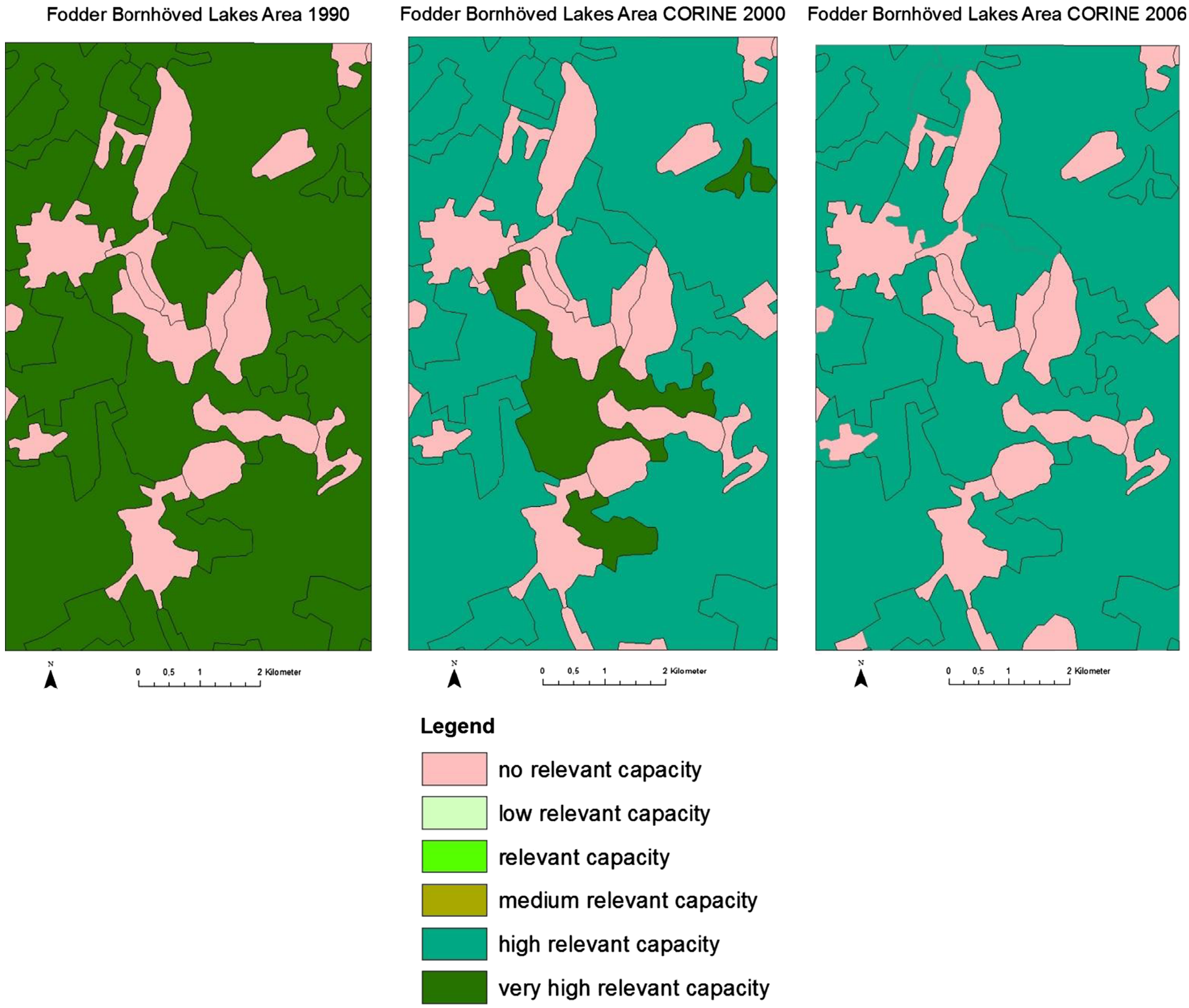

Fig. 5. Comparison of supply capacities for the provisioning ecosystem service "fodder" in the years 1990, 2000 and 2006 based on the CORINE data set.

cereals and 0.10 for fruit trees; Stone and Hilborn, 2000). However, also pesticide and fertilizer application differs for crops and cultivation techniques influencing regulating services like nutrient regulation and water purification (KTBL, 2009). Furthermore, information on agricultural production over a longer time span gives more insight on the influence of climatic conditions on yields as well as on the adaptive management cycle of agroecosystems by management and policy-making. In Germany, the cultivation of silage maize for biogas plants is a political issue, being discussed widely due to its impact on land use, other ecosystem services and biodiversity (Landwirtschaftskammer, 2011; Papendiek et al., 2012).

When services are only assessed on the annual basis (e.g. 1990, 2010) the major drawback is the omission of temporal changes of ecosystem service supply within each year. Temporal changes in ecosystem service supply capacities appear over different time scales for different services. Provisioning services, such as crops, wild foods and animals, vary over the year based on growing season or regulations, e.g. for hunting/fishing. Such information has to be taken into account when communicating ecosystem service supply capacities to stakeholders. The comparison of CORINE data for the Bornhöved Lakes Area demonstrates only little change in land cover (only in the classes mineral extraction site, industrial and commerce units, non-irrigated arable land and complex cultivation patterns), while data on the agricultural yields show significant variations over the past years (Statistikamt Nord, 2012). Dynamics in service supply result in questionable proxies of land cover (Haines-Young et al., 2012) and therefore more detailed assessments of ecosystem services need to be conducted on local scales, which can also help to improve benefit–transfer methods (Seppelt et al., 2011a). The combination of several data sets (ATKIS/InVeKoS/Landsat) is considered as a help to improve ecosystem service assessments.

The available statistical information exposes the mismatch of indicators for quantification (yields on district level) and spatial mapping units on local scale (e.g. field blocks or fields). This results in a proxy assessment of provisioning services for this case study as only two indicators (winter wheat and rapeseed yields for crops; maize and grass yields for fodder) were utilized in this assessment. Statistical data for agricultural production has been available at the district level for several years in Germany giving a high temporal resolution on the annual base. However, the statistical data do not give detailed information on the use of the harvested products, making it difficult to address other provisioning services (e.g. crops, fodder or energy for biomass) for quantification. The multiple use of one agricultural product (e.g. rapeseed used for oil and biodiesel production, and then the pressed residues are used as fodder) introduces another temporal scale

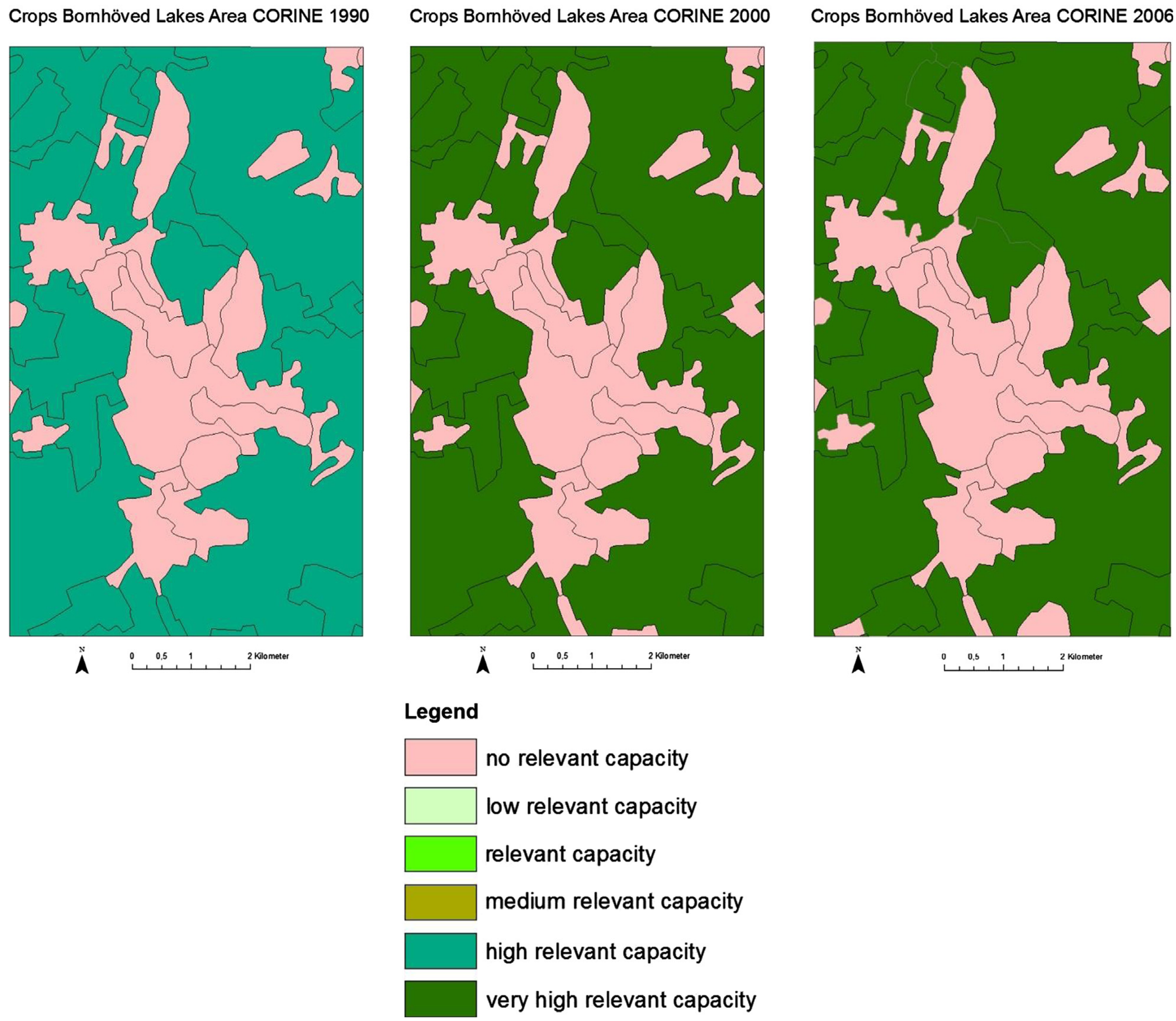

Fig. 6. Comparison of supply capacity capacity for the provisioning ecosystem service "crops" in the years 1990, 2000 and 2006 based on the CORINE data set.

in the assessment and mapping of ecosystem services which could not be taken into account in this assessment. This can have effects on the ecosystem service supply/demand assessment and respective service balance calculations for the case study area, which are relevant for decision making and policy (e.g. the recent development in agricultural policy in Germany). The quantification of livestock, a major contribution to food, was neglected in this assessment though data is available (e.g. meat and dairy production). Pastures are included in all three LULC maps, but most livestock are kept in buildings ("point sources" of ecosystem service supply) most of the year. Therefore, an even distribution of livestock to pasture areas was considered invalid. For the holistic assessment of supply capacities of provisioning services (crops, livestock, wild food, and aquatic products), these point sources must be included, even though these "food industrial" buildings are not perceived as literal ecosystems.

Mapping and quantification of ecosystem services should not only be based on LULC proxies. More information is needed for the quantification of ecosystem service supply capacities and their changes over time (Kroll et al., 2012). Some ecosystem services are not supplied homogenously within whole LULC classes (e.g. timber production in parts of forest areas), and/or are instead connected to larger landscape areas containing several LULC types (e.g. cultural services such as landscape esthetics) or to only selected points of a LULC (e.g. religious or spiritual experiences; tourism and recreation). Therefore, additional spatial data need to be included, as pointed out by Gulickx et al. (2013). Point and linear information (e.g. streets and landscape elements like hedgerows) are not included in small scale pan-national data sets like CORINE. Neglecting these landscape features can result in the omission of ecosystem functions and ecosystem services. Based on the research question, intention and desired accuracy, appropriate spatial data must be chosen (Bach et al., 2006). For cultural services like "landscape esthetics, amenity and inspiration" (Kandziora et al., 2013) other assessment methods like viewsheds, scenic estimation by questionnaires and surveys (Daniel and Boster, 1976; Chen et al., 2006) and preference maps (van Berkel and Verburg, in press) need to be applied. The importance of intangible, cultural ecosystem services is described by Vejre et al. (2010) and needs to be incorporated in the full assessment of ecosystem services and their interactions.

5. Conclusion

Various case studies demonstrated the necessity of ecosystem service mapping for decision making and management. Locally made decisions can affect ecosystem service supply on local scales

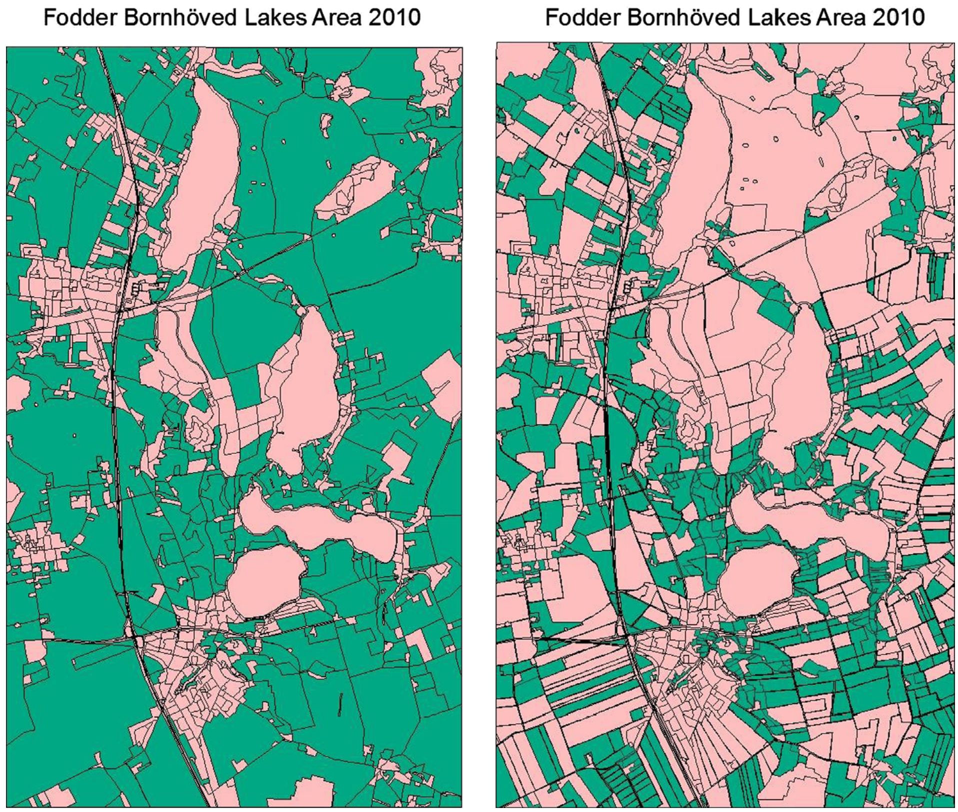

Fig. 7. Comparison of supply capacities for the provisioning ecosystem service “fodder” in 2010 based on the ATKIS data set (left) and the combined ATKIS/InVeKoS/Landsat classification data set (right) (Legend see Figs. 5,6).

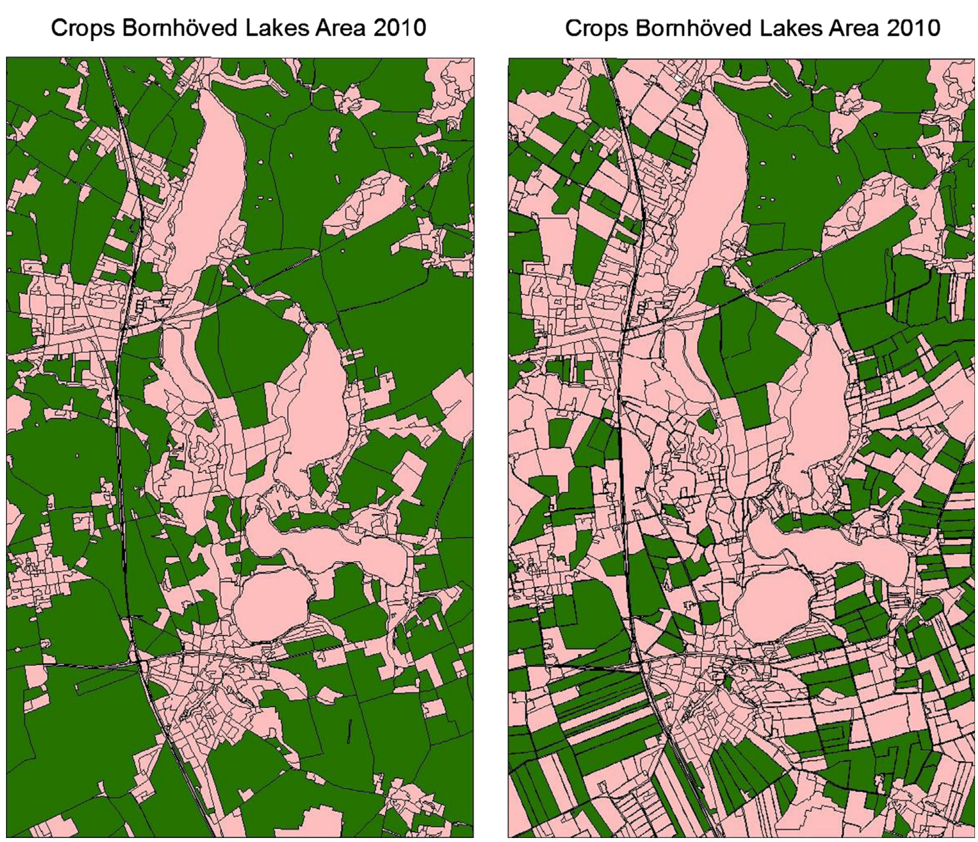

Fig. 8. Comparison of supply capacities for the provisioning ecosystem service “crops” in 2010 based on the ATKIS data set (left) and the combined ATKIS/InVeKoS/Landsat classification data set (right).

but also in distant areas (Seppelt et al., 2011b). There are already several attempts to map ecosystem services on local, regional, continental and global scales including different methods from e.g. participatory mapping to value/benefit-transfer (e.g. Fagerholm and Käyhkö, 2009; Koschke et al., 2012).

The presented approach of a LULC-based ecosystem service assessment for a local Northern German case study gives insight into the need for more detailed LULC information for the quantification and mapping of local ecosystem service supply capacities. There are several data sets available for Northern Germany to quantify and map ecosystem services. The data sets differ significantly in their spatial and temporal resolution, information content, and number of LULC classes and therefore their accuracy of spatial representativity.

Since the land cover information from CORINE is rather coarse and general for this 60 km² case study area, other official spatial information sources were considered as alternative input data. For the detailed assessment of provisioning services, the more accurate ATKIS/InVeKoS/Landsat spatial data set is considered as the best input data at hand to analyze provisioning services and to quantify their supply capacities. Also Bach et al. (2006) argue for a higher degree of accuracy of their analyzed ATKIS maps due to the higher aggregation of CORINE maps and the lower minimal object size of 25 ha. Because specific crop types cannot be distinguished in the CORINE and ATKIS data sets, the Landsat classification with the spectral information of the agricultural areas is considered as an important data set to distinguish crops and their shares in the data sets, which improves the assessment of other ecosystem services. When using too coarse LULC input data, ecosystems supplying services might be overlooked and are not assessed or some services might be overestimated in supply and value, resulting in a distorted supply assessment. This can impact decision making and guidelines formulation. However, it is more difficult to compare case studies when using different spatio-temporal assessment data. The question arises whether or not aggregation of detailed data into land cover categories for comparison (e.g. CORINE) will be the solution for this problem. The quantification of provisioning services based on the four available spatial data sets illustrates the challenges the scientific and user community has to face as several important aspects of ecosystem service quantification and mapping are still hard to account.

For the local scale, this detailed LULC analysis is required for the assessment of ecosystem services, temporal and spatial changes in their supply and possible trade-offs due to management and policy decisions. For regional, continental and global assessments of ecosystem service capacities, coarse land cover data sets such as CORINE are a valid tool for appropriate assessment. However, other relevant mapping and quantification methods (e.g. participatory mapping) also need to be included in management and decision making, especially on local scales.

The future quantification and mapping of other ecosystem services in the Bornhöved Lakes Area for several consecutive years, will show more challenges and possible solutions to some of the drawbacks discussed above for an improved development and application of the ecosystem service concept in science, decision making, resource management and policy. One should consider and document the spatial and temporal data sources used for modeling and mapping carefully as they influence the results of the ecosystem service assessments substantially.

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