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Regional assessments of selected ecosystem services in northern Germany

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Zusammenfassung

Das zentrale Ziel dieser Arbeit liegt in einer Verbesserung unseres Wissens über die regionale Landnutzungsverteilung, die zeitlichen Landnutzungsänderungen und die hieraus folgenden Unterschiede in der Bereitstellung von ausgewählten Ökosystemleistungen auf der Basis von CORINE Landbedeckungsklassen. Vorangegangene Abschätzungen von Ökosystemleistungen wurden häufig mit qualitativen Indikatoren und mit einem lokalen Flächenbezug durchgeführt. Ihre Resultate müssen im Vergleich mit quantitativen Verfahren auf Landschaftsebene folglich nicht fehlerfrei sein. In dieser Arbeit werden verschiedene Methoden zur Abschätzung der Ökosystemleistungen anhand des Beispielsfalles „Globale Klimaregulation" für das Bundesland Schleswig-Holstein und Zeitraum 1990 bis 2012 verglichen. Hierbei werden im Wesentlichen folgende Parameter für die Analyse herangezogen: die jährliche totale Bruttoprimärproduktion (GPP) und Nettoprimärproduktion (NPP) für die Jahre 2000, 2006 und 2012, der Kohlenstoffgehalt der Böden im Jahr 2006 (SOC), die Kohlenstoffspeicherung in 2006 (CS) und die qualitative Bewertung der Ökosystemleistung anhand des „Matrix-Ansatzes" für 2006 (GCR). Dabei werden die Landbedeckungsklassen differenziert für das gesamte Bundesland Schleswig-Holstein, die drei Landschaftszonen der Geest, der Marsch und des östlichen Hügellandes sowie für die Landkreise in Schleswig-Holstein analysiert.

Um diese Zielsetzungen zu erreichen, werden raumzeitliche statistische Methoden im Hinblick auf die Nutzung Geographischer Informationssysteme (GIS) benutzt, Für die Arbeiten wurden daneben Programme aus den Software-Paketen R und SPSS verwendet. Zur Analyse der Landbedeckungsdynamik wurden 32 CORINE-Klassen mit Datensätzen aus den Jahren 1990, 2000, 2006 und 2012 genutzt. Bei der Berechnung der Größen GPP und NPP wurde auf 17 relevante Landnutzungs-Klassen zurückgegriffen. Diese Gruppierung enthielt landwirtschaftliche Flächen, Forsten und Wälder, seminatürliche Areale und Feuchtflächen. Im Verlauf der Arbeiten wurden die genannten Landbedeckungsklassen anhand der oben aufgeführten Indikatoren mit verschiedenen Verfahren verknüpft, so dass verschiedene Indikatoren landesweit für einen Vergleich zur Verfügung standen.

Die Auswertungen ergaben unter anderem, dass Ackerland und Grünland zu allen Aufnahme-Zeitpunkten die dominanten Landnutzungstypen waren. Auch die größten nutzungsbedingten Verschiebungen fanden zwischen diesen Klassen und den sogenannten „komplexen Anbaumustern" (complex cultivation patterns) statt. Aufgrund der großen Flächenausdehnung ergeben sich für Ackerland und Grünland auch die höchsten NPP- und GPP-Werte. Dabei sticht die Geest – ebenfalls aufgrund der Flächengröße – mit den höchsten Gesamtspeichermengen hervor, obwohl die relativen Umsätze 2006 geringer waren als in der Marsch. Unter den Landkreisen zeigen Rendsburg-Eckernförde und Dithmarschen die höchsten gespeicherten GPP- und NPP-Mengen, während grundsätzlich eine hohe abundante Vegetation mit einem hohen ökosystemaren Speicherpotenzial für Kohlenstoff einhergeht.

Beim Vergleich der benutzten quantitativen und qualitativen Indikatoren, der jährlichen GPP, der jährlichen NPP, der Bodenspeicherung (SOC) und der Gesamt-System-Speicherung (CS) sowie dem qualitativen Matrix-Indikator zeigen sich sehr hohe Korrelationen zwischen den einzelnen Mess- und Modellgrößen. Die Unterschiede im Potenzial zur globalen Klimaregulation ergeben sich oft erst aus den reklassifizierten Landbedeckungs-Gruppen und deren jeweiliger Flächengröße. Dabei zeigen sich auch positive Korrelationen im Rahmen eines Datenvergleichs mit der amtlichen Statistik: GPP- und NPP – Umsätze und Speicher stehen in hohen korrelativen Beziehungen etwa zu den Daten der Gesamterntemengen, der Ernten von Getreide, Mais, Rüben und Raps.

Auf der Grundlage dieser Resultate werden abschließend neben methodischen Schlussfolgerungen Empfehlungen zur Verbesserung der Service-Leistungen in Bezug auf die „globale Klimaregulation" ausgesprochen. Im Wesentlichen sollten hierzu die jährlichen GPP- und NPP-Leistungen in Bezug auf die Gesamtmengen und die gespeicherten Mengen erhöht werden. Dies gilt ebenso für die Indikatoren SOC und CS. Diese Modifikation kann durch eine Änderung der Landnutzungsstruktur hin zu Klassen mit hohen Fixierungspotenzialen wie „Grünland", „Laubwald", „Nadelwald", Mischwald" oder auch zu „nicht bewässerte Ackerflächen" geschehen.

Abstract

The purpose of this study is to gain a better understanding of the land cover distributions, land cover changes and the differences in ecosystem service provisions resulting from distinctive indicators based on various CORINE land cover classes. Previous ecosystem service assessments focused on estimating ecosystem services with qualitative indicators or which have been carried out at local scales with limited land cover classes, and did not provide a sufficient understanding of the ecosystem service distributions and dynamics. Therefore this study includes an attempt to consider quantitative indicators on regional scales including the number and development of different land cover classes. By analyzing the land cover dynamics in Schleswig-Holstein from 1990 to 2012 and the "global climate regulation" service that uses information on the annual total Gross Primary Production (GPP) and Net Primary Production (NPP) for the years 2000, 2006 and 2012, Soil Organic Carbon (SOC) in 2006, Carbon Storage (CS) in 2006, and a qualitative indicator derived from the ecosystem service matrix method (GCR) in 2006, this study measures the land cover distributions based on the whole state, the landscape regions and the administrative districts. The land-cover-based global climate regulation potential in Schleswig-Holstein is assessed with regional distinctions, using different methods for the assessment and developing strategies to improve global climate regulation.

To achieve these goals, this study uses spatial and statistical analysis tools referring to Geographic Information Systems (GIS), the statistical package R and the software of SPSS were used to estimate the land cover and ecosystem services dynamics in Schleswig-Holstein. 32 CORINE land cover classes were used to evaluate their distributions in Schleswig-Holsten, in the three landscape regions of Geest, Marsch and Hügelland and in the 15 administrative districts of Schleswig-Holsten in 1990, 2000, 2006 and 2012. In terms of the annual total GPP and NPP and the annual total stored GPP and NPP, 17 land cover classes including agricultural areas, forests, semi natural areas and wetlands were used to evaluate their effects on the distributions of the annual total GPP and NPP and the annual total stored GPP and NPP. The study then estimated the differences of distinct ecosystem service assessment concepts applying various indicators and using the data of the land cover map, the annual total GPP, the annual total NPP, SOC, CS and GCR with the best accessibility in 2006.

Through the analysis, the study has found that "non-irrigated arable land" and "pastures" are the dominating land cover classes in Schleswig-Holstein, and the significant land cover changes during the study periods are also among the land cover classes of "non-irrigated arable land", "pastures" and "complex cultivation patterns". Because of the large areas, "non-irrigated arable land" and "pastures" are having higher annual total stored GPP and NPP values than the other land cover classes. The annual total stored GPP and NPP are significantly correlated with the areas. Due to the big area, Geest has the largest annual total stored GPP and NPP even though the annual total GPP and NPP are less than the annual total GPP and NPP in Marsch. Simultaneously, Dithmarschen and Rendsburg-Eckernförde are the districts holding larger annual total stored GPP and NPP amounts than the other districts of Schleswig-Holstein due the size of the areas. The areas covered with abundant vegetation have high carbon-stock capabilities.

The outcome of the comparison of qualitative and quantitative indicators of the global climate regulation service, the annual total GPP, the annual total NPP, SOC, CS and GCR is that all of them show significant correlations. The differences in mapping global climate regulation are mainly consequences of different reclassified groups of land cover types in different indicator categories and distinctions of areas among land cover classes. The interrelations among the different indicators, the annual total GPP, the annual total NPP, and the statistical data of average harvest, the harvests of grain, green corn, root crops and winter rape evaluated based on districts also correlate significantly.

Based on these findings, this study proposes methodological conclusions and the recommendations to enhance the annual total GPP and NPP, the annual total stored GPP and NPP, as well as SOC, and CS through replacing the land cover classes with low carbon storage capabilities into the ones with high potentials, such as "pastures", "broad-leaved forest", "coniferous forest", "mixed forest" and "non-irrigated arable land".

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List of Abbreviation

ARIES	Artificial Intelligence for Ecosystem Services
ATKIS	Amtliches Topographisch–Kartographisches Informations-System;
CEC	Cation Exchange Capacity
CICES	Common International Classification of Ecosystem Services
CORINE	Co-ORdinated of INformation on the Environment
CS	Carbon Storage
EEA	European Environmental Agency
ESMERALDA	Enhancing ecoSysteM sERvices mApping for poLicy and Decision mAking
EU	European Union
EVI	Enhanced Vegetation Index
GCR	qualitative indicator of Global Climate Regulation
GPP	Gross Primary Production
GPPAgri	annual GPP of the Agricultural areas based on the CORINE land cover classification
GUMBO	Global Unified Metamodel of the BiOsphere
H^+	Hydrogen ion content
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
LAI	Leaf Area Index
MCS	Map Comparison Statistic
MODIS	Moderate Resolution Imaging Spectroradiometer
Nd	soil Nitrogen density
NDVI	Normalized Difference Vegetation Index
NPP	Net Primary Production
NPPAgri	annual NPP of the Agricultural areas based on the CORINE land cover classification
SHDI	Shannon’s Diversity Index
SOC	Soil Organic Carbon
SolVES	Social Values for Ecosystem Services
SOM	Soil Organic Matter
TEEB	The Economics of Ecosystems and Biodiversity
USGS	the United States Geological Survey

Chapter 1. Introduction

Ecosystem services are benefits obtained from ecosystems by human beings (Costanza et al., 2014; Millennium Ecosystem Assessment, 2005). Assessing the ecosystem services with appropriate indicators and methods is important for clarifying how many benefits can be obtained. The first section of this chapter presents definitions of ecosystem services and their respective indicators, ecosystem assessments, and methods used for these assessments. The regulating services, especially the global climate regulation services, are described and defined in the second section. Different carbon storage pools and the quantifying methods via various scales are also shown in this section. In the third section, the objectives and research questions are represented.

1.1 Country-wide ecosystem service assessments

Ecosystem service assessments encompass a range of concepts and methodologies from the natural and social sciences. A shared conceptual and analytical framework is necessary for being understood by researchers, practitioners, managers and stakeholders with various backgrounds. The assessments need to determine which ecosystem services are estimated at a regional scale, which measures of ecosystem services inform the decision-making processes, and which methods can quantify ecosystem services to efficiently inform regional policy.

Country-wide assessments, as an important component of evaluating the targets of researches in the study area, have been widely used in comprehensive studies (Cruickshank *et al.*, 2000; Muñoz-Rojas *et al.*, 2011; Hu *et al.*, 2015; Li *et al.*, 2016a). These country-wide assessments can present research results, for example in Schleswig-Holstein, better than local and regional evaluations. Studying land cover and land cover changes, as well as related ecosystem services, using qualitative and quantitative methods are necessary to further understand ecosystem services of the state, even if the studies on land cover and land cover changes and their services have been done at other scales, e.g. in the Bornhöved Lakes District. The research outcomes are also supplementary findings for managers to make decisions for the development of the state.

1.1.1 Regional ecosystem service assessments

Fundamental questions about interactions between nature and society as well as compelling and urgent social needs motivate sustainability science. Maintaining the earth's life-support systems and meeting human beings' needs are the bases of a sustaining future in which the activities of human beings must be recognized as an integral component of ecosystems (Schröter *et al.*, 2005). A massive synthesis of scientific knowledge about global ecosystems and their capacity to support human well-being is undertaken herein. However, pressure has already been placed on environmental systems resulting from the increase of human population, economic growth and global consumption patterns, and this affects the provision of ecosystem goods and services (Seppelt *et al.*, 2011).

Assessing the ecosystem services reveals processes and the possible effects of pressure on ecosystems from human activities. Ecosystem service assessments at regional scales support a suitable study area of ecosystem that either presents the ecosystem services of the whole system or presents decreased uncertainties for one ecosystem. Meanwhile, a global ecosystem service assessment is difficult for the reason that multitudinous of global ecosystems increase the uncertainties of ecosystem services provisions. Moreover, ecosystem service assessments at local scales usually limit the accuracy of the evaluation if the sample sites cannot completely present the study areas.

1.1.2 Definitions of ecosystem services and ecosystem assessment

Ecosystem services are defined as the benefits people obtain from ecosystems, which includes regulation services, such as global climate regulation, provisioning services and cultural services (MA, 2005). There are several sub-services in the general ecosystem service groups and they are classified differently among the classification frameworks from the Millennium Ecosystem Assessment (MA) (Duraiappah *et al.*, 2005), from the Economics of Ecosystems and Biodiversity (TEEB) (TEEB – The Economics of Ecosystems and Biodiversity, 2010) and from the Common International Classification of Ecosystem Services (CICES) (Potschin & Haines-Young, 2016). The ecosystem assessment aims at clearing and formulating the consequences of ecosystem change for respective environmental human well-being and establishing a scientific basis for actions which are needed to enhance the conservation and sustainable use of ecosystems and their contributions to human well-being (Millennium Ecosystem Assessment, 2005). The ecosystem services concept as a policy tool for achieve the sustainable use of natural resources has been brought forward with the process of the Millennium Ecosystem Assessment (Seppelt *et al.*, 2011). This helps policymakers and researchers to take the provision of natural goods and services into account as basic arguments to define and evaluate the sustainability of certain directions.

1.1.3 List of ecosystem services, ecological integrity, and respective indicators

Indicators depict indirectly accessible qualities, quantities or states of ecosystems (Busch *et al.*, 2011; Kandziora *et al.*, 2013a). “Ecological indicators characterize and provide communication tools in environmental management through supplying aggregated information on phenomena in the human-environment system” (Müller *et al.*, 2016). The provision of quantitative information for decision-making processes is the target of ecological indication, and requires ecosystem-based indicators to represent the complex interactions between biotic and abiotic components. Coping with this enormous complexity and providing essential arguments for trade-offs throughout the planning processes are necessary items for ecological indicators to incorporate complexity, interdisciplinary and multidimensional procedures of indicator derivation, and application and valuation for the representation of ecosystem states and viabilities (Müller *et al.*, 2016).

An indicator set can be characterized by different suitability and quality criteria, whereby the communication of high “scientific correctness” and high “practical applicability” are focal items of indicator quality (Müller; Müller *et al.*, 2016). The indicators should be clear, understandable, comprehensive and sensitive to the slightest change of the indicated ecosystem. At the same time, integration, a known response to stress and disturbance and a low variability are vital characteristics for the indicators (Busch *et al.*, 2011; Egoh *et al.*, 2012; van Oudenhoven *et al.*, 2012). Some of the ecosystem services indicators that depict qualities, quantities or states of systems are various and distinct from one ecosystem classification framework to another (Haines-Young, Roy; Potschin, 2010; TEEB – The Economics of Ecosystems and Biodiversity, 2010). TEEB and the Common International Classification of Ecosystem Services (CICES) are considered as the most commonly applied indicator sets. However, indicators are needed for the economic value in relation to the changes in ecosystems and biodiversity because the specific focus of TEEB is on economic assessment. Human needs are primarily described by ecosystem outputs contributing to human beings. Burkhard et al. (2009, 2012, and 2014) presented another comprehensive ecosystem service indicator set that distinguishes indicators of ecosystem service potentials, flows and societal demands for ecosystem services. Definitions and proposed indicators for ecosystem services potentials and ecological integrity are listed in Tables 1-4.

Table 1. Definitions of regulating ecosystem services and potential indicators (based on Kandziora et al. 2013a; Burkhard et al. 2009, 2012 and 2014; Syrbe and Walz 2012; de Groot et al. 2010).

Regulating service	Definition	Potential indicators
Global climate regulation	Long-term storage of potential greenhouse gases in ecosystems.	Source-sink of methane, carbon dioxide and water vapor (t C/ha*a); Amount of methane, carbon dioxide and water vapor stored in vegetation, soils and marine systems (t C/ha)
Local climate regulation	Changes in local climate components like wind, precipitation, temperature, radiation due to ecosystem properties.	Temperature (°C); albedo (%); precipitation (mm); wind (Bft); evapotranspiration (mm); shaded areas (ha; %)
Air quality regulation	Capturing/filtering of dust, chemicals and gases from air.	Leaf area index, difference between open land and through fall deposition (kg/ha); emission concentrations (ppm); level of pollutants in the air Critical loads (kg/ha*a)
Water flow regulation	Water cycle feature maintenance (e.g. water storage and buffer, natural drainage, irrigation and drought prevention).	Water storage capacity (m^3/ha); groundwater recharge rate (mm/ha*a)
Water purification	Ecosystem ability to purify water, e.g. from sediments, pollutants, nutrients, pesticides, disease-causing microbes and pathogens.	Water quality indicators: sediment load (g/l); total dissolved solids (mg/l)
Nutrient regulation	Ecosystem ability to recycle nutrients, e.g. N, P.	Nutrient turnover rates of, e.g. N, P (y^{-1}); water quality indicators, e.g. N (mg/l), P (mg/l); electrical conductivity (μS/cm); total dissolved solids (mg/l); soil potentials (CEC; SOC; texture); leakage of nutrients (kg/ha*a)
Erosion regulation	Soil retention and the ability to prevent and mitigate soil erosion and landslides.	Vegetation cover (%); loss of soil particles by water and wind (kg/ha*a); USLE factors for assessment of potential soil loss and landslide frequency (n/ha*a)
Natural hazard protection	Protection and mitigation of floods, storms, fires and avalanches.	Water-storage potential (m^3/ha); natural barriers (dunes, mangroves, wetlands, coral reefs, forests) (%; m/ha, ha)
Pollination	Bees, birds, bats, moths, flies, wind, nonflying animals contributing to pollen transfer and reproduction of plants.	Species numbers and amount of pollinators (n/ha); potential habitats for pollinators (ha/ha; %; n/ha)
Pest and disease control	Ecosystem ability to control pests and diseases due to genetic variations of plants and animals making them less prone to diseases and actions of predators and parasites.	Populations of biological disease and pest control agents (n/ha); Potential habitats for control agents (ha/ha; %; n/ha)
Regulation of waste	Ecosystem ability to filter and decompose organic material in water and soils.	Amount and number of decomposers (n/ha); Decomposition rate (kg/ha*a)

Table 2. Definitions of provisioning ecosystem services and potential indicators (based on Kandziora et al. 2013a; Burkhard et al. 2009, 2012 and 2014; Syrbe and Walz 2012; de Groot et al. 2010).

Provisioning service	Definition	Potential indicators
Crops	Plants usable for human nutrition.	Standing stock +/or net primary production (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Biomass for energy	Plants used for energy conversion (e.g. sugar cane, maize)	Standing stock +/or net primary production (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Fodder	Nutritional substances for domestic animals.	Standing stock +/or net primary production (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Livestock (domestic)	Domestic animals useable for nutrition and related products (dairy, wool).	Number of animals (n/ha; kJ/ha); Animal production (t C/ha*a; kJ/ha*a)
Fiber	Natural fiber (e.g. cotton, jute sisal, silk, cellulose) usable for e.g. cloths, fabric, paper.	Biomass +/or growth of fiber (t/ha + t/ha*a)
Timber	Wood useable for human purposes (e.g. construction).	Standing stock +/or net primary production (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Wood fuel	Wood suitable for energy conversion and/or heat production.	Standing stock +/or net primary production (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Fish, seafood and edible algae	Seafood, algae useable for food, fish meal and fish oil.	Fish stock +/or growth (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Aquaculture	Seafood/algae in marine and terrestrial aquaculture farms.	Animal stock +/or growth (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Wild food, semi-domestic livestock and ornamental resources	Berries, mushrooms, (edible) plants, wild animals, fish and natural ornaments available for recreational fishing, hunting or collection; semi domestic animal husbandry.	Amount of respective items available; stock +/or growth of respective wild species (n/ha; kg/ha; kg/ha + kg/ha*a; kJ/ha + kJ/ha*a)
Biochemicals and medicine	Natural products useable as biochemicals, medicine and/or cosmetics.	Amount or number of substances useable for medicine, biochemical, cosmetics (kg/ha; n/ha); Stock +/or net primary production (t C/ha + t C/ha*a; kJ/ha + kJ/ha*a)
Freshwater	Fresh and process water available for e.g. drinking, domestic use, industrial use, irrigation.	Fresh- and/or process water availability (l/ha*a; m^3/ha*a); Total amount of water (m^3/ha); Groundwater recharge rate (m^3/ha)
Mineral resources	Minerals extractable close from surface or above surface (e.g. sand for construction, lignite, gold, salts).	Minerals available for extraction (t/ha)
Abiotic energy sources	Abiotic energy sources useable for conversion (e.g. solar, wind, water and geothermic power).	Areas and natural settings potentially suitable for energy conversion (ha/ha; n/ha; GW/ha)

Table 3. Definitions of cultural ecosystem services and potential indicators (based on Kandziora et al. 2013a; Burkhard et al. 2009, 2012 and 2014; Syrbe and Walz 2012; de Groot et al. 2010).

Cultural service	Definition	Potential indicators
Recreation and tourism	Outdoor activities and tourism relating to the local environment or landscape, including forms of sports, leisure and outdoor pursuit.	Number of facilities (e.g. hotels, restaurants, hiking paths, parking lots; n/ha); Results from questionnaires on nature and leisure preferences (wildlife-viewing, hiking, fishing, sports)
Landscape aesthetic, amenity and inspiration	Visual quality of the landscape/ecosystems or parts of them influencing human well-being and the need to create something as well as the sense of beauty people obtain from looking at landscapes/ecosystems.	Evaluations from questionnaires; Scenic beauty estimation via landscape metrics; Travel cost estimation Willingness to pay
Knowledge systems	Environmental education based on ecosystems/landscapes and knowledge in terms of traditional knowledge and specialist expertise arising from living in this particular environment.	Number of environmental educational-related facilities (n/ha)
Religious and spiritual experience	Spiritual or emotional values that people or religions attach to local ecosystems or landscapes due to religious and/or spiritual experience.	Number of spiritual facilities or items (n/ha)
Cultural heritage and cultural diversity	Values that humans place on the maintenance of historically important (cultural) landscapes and forms of land use (cultural heritage).	Areas and natural settings potentially suitable for traditional land use (ha/ha; n/ha); Results from questionnaires on local people's personal preferences
Natural heritage and natural diversity	The existence value of nature and species themselves, beyond economic or direct human benefits.	Potential habitats for endangered, protected and/or rare species (n/ha)

Table 4. Definitions of ecological integrity and potential indicators (based on Kandziora et al. 2013a; Burkhard et al. 2009, 2012 and 2014; Syrbe and Walz 2012; de Groot et al. 2010).

Ecological integrity	Definition	Potential indicators
Exergy capture	The capacity of ecosystems to enhance the input of usable energy. Exergy is derived from thermodynamics and measures the energy fraction that can be transformed into mechanical work. In ecosystems, the captured exergy is used to build up biomass (e.g. primary production) and structures.	Net primary production (t C/ha*a, kJ/ha*a); Leaf area index
Entropy production	Non-convertible energy fractions which are exported into the environment of the system.	C from respiration entropy balance
Storage capacity	The capacity of an ecosystem to store nutrients, energy and water when available and to release them when needed	N, Corg in the soil (kg/ha) N, C in biomass (kg/t)
Cycling & nutrient loss reduction	The capacity of an ecosystem to prevent the irreversible output of elements from the system; referring also to nutrient and matter cycling.	Leaching of nutrients, e.g. N, P (kg/ha, mg/l)
Biotic water flows	The water cycling affected by plant processes in the system.	Transpiration/total evapotranspiration
Metabolic efficiency	The amount of energy necessary to maintain a specific biomass, also serving as a stress indicator for the system.	Respiration/biomass (metabolic quotient)
Heterogeneity	The capacity of an ecosystem to provide suitable habitats for different species, for functional groups of species and for processes. It is essential for the functioning of ecosystems.	Abiotic habitat components' heterogeneity indices (e.g. humus content in the soil (%)) Number/area of habitants (n/ha)
Biotic diversity	The presence and absence of selected species, (functional) groups of species, biotic habitat components or species composition.	Indicator species representing a certain phenomenon or being sensitive to distinct changes (n/ha); Number and identity of selected species (n); Shannon-Wiener index; Simpson index

1.1.4 Methodologies for deriving ecosystem services

The concept of ecosystem services has been evolving for several decades. Before this period, the provided 'services' had been accounted for as 'environmental services' in the study of *Man's Impact on the Global Environment* (SCEP, 1970). Ideas of 'public-services' and 'nature's services' were also developed in the publications of Ehrlich and Holdren, and Westman (1974; 1977). However, the term of 'ecosystem services', which was already used in the common currency, did not enter into scientific discourse until 1981. This resulted from the idea that people directly benefit from nature and the idea of nature's capacity to support those benefits (Potschin *et al.*, 2016). Even so, in the history of the concept and its link with an economic evaluation of the environment, the effects of human actions on nature that can benefit people have been discussed even in ancient civilizations, as mentioned by Mooney and Ehrlich in 1997 (Westman, 1977) .

The conceptual definition is the basis of the development of ecosystem services. The services integrate experts, decision-makers, and citizens of different kinds, to address a common issue and make a distinction between the definition and the approaches that can be used to operationalizing the analysis of ecosystem services (Burkhard *et al.*, 2013; Potschin *et al.*, 2016). Potschin and Haines-Young (2013) classified the approaches of their analysis as involving a habitat, systems or place-based approach. Cognition of the participants in terms of their knowledge and the emphasis they put on particular issues resulted in a respective choice of an approach.

The habitat approach is probably one of the most widely used in ecosystem assessment, taking the ecological habitats into consideration and using these units to look at the relationship between people and nature (Potschin & Haines-Young, 2013). Many different systems and land cover or land use which are based on an ecological unit have been used in some assessment exercises (Yu *et al.*, 2001; Feng *et al.*, 2007). The approach is much more meaningful at regional, national or local scales compared to the global scale. The approach is also clearly an efficient way of organizing data and presenting the service status and trends. Spatially explicit habitat and land cover data are often widely available and matrix approaches have been widely used for mapping and modeling ecosystem services based on land cover or land use data (Troy & Wilson, 2006; Egoh *et al.*, 2008; Maes *et al.*, 2012), thus supporting the habitat approach to mapping services (Kienast & Helfenstein, 2016; Maes *et al.*, 2016).

A systems approach provides a more complete, system-orientated or process-orientated method to identify the ways services are generated and used. It is helpful in an implicit or indicative way and underpins the unspecified service relationships (Potschin & Haines-Young, 2013). Case studies using a system approach range from different scales and issues containing both global and national-scale integrated modelling work (Alcamo *et al.*, 2005; Bateman *et al.*, 2013). Modelling quantitative ecological and economic production functions that express the outputs and benefits varies with changes in the various direct and indirect drivers of change (Nelson *et al.*, 2009; Seppelt *et al.*, 2011; Costanza *et al.*, 2013). Modelling can be helpful in understanding the changes in value that might result from modifications of different factors. These factors may influence service supply and demand, characterize service providing units, and identify and understand ecosystem service providers (Luck *et al.*, 2003, 2009; Kremen *et al.*, 2007).

Place-based approaches aim to create an understanding of the place, involving people who know or use the area through a deliberative process. The emergence of a place-based approach to ecosystem assessment reflects the increasing emphasis given to trans-disciplinary styles of working, and the need to focus on achieving sustainable solutions either in social and economic terms or in ecological terms (Potschin & Haines-Young, 2013). Assessing, mapping and quantifying cultural ecosystem services at the community level to account for a place-based approach has been demonstrated by Plieninger et al. (2013). Another study which was carried out by interviews with maps to help identify the meaning of place and facilitate value articulation was done by Klain et al. (2014). These studies suggest that the development of participatory mapping, as a key component of a place-based approach, offers important opportunities for the analysis of stakeholders' perspectives (Raymond *et al.*, 2009).

1.1.5 Practical significance of ecosystem service mapping

Mapping ecosystems and their services supports assessments with high-quality and consistent information on the condition of the ecosystems and the services provided at different scales. Mapping is an intuitive and simple method for communicating information among stakeholders, for instance scientists, policy makers, resource managers and citizens, about the complex interactions between ecosystem services at special-temporal scales (Burkhard *et al.*, 2013). Trade-offs and synergies among ecosystem services can be visualized with maps, that may help identify spatial congruence or mismatches among supply, flow, and demand of ecosystem services or between ecosystems providing services and beneficiaries receiving these services (Kroll *et al.*, 2012a; Burkhard *et al.*, 2013). At the global scale, transitions and trade have led to beneficiaries of provisioning services for one hemisphere being provided by another hemisphere (Meyfroidt *et al.*, 2010). At national, regional or local scales, citizens are beneficial from ecosystem services supplied by the agro-ecosystem that are strongly correlated with long-distance ecosystem services (Kroll *et al.*, 2012b; Hou *et al.*, 2015). Maps can help the stakeholders to better understand these spatial relationships, supporting the selection, planning, and management of areas for conservation.

1.1.6 State of the art in ecosystem service mapping

Mapping ecosystem services can be classified either with an ecosystem supply chain or with ecosystem service mapping approaches and tools. Mapping ecosystem service supply, ecosystem service demand and value, and ecosystem service flows have been included in the ecosystem supply chain (Kroll *et al.*, 2012a; Burkhard *et al.*, 2013, 2014).

The type, spatial arrangement, productivity and condition of ecosystems are frequently used to map the supply of ecosystem services due to a profound influence on their capacity to deliver ecosystem services (Maes *et al.*, 2012; Pagella & Sinclair, 2014). Primary data, measurements, and observations stemming from remote sensors or collected in the field are considered to be the most accurate data for mapping ecosystem service supply, and process models offer the most reliable method of estimating change to supply from a management intervention (Maselli *et al.*, 2006; Tang *et al.*, 2013; Kandziora *et al.*, 2014). Meanwhile, the data might be not always available, and have limitation on provisioning services. Up-scaling, down-scaling, and interpolation to cover areas with missing data are the main consequences of data unavailability (Crossman *et al.*, 2013). Land cover data that can be representative of the ecosystem types are often used to map ecosystem services in absence of primary data and models (Nelson *et al.*, 2010; Li *et al.*, 2016b). Furthermore, mapping the supply of ecosystem services is improved by gathering soil, hydrological, or vegetation data.

Quantifying and mapping ecosystem service demand is not as common as quantifying ecosystem service supply (Burkhard *et al.*, 2013; Honey-Rosés & Pendleton, 2013). This is because spatial information on where benefits are received or enjoyed and what values are attributed to these benefits by beneficiaries is required. Biophysical data and models (e.g. land cover classes, other environmental information and process models) are important tools for mapping ecosystem service supply (Nedkov & Burkhard, 2012; Mitchell *et al.*, 2015). However, mapping demand is dependent on socio-economic data, for example land use, and demographic and population statistics (Maes *et al.*, 2016). Not all ecosystem service values, especially values correlating cultural and spiritual ecosystem services, can be described in economic or monetary terms (Chan *et al.*, 2012). Participatory GIS has also been used for mapping social and community ecosystem service values (Fagerholm *et al.*, 2012).

Ecosystem goods and services "flows" are the transfers of ecosystem services from where they are generated to where they are received (Burkhard *et al.*, 2014). Mapping ecosystem service flows includes a dynamic temporal dimension that is often difficult to capture on a map. In this sense, mapping the ecosystem service supply and demand separately has been used to visualize flows of ecosystem services (Chan *et al.*, 2006; Nelson *et al.*, 2009; Seppelt *et al.*, 2011; Costanza *et al.*, 2013). Flood regulation services and hotspot maps show ecosystem service flows in areas where supply and demand overlap (Nedkov & Burkhard, 2012; García-Nieto *et al.*, 2013).

Similar to other scientific disciplines that use maps and models (e.g. climate research, spatial economics and ecosystem modeling), mapping ecosystem services involves a trade-off between simple and more complex approaches (Maes *et al.*, 2016). Simple mapping approaches need fewer data, being easier to explain and understand, being transparent and trusted among users. But the accuracy of simpler approaches may be lower (Maes *et al.*, 2016). More complex approaches may be more credible and accurate despite of requiring more data and expertise (Kareiva *et al.*, 2011). The more complex approaches to mapping ecosystem services have been separated into three tiers (Maes *et al.*, 2016). The first tier is based on land cover and land use data or other environmental data, being the simplest form of mapping. The second tier improves earlier data at different levels of aggregation and uses them as a base to derive more complex indicators. Tier 3 is an approach which further refines tier 2 with modeling biophysical processes (Maes *et al.*, 2016).

Along with the various methods of mapping ecosystem service, the tools range from simple spreadsheet models to complex software (Bagstad *et al.*, 2013). Spreadsheet models can link the quantity of an ecosystem service to other available data, such as land cover or land use data (Olavson & Fry, 2008). Compared to simple spreadsheet models, a new generation of generic ecosystem service modeling and mapping tools is replicable and quantifiable on ecosystem service analysis, and independent of scale, site or policy context. Many of them are provided as GIS toolboxes or as stand-alone applications (Bagstad *et al.*, 2013). InVEST (Integrated Valuation of Ecosystem Services and Tradeoffs) (Sharp *et al.*, 2015a), ARIES (Artificial Intelligence for Ecosystem Services), SolVES (the Social Values for Ecosystem Services) (Maes *et al.*, 2012) and GUMBO (Global Unified Metamodel of the BiOsphere) (Farley *et al.*, 2002) are the most commonly used tools for estimating ecosystem services and the trade-offs (Kienast & Helfenstein, 2016).

1.1.7 A regional contribution to the MAES-concept

Land cover and land cover change are focal challenges for Mapping and Assessment of Ecosystem Services (MAES), because they are major drivers of the distribution and functioning of ecosystems, and in the delivery of ecosystem services. Loss or fragmentation of natural habitats and their species are caused by land cover and land use (Pelorosso *et al.*, 2009; Nelson *et al.*, 2010; Clerici *et al.*, 2014; Martínez-Fernández *et al.*, 2015). The threats to biodiversity and ecosystems are impacted by land cover and land cover changes and they could be minimized through better spatial planning (Maes *et al.*, 2012). Respective targets of European Union (EU) biodiversity strategy is described within 6 sections (European Environment Agency, 2010). Target 1 is fully implementing the birds and habitats directives. The second target is focusing on maintaining and restoring ecosystems and their services. Target 3 is increasing the contribution of agriculture and forestry to maintaining and enhancing biodiversity. Ensuring the sustainable use of fishery resources presents the fourth target. Helping to combat invasive alien species and helping to avert global biodiversity loss are considered to be the fifth and sixth targets, separately. This study is associated with the land cover and land cover changes based on the CORINE (CoORdination of InformatioN on the Environment) land cover classification, and correlates with assessing global climate regulation with qualitative and quantitative indicators. It relates to the target 2 and target 3 of the Biodiversity Information System for Europe (European Union, 2013).

Considering the land cover distributions and land cover changes comprehensively is basis for understanding the respective land cover situations and ecosystem service potentials. The detected land cover patterns and dynamics form a basic data source for the interpretations and calculations which are referring to different approaches in characterizing the landscapes' potentials to provide ecosystem services. Mapping and assessing ecosystems and their services are core units of the EU biodiversity strategy (Maes *et al.*, 2012). A primary data source for developing an European green infrastructure, resources to identify areas for ecosystem restoration, and a baseline against the goal of 'no net loss of biodiversity and ecosystem services' are the required EU-wide objectives (Palik *et al.*, 2000; Loreau *et al.*, 2001; Olavson & Fry, 2008). In response to these requirements, the research and development project ESMERALDA (Enhancing ecoSysteM sERvices mApping for poLicy and Decision mAking) aims to provide the building blocks for assessments in pan-European and at regional scales through a flexible method. The work will also ensure the European Union (EU) member states to support the assessments in relation to the requirements for planning, agriculture, climate, water and nature policy. The proposed mapping approach integrates biophysical, social and economic assessment techniques, being flexible due to a tiered methodology (ESMERALDA, 2015). As an associated part of this project, the study area is Schleswig-Holstein, locating on northern Germany. In this study, expert- and land cover-based methods, ecosystem service indicators and complex ecosystem service models will be exploited. Assessments of land cover distribution, land cover changes, modeling carbon storage of the state, and mapping the global climate regulation service with multiple indicators based on the CORINE land cover classification support the European studies of mapping and estimating of ecosystem services in ESMERALDA. The case study provides a way of estimating ecosystem services at regional scale as a part of Europe.

1.1.8 Research gaps

The definition and the importance of ecosystem services and their assessment have been illustrated in this section. Suitable indicators used for analyzing ecosystem services, especially mapping ecosystem services, here also have been described at different scales. However, some important research gaps remain about qualitative and quantitative ecosystem services based on land cover studies:

● Dynamics: How is land cover distributed spatially, and how did the land cover pattern change?

● Carbon flows: How are Gross Primary Production (GPP) and Net Primary Production (NPP) distributed over the various land cover classes, landscapes and districts?

- Indicators: What are the different outcomes of mapping ecosystem service with various ecosystem indicators?

1.2 Carbon storage as a focal regulating service

Carbon storage influences human well-being through direct ways mainly related to obtaining the energy stored in vegetation, food and fiber from crops and animals, as well as wood products, and to indirect ways that regulate climate condition affecting the direct ways and living circumstances.

1.2.1 Special features of regulating services

Regulating services are the services which have very close relationships with ecosystem structures, processes and functions compared to provisioning services and cultural services. They are also the services related strongly to the control of biogeochemical cycles and biophysical structures at different scales, including all the benefits obtained from the regulation of ecosystem processes and a "potpourri of intangible benefits" (Potschin & Haines-Young, 2011; Watanabe & Ortega, 2011; Raymond *et al.*, 2013). Regulating services that can be changed through management, planning, and policy making have been considered as the key services. They support the supply of other services (e.g. provisioning services and cultural services) to contribute to human well-being and cannot easily be expressed in monetary terms due to their strong indirect contribution to human welfare.

Most regulating services depend on biogeochemical processes, for example, carbon storage that is a critical indicator of global climate regulation and water purification, or rely on biophysical factors or characteristics, for instance, canopy structure and soil quality (Haines-Young, Roy; Potschin, 2010; Lauf *et al.*, 2014). Land cover and land use, and the type and intensity of land management can change either biogeochemical processes or biophysical properties (Maes *et al.*, 2012). Management strategies can modify the regulating capacities of different land cover and land use types, which is one of the most fatal issues that need to be considered to improve the estimation of regulating services (Fürst *et al.*, 2016). The scale is another factor affecting biogeochemical processes and biophysical properties on regulating services. Multi-scale interactions and dependencies necessitate multiple actors in strategies to sustain or enhance regulating ecosystem services. A case in point is that organic matter accumulation in soils of agriculture and forest supports the water and nutrient cycle at local regulating services and contributes to the global climate regulation through carbon storage (Cuevas *et al.*, 1991; Koschke *et al.*, 2013; Kruse *et al.*, 2013). Considering the dependence on measurements on biogeochemical processes and biophysical properties of the land cover and land uses is important as is considering the most appropriate scale for enhancing regulating services.

1.2.2 Focal regulating services

Ecosystems are sensitive mostly to the climate and can be strongly influenced by climate conditions. Ecosystems take up carbon dioxide (CO_2) through the process of photosynthesis, sequestrate it in the form of organic carbon in biomass and soils, and release CO_2 through respiration and combustion to the atmosphere (Rubin, 2006). Therefore, sequestrating more carbon, and emitting less could help to reduce the concentrations of carbon in the atmosphere, counteract the effects of global climate change (Hungate & Hampton, 2012), and provide functional human benefits that can be derived from ecosystem processes (Palmer M. A. et al., 2009). The Millennium Ecosystem Assessment (MA; 2005) identified that drivers of ecosystem changes as natural and human-induced factors that can directly and indirectly cause the changes. In the MA categories, the indirect drivers include demographic, economic, sociopolitical, scientific, technological, cultural and religious factors. Important direct drivers are climate change, nutrient regulation, conversion in the atmosphere of land use and land cover, and invasions of species and diseases (de Groot *et al.*, 2002). Fluctuations of the CO_2 concentration could lead to the change of climate conditions that may result in changes in ecosystem services. Carbon capture and storage, as important factors that can influence the concentration of CO_2, play a significant role in ecosystems. Urban ecosystems can be cleaned up by forest areas in cities, for instance, 3.02% of the annual carbon emission from fuel combustion is sequestrated by urban forests, and 0.26% of the annual carbon emission is offsite in Shenyang, a heavily industrialized city of China (Liu & Li, 2012). Chisholm (2010) considers that afforestation can decrease the speed of global climate change due to the replacement by one land cover and land use with less carbon capture and storage. Carbon capture and storage are physical changes to an ecosystem’s structures and processes, leading to the plurality of services in an ecosystem and the benefits that can be received by humans (Daily, 1997).

1.2.3 Global climate regulation

Ecosystem services play a vital part in tackling climate change through affecting mitigation and adaptation (Turner *et al.*, 2009). This potential results from forests, peatlands, oceans and other ecosystems that control carbon processes and other global biogeochemical cycles. Another important reason is that the maintenance and restoration of natural habitats are among the cheapest, safest and easiest solutions to deduce greenhouse-gas emissions, which is a prime factor on global climate change (Abson *et al.*, 2011; Hungate & Hampton, 2012; Nedkov & Burkhard, 2012; Delphin *et al.*, 2013; Karabulut *et al.*, 2016). Reducing emission sources or enhancing sinks of greenhouse gases are targets of mitigation, and adjusting natural or human systems to moderate harm or exploiting beneficial opportunities from climate variations are aims of adaptation (Locatelli, 2016). It is obvious that mitigation prioritizes emission sources or potential sinks, while adaptation prioritizes human well-being, ecosystems and activities. Ecosystems contribute to mitigation and adaptation due to their capacity of removing carbon from the atmosphere and storing it, thereby the ecosystems help people adapting to current climate hazards and future climate change (Fürst *et al.*, 2016). On the other hand, changing climatic conditions affect ecosystem services that are part of the solution to climate change (Sitch *et al.*, 2003). Recognizing the multiple links between ecosystem services and climate change is necessary in the progress of recognition. Ecosystem services management can enhance the contribution of ecosystem services to mitigation and adaptation. Meanwhile, climate change will affect ecosystems and their services through adaptation measures, thereby reducing negative impacts and maintaining ecosystem functions (Beer *et al.*, 2010).

1.2.4 Practical environmental significance of carbon storage

Carbon is a necessary element for living and closely related with the environment via fluctuations of carbon concentration. A recognition which has been widely accepted is that detrimental effects on the environment result from high levels of CO_2 in the atmosphere (Verchot *et al.*, 2006). The increase of CO_2 in the atmosphere is primary caused by the combustion of fossil fuels (Hughes & Benemann, 1997; Raven & Falkowski, 1999; Soon *et al.*, 1999; Kessel, 2000). Increased atmospheric CO_2 concentrations are positively related to greenhouse effects that may accelerate the global increase in the atmospheric temperatures (Soon *et al.*, 1999). Carbon capture and storage is a process of separating CO_2 emitted by the industrial sources from the atmosphere into a permanent or long-lived pool (e.g. pools in oceans, geological formations and vegetation) (Melillo *et al.*, 1989; Heath *et al.*, 2005; Salahshoor *et al.*, 2012; Robinson *et al.*, 2013). Carbon capture and storage play important parts in the carbon cycle, as it can have effects on climate change and extreme weather conditions, like the melting of the polar ice which can therefore accelerate the rise of the sea level. CO_2, together with climate change and nitrogen deposition leads to changes in carbon sinks, variation in the productivity of vegetation and several negative feedbacks on climate change, such as deducting the efficiency of the anthropogenic carbon perturbation (Friedlingstein *et al.*, 2006; Reichstein *et al.*, 2013), increasing species extinction and decreasing biodiversity as well as wild life populations (Fao, 2004; Bunker *et al.*, 2005; Tilman *et al.*, 2006). These factors bring changes of ecosystems services, and most of them need to be avoided directly and indirectly.

1.2.5 Single pools and processes of landscape carbon budgets

Carbon is exchanged between different pools through chemical, physical, geological and biological processes (Muñoz-Rojas *et al.*, 2011). Several internationally accepted consensus papers and reports have been published. One of them is the Kyoto Protocol that requires national governments to estimate carbon storage changes by evaluating and reporting national atmospheric carbon emissions (Nations, 1998; Feroz *et al.*, 2009). Another is the assessment report published by the Intergovernmental Panel on Climate Change (IPCC) about global climate change, which is considered closely related to carbon cycle (Eggleston *et al.*, 2006; Verchot *et al.*, 2006; Constable *et al.*, 2013).

Carbon cycles and the different storage pools of the earth are debated issues. The four main carbon pools are: (i) atmosphere, (ii) terrestrial vegetation and soil (aboveground and belowground biomass), (iii) oceans, and (iv) sediments and rocks (Rubin, 2006). Carbon in the atmosphere, in the form of CO_2, is the most dynamic carbon pool (Churkina, 2013). Soils on land contain three or four times as much carbon as terrestrial vegetation that has similar carbon content as the atmosphere (Tarnocai *et al.*, 2009). However, oceans are the largest carbon pools. They contain two forms of CO_2: One is calcified by corals, coccolithophores and bivalves; and the other is calcium carbonate dissolved in ocean water (Gattuso *et al.*, 1998; Bijma *et al.*, 1999; Kleypas *et al.*, 2006; Kurihara, 2008). Carbon in sediments and rocks is another important pool on earth (Robertson *et al.*, 1997) that correlates with geological processes, especially with diagenesis. Carbon exchanges occur in the atmosphere, aboveground biomass, belowground biomass and soil through geophysical, biogeochemical and biological processes. Photosynthesis, evaporation, decomposition, being logistical problems, can determine the ratio and amount of carbon storage and storage. Producers (such as vegetation, autotrophic algae, and autotrophic bacteria, etc.) fix carbon, mainly from CO_2, through the processes of photosynthesis and autotrophy into gross primary production. Then, carbon flows into predators through food webs. Respiration from producers, predators, microbes, roots and decomposition processes are the prior methods of emitting carbon from the relatively stable carbon pools. Except for the emitted carbon, parts of carbon remain in roots of vegetation, vegetation, predators and microbes, and soil organic matter. Other parts turn into lithogenic and pedogenic inorganic carbon through diagenesis and soil formation (see Figure 1).

Metamorphic, organic carbon sequestered in sedimentary rocks and petrogenic organic carbons are considered as two long-term forms of the element. According to the report by IPCC (IPCC, 2005), carbon could be stored either in geological formations or in oceans (Metz *et al.*, 2005). In the progress of the geological carbon cycle, carbon emissions could be reduced using carbon capture and storage if the geographical relationship between the large stationary emission sources and potential storage sites is suitable, but the costs spent on the length and size of the transmission should be considered (Metz *et al.*, 2005).

Carbon dioxide storage, groundwater flow, emissions of methane and nitrous oxide and nitrogen leaching and fixation are the most critical biogeochemical flows in terrestrial systems according to Watanabe et al. (2011). Priming effects can provoke strong short-term changes made by comparatively moderate treatments of the turnover of Soil Organic Matter (SOM), which could be tested for Soil Organic Carbon (SOC) (Bingeman *et al.*, 1953). They include co-metabolism-additions of labile or fresh carbon that can stimulate a suite of microorganisms that in turn raise microbial enzyme production (Kuzyakova et al., 2000). Isotopic labelling, as a preferred approach in estimating priming effects, limits research scales, because it is much more suitable to evaluate short-term and local effects (e.g. pulses of CO_2 and other greenhouse gases to the atmosphere) than effects at long-term and regional or global scales (Stockmann *et al.*, 2013). Root-derives and root exudates are related to the chemical conditions in soils. Sanderman (2010) showed that root exudates accelerated the rates of SOC decomposition, resulting in the depletion of SOC. Mineralization has a directly linkage to SOC via soil microbial communities and their molecular size, specific activity or composition (Fontaine & Barot, 2005).

Microbial ecology, enzyme kinetics, environmental drivers and matrix protection are the main factors that decide the ratio and amount of carbon storage. Microbial activity is considered as the primary active agent for SOC stabilization (Chabbi & Rumpel, 2009). Changes between incomplete decomposition and mineral surfaces are helpful for decomposing plant residues and remnants of microbes and fungi (Stockmann et al., 2013). Four main biological factors strongly influence the decomposition of SOC: priming effects, biodiversity, roots and root exudates, and chemical and physical processes. Biological factors also have effects on carbon capture and storage through controlling the growth speeds of flora, fauna and microbes that need carbon as necessary elements of their lives (Attiwill & Adams, 1993; Fan *et al.*, 2008; Xiaonan *et al.*, 2008; Acharya *et al.*, 2012). The mineralization rate of humified SOC is independent of the size, structure, or activity of the soil microbial community. Observations of fumigation experiments show that besides microbial processes abiotic factors are the rate-limiting steps in the overall system of SOC dynamics (Kemmitt *et al.*, 2008).

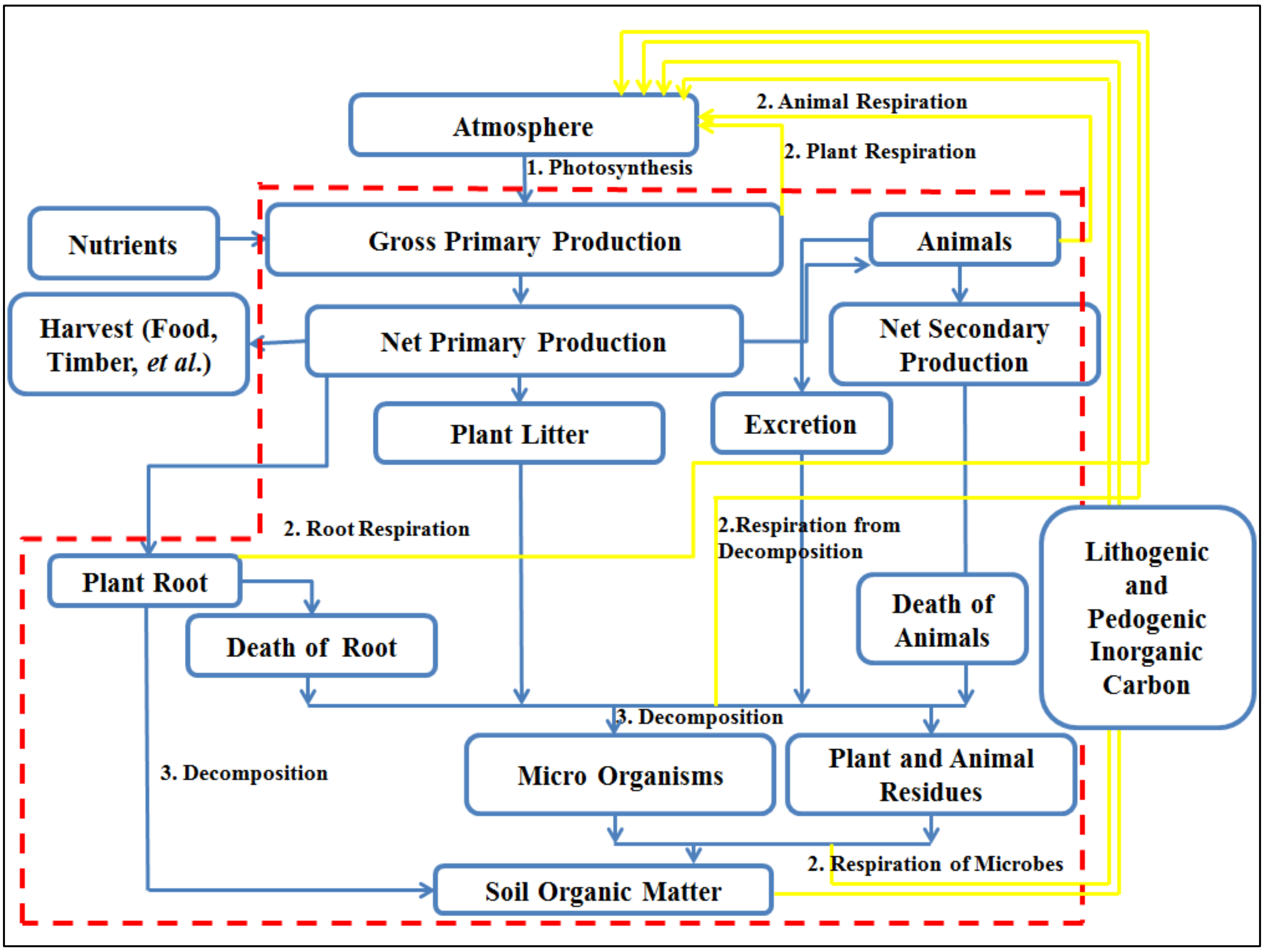

Figure 1. Carbon fluxes in an ecosystem. Red box represents the ecosystem, blue and yellow arrows show the processes of carbon storage and carbon emission, respectively (Rubin, 2006).

1.2.6 State of the art in quantifying carbon sequestration

Several methods, processes and technologies are used to sequester carbon from the atmosphere to various carbon pools. Mineral carbon sequestration, industrial uses, biotic carbon storage, geological sequestration and ocean storage are the five main pathways that have been used to capture and store carbon from a distinctive variety of carbon pools (Figure 2). Mineral carbon sequestration is based on carbonate, which is generated with mineral alkalinity, forming carbonate minerals through the dissolution of CO_2 in the atmosphere, raw minerals or industrial uses. Products, such as feedstock dependent products, construction materials, fire retardants are produced via this method. Industrial uses, as a main artificial pathway of storing carbon, change CO_2 with atmosphere through methods of post combustion, pre combustion, and oxy-fuel and industrial utilization. Most of the raw materials are biomass and coal which are important products of biotic carbon storage and raw minerals. Photosynthesis and predation determine the process of carbon storage made by organisms. Besides the biotic carbon storage, carbon in atmosphere can be sequestered into geological carbon pool through injection, which enhances oil recovery, changing amounts of gas, saline material and raw minerals. It is one of the long-term carbon sequestration methods. Carbon could be injected into oceans at great depth or sea floor by ship or pipeline. This method could enable carbon to remain isolated from the atmosphere for centuries (Metz *et al.*, 2005).

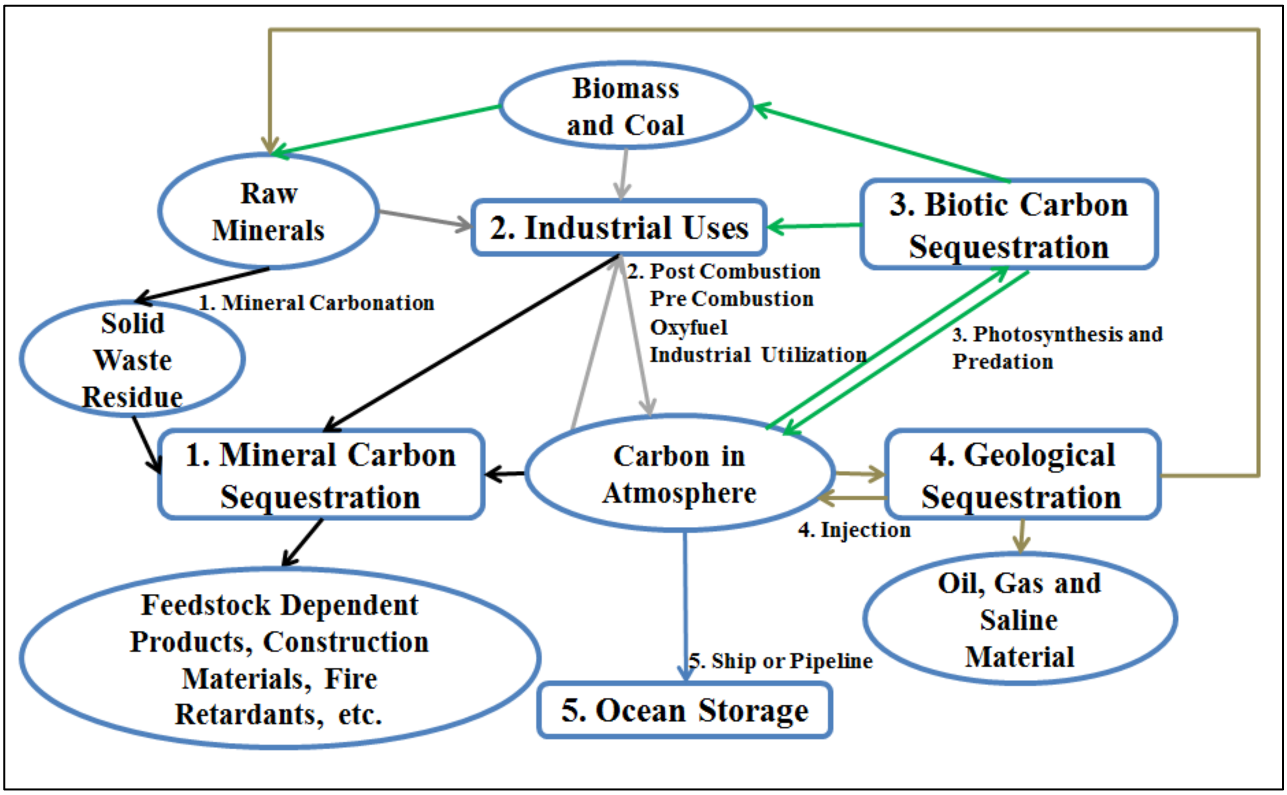

Figure 2. Carbon emission, storage and sequestration processes. Numbers 1-5 show carbon emission, storage and sequestration systems and correlated methods. Arrows of different colors represent processes of carbon cycles among carbon pools through main carbon emission and sequestration methods (Stocker *et al.*, 2013; IPCC, 2014).

1.2.6.1 Quantifying carbon storage at the local scale

Carbon storage and carbon cycling in forests, grasslands and arable land ecosystems are frequently studied at local scale. Moreover, eddy correlation measurements are considered as methods of estimating carbon storage and quantifying carbon flows. To demonstrate the empirical determination for carbon storage, four core studies with representative methods of carbon storage estimation from the literature are chosen and summarize. Methods of evaluating carbon storage in forest are concluded from studies of Wang et al. (2013) and Zheng et al.(2008). Processes of using eddy correlation measurements are described in publications from Aubinet et al. (1999) and Carrara et al.(2003). Carbon storage assessment strategies in grassland are introduced in Acharya's study (2012), and the assessment in arable land is illustrated by the studies of Bolinder et al. (2007) and Kuzyakov and Schneckenberger (2004). The details are as follows:

(1) Forest plot analysis:

Wang and Zheng's (2013 and 2008) studies present measuring processes of carbon storage in forests. To investigate the carbon budgets of forests, the diameter at breast height, the basal diameter, and the height of living trees were measured. Then, the sample trees were harvested for measurements of aboveground-biomass (including stem wood, stem bark, course branch, fine branch, and foliage), belowground-biomass (>2cm, 0.2-2cm, <0.2cm in diameter,) and tissue carbon concentrations. Four to six branches were sampled from each tree at regular intervals over the entire length of the crown. Foliage on the sample branches was collected. Trunk was sectioned into meter-long pieces. Coarse roots (diameter of root>2cm) were gathered from the stump until it was difficult to distinguish root from one tree to another. Roots of diameter <2cm were obtained by excavating large soil blocks (1m×1m×1m), isolating roots from the soil. Understory biomass was calculated using total harvesting techniques within five randomly selected (2m×2m) subplots. The forest floor component, including coarse wood, litter, and the fragmentation layer were also sampled within six 1m×1m subplots. Volumetric samples of mineral soil were collected at different depths (usually taken at 0-20cm, 20-40cm, 40-60cm, 60-80cm, and 80-100cm) on at least three randomly chosen locations of a plot for determining carbon concentrations. Then, an oil-bath $K_2Cr_2O_7$ titration method was used to establish soil organic carbon from the sample. After that, a generalized linear model of weight of each biomass component was used for estimating the biomass components of trees. The biomass of every part on plots times' carbon concentration was the carbon content of each part. The whole carbon content was estimated by summing all the parts' contents up. Carbon concentrations were estimated by the ratio between carbon and biomass via experiment or published values.

(2) **Eddy correlation measurements:**

The eddy correlation measurements of Aubinet et al. (1999) and Carrara et al.(2003) describe the vertical flux of CO_2 between the forests or grasslands and the atmosphere. Fluxes of CO_2, water vapor and sensible heat needed to be measured during a relatively long term. Fluctuations in the vertical wind speed and CO_2 concentration could be used to calculate the CO_2 vertical flux. Wind speed and temperature were tested by a three-dimensional sonic anemometer. CO_2 and water vapor concentrations were estimated by an infrared gas analyzer. A software named EDISOL analyzed gas fluxes monitored for monitoring IRGA. The equipment measured the above canopy flux of CO_2 at the top of the tower (40m) and stored data as half-hourly means on a data logger. A profile of CO_2 concentrations at 10, 24, 32 and 40m above the ground was measured for CO_2 estimating storage in the air layer below the eddy correlation measurements height. The CO_2 soil efflux was monitored with a closed dynamic system. Soil heat flux and soil temperature were also measured because they were influencing factors of the CO_2 soil efflux. The CO_2 biotic exchange (NEE, F_{NEE}) can be calculated by the following algorithm:

$$F_{NEE} = F_c + F_{\Delta S} + \text{advection terms} \quad (1)$$

It is based on the assumption of stationarity and horizontal homogeneity of turbulence, and under the hypothesis of negligible horizontal flux divergence and molecular diffusion.

(3) Grassland quantification:

Carbon storage quantification in grassland is illustrated in the study by Acharya (2012). Target species of grass were chosen in a representative area. Plots were set with the size of 9m×15m, establishing subplots (3m×6m) that were used to collect aboveground biomass. Then, the aboveground biomass was harvested in the subplots by cutting at 5 cm stubble height in June, July, August, and October respectively. 40 soil sub-samples, which were taken randomly to overcome soil heterogeneity, were sampled to the depth of 20 cm with an auger. Roots were isolated by wet sieving of soil with a gentle spray of water, removing soil adhering to roots. Then, roots were collected in finely woven silk organza and dried in an oven at 70 ℃ (Rasmussen et al., 2010). Carbon concentration of parts of plants or soil could be tested with a varioMAX CNS elemental analyzer (Uri *et al.*, 2012) or estimated from published values. Moreover, each sample was separated into two parts, one part was stored at 2℃, analyzing for dissolved organic carbon. The other part of soil was used for determining gravimetric water, carbon and nitrogen concentration, soil respiration and root extraction. Gravimetric water content was tested by oven drying soil samples for 48h at 80℃. Carbon and nitrogen concentration in soils were analyzed on a LECO CNS-1000 analyzer. The soil respiration was tested in a respirometer that calibrated total CO_2 and accumulated CO_2 through measuring change in conductivity made by respired CO_2 from soil in a potassium hydroxide solution. DOC was analyzed using a TOC-V analyzer.

(4) **Arable land measurement**:

A method which can calculate total NPP, carbon allocation and carbon input to soil via testing carbon concentrations of different parts of plants in arable land has been used in this case study (Kuzyakov & Schneckenberger, 2004; Bolinder *et al.*, 2007). It separated the carbon contents in the plant into four parts: C_p (carbon in products, e.g. grain, forage, and tuber), C_s (carbon in above-ground residue, e.g. straw, stover, chaff), C_r (carbon in roots, except that fraction designated as product), and C_E (extra-root carbon, including all root- derived materials).

$$NPP=C_p+C_s+C_r+C_E \tag{2}$$

The amount of carbon in each fraction can be estimated from agricultural yields in sample plots, from published or assumed values for harvest index (HI), S: R ratio.

$$C_P = Y_P \times C_C \tag{3}$$

$$C_S = Y_P (1 - HI) / HI \times C_C \tag{4}$$

$$C_R = Y_P / (S{:}\ R \times HI) \times C_C \tag{5}$$

$$C_E = C_R \times Y_E \tag{6}$$

Y_P was the dry matter yield of above-ground product (g m^{-2} yr^{-1}) that could be estimated from the amount of harvest. C_C was the carbon concentration of all plant parts which could be tested through dry combustion method with a CNS elemental analyzer (Uri *et al.*, 2012). The harvest index equaled to dry matter yield of grain divided by total above-ground dry matter yield. S:R meant shoot: root ratio, shoots (leaves and petioles) and roots needed to be dried at 70 ℃ and weighted in this process. Shoots could be cut directly from sample plants and roots were separated from soil particles with wetting solution, passing roots through a metal screen (Maggio *et al.*, 2005). Y_E is the extra-root carbon, testing with tracer techniques of pulse labelling, continuous labelling and ^{13}C natural abundance.

1.2.6.2 Quantifying carbon storage at the global scale

The emerging climate crisis is correlated with fossil fuel combustion and land cover changes, and economic demands for increasingly scarce and nonrenewable fossil fuels are two global concerns (Ben íez *et al.*, 2007; Bleken *et al.*, 2009). Quantifying global carbon storage appears to be an important step for understanding global climate change and ecosystem services. However, not everything can be observed and measured due to many practical, financial, logistic, and physical reasons. For instance, some carbon storage processes occur over decades, centuries, or millennia at the global scale (Rubin, 2006). Supporting for long-term and large-scale monitoring is difficult to obtain only with field work. In contrast to field work, models, being properly designed and used, can play a valuable role in elucidating long-term, global, and complex processes (Foley *et al.*, 1996; Ben íez *et al.*, 2007; Bleken *et al.*, 2009; Lenz-Wiedemann *et al.*, 2010). A terrestrial carbon model involves natural and human induced processes through estimating absorption and emitting CO_2, and through assessing carbon storage by plants and soils (Bondeau *et al.*, 2007). Dynamic global vegetation models are a kind of the terrestrial carbon models which combine process-based representations of terrestrial vegetation dynamics and land-atmosphere carbon and water exchanges in a modular framework (Sitch *et al.*, 2003). Simulations have been made at specific sites where field measurements are available for model evaluation (Falge *et al.*, 2005; Billen *et al.*, 2009). The United States Geological Survey (USGS) is developing a quantitative understanding of the terrestrial carbon cycle with satellite remote sensing, carbon biogeochemistry, and advanced spatial modeling. Products include GPP, Normalized Difference Vegetation Index (NDVI), Enhanced Vegetation Index (EVI), and Leaf Area Index (LAI), all of which can present carbon storage to some extent. Modeling carbon storage within data sources of remote sensing imagines makes the estimation time-saving and globally available.

1.2.7 State of the art in modelling and mapping carbon storage

Methods used for studying the carbon cycle, relating to GPP, NPP, SOC and CS are various and need to be used by exactly considering the study scales. GPP and NPP are essential components of the carbon cycle and could be experimented with using various methods. The eddy covariance technique is a useful independent approach for quantifying the GPP and NPP (Chen *et al.*, 2015) at local or regional scales. It is also a data source for establishing, verifying, modeling or mapping process-based ecosystem models, which could be used at larger scales, as regional, national or global scales (Chang *et al.*, 2013). SOC influences plant productivity by mediating nutrient supply, and affects ecosystem functioning by improving the biophysical environment and biodiversity (Wang *et al.*, 2015). The experimental method is the prime one which has been used on studies of SOC (Wang & Dalal, 2006; Vesterdal *et al.*, 2013). However, taking samples at whole regions or at the globe is hardly possible. Therefore, model evaluation of SOC storage at the regional and global scales is more frequently that experimental method (Wu *et al.*, 2015). Besides SOC, CS includes above-ground, below-ground and litter carbon stocks. The traditional methods for estimating carbon stocks in ecosystems are vegetation inventory, satellite remote sensing, inverse modelling which associates to atmospheric transport models and atmospheric CO_2 observations and simulations based on carbon cycle model (Ma *et al.*, 2015). Similarly to the methods which have been used to assess regional and global GPP, NPP and SOC, the mapped modelling and satellite remote sensing database are frequently used in CS researches. It results in previous researches on carbon evaluation and mapping at regional or national scales via the InVEST model which is aiming to estimate the amount of carbon stocks or carbon storage for a defined area (Sharp *et al.*, 2015b).

1.3 Objectives and research questions

Based on the results of the described methods, this research focuses on the carbon flows at the regional scale, which is often suffering from an extreme direct severity of data. Therefore, land cover has been chosen as a starting point of the investigation. Land cover is one of the critical factors influencing carbon emission and storage and provides widely used indicators of ecosystem services for global climate regulation. A few studies paid attention on the case studies based on land cover as well as on the carbon storage of above-ground, below-ground, litter and soil organic carbon in Europe (Cruickshank *et al.*, 2000; Muñoz-Rojas *et al.*, 2011). However, there are rare studies on carbon distribution and stocks estimated by GPP and NPP based on the land cover classes, and no study assesses the differences due to the different quantitative indicators for one ecosystem service.

In this research, an attempt is made to characterize focal components of the ecosystem service 'global climate regulation' for different spatial scales by focusing on the German state of Schleswig-Holstein in relation with the spatial-temporal dynamics of ecosystem services. The carbon storage is the primarily important function of the ecosystem service of global climate regulation. In order to assess global climate regulation, the distributions of the annual total GPP, the annual total NPP, soil organic carbon (SOC) and Carbon Storage (CS) with quantitative databases, land cover dynamics, and quantitatively evaluations of the differences deriving from various indicators are estimated. The study aims to:

- Analyze the land cover areas of Schleswig-Holstein during the years 1990, 2000, 2006 and 2012 based on the CORINE land cover dataset, distinguishing landscapes and districts of Schleswig-Holstein (chapter 3.1.1.1-3.1.1.4 and 3.1.1.6);
- Use the CORINE land cover dataset to evaluate land cover changes of Schleswig-Holstein from 1990 to 2000, from 2000 to 2006, and from 2006 to 2012 (chapter 3.1.1.5);
- Map ecosystem services indicators with the ecosystem service matrix after Burkhard et al. (2014) (chapter 3.1.2);
- Illustrate the distributions of the annual total GPP and the annual total NPP in various land cover classes, landscapes and districts, and assess the effects of land cover on GPP and NPP distributions (chapter 3.1.3.1-3.1.3.3);
- Identify the respiration and the ratio between the annual total NPP and the annual total GPP in 2000, 2006 and 2012 based on the classification of the CORINE land cover, and the hotspots and cold spots of Schleswig-Holstein in 2000, 2006 and 2012 (chapter 3.1.3.3-3.1.3.4);
- Evaluate the carbon stocks and carbon storage based on CORINE land cover classes in Schleswig-Holstein (chapter 3.1.3.5);
- Estimate the carbon storage of Schleswig-Holstein based on the InVEST model (chapter 3.1.3.6);

- Analyze the correlation among the quantitative indicators (the annual total GPP, the annual total NPP, SOC and CS) and the qualitative indicator (GCR) from the ecosystem service matrix after Burkhard et al. (2014) of the global climate regulation service (chapter 3.1.3.7);

- Compare the results of ecosystem service mapping related to the global climate regulation, using the annual total GPP, the annual total NPP, SOC and CS as indicators, with the mapping results from the ecosystem service matrix related to the global climate regulation (chapter 3.1.3.7);

- Calculate carbon storage in biomass and soil organic carbon, and analyze the correlations of soil conditions in the land cover types of Bornhöved Lakes District (chapter 3.1.3.7).

In order to approach the objectives of the study, three key research questions are:

1. How are different land cover classes distributed spatially, and how does the land cover pattern change based on the datasets of CORINE land cover in Schleswig-Holstein?

2. How much carbon has been stocked, evaluated with parameters of the annual total GPP, the annual total NPP, SOC and CS based on CORINE land cover?

3. What are the relationships among the quantitative indicators (the annual total GPP, the annual total NPP, SOC and CS) and GCR of global climate regulation in Schleswig-Holstein?

The dissertation is divided into five chapters, containing the following units:

Chapter 1 provides an introduction of the study, which includes the research targets, research questions, and objectives. This chapter explains the importance and definitions of ecosystem services and ecosystem assessment firstly. Then, it presents the methods for deriving ecosystem services, and reviews ecosystem service mapping. Furthermore, features of regulating services, especially features of global climate regulation are presented as well. Carbon storage, as one of the significant indicators of global climate regulation, carbon pools and processes of landscape carbon budgets, and quantifying and mapping carbon storage have been involved in this chapter.

Chapter 2 introduces the study areas and the applied methods. The research uses qualitative and quantitative methods to investigate the global climate regulating service. Both the process of data collection and data analysis methods are shown.

Chapter 3 describes the empirical findings that are presented with in sub-chapters of country-wide assessments, local assessments and regional assessments. Land cover distribution and land cover changes of the country-wide scale are evaluated. Mapping ecosystem services with qualitative indicators are presented as well. Then, qualitative assessments of different ecosystem services based on the CORINE land cover are presented and a comparison of different global climate regulation indicators is shown. Former studies on ecosystem services in the Bornhöved Lakes District have been reviewed. Moreover, carbon storage in biomass and soil organic carbon of several land cover classes in the Bornhöved Lakes District, correlations of soil conditions of land cover classes of beech forest, spruce forest, mixed forest, grassland and arable land are analyzed. Former studies on ecosystem services in the Bornhöved Lakes District have been reviewed in this sub-section.

Chapter 4 discusses uncertainties and methodological problems, and compares the results, methods and concepts of this study with those from the literature.

Chapter 5 summarizes the focuses of chapters 2 to 5, concluding the implications of outcomes from conceptual, methodological and environmental aspects of ecosystem services assessments, and answers the questions from the introduction.

Chapter 2. Materials and methods

This chapter introduces the data sources and methodologies that have been used in the study. The research areas are described in the first section, including Schleswig-Holstein, Bornhöved Lakes District and Bornhöved Forest. The second section illustrates the assessment methods and indicators. Data sources and analyses based on GIS are presented, for example land cover distributions and land cover change detection, land cover diversity, the annual total GPP and NPP, differences between the annual total GPP and NPP, and the carbon storage modelling. Furthermore, the methods used for estimating qualitative and quantitative ecosystem service assessments are explained. The last section addresses the statistical methods used for the spatial-temporal analyses.

2.1 Research areas

The investigations have been carried out at different scales, ranging from the whole state of Schleswig-Holstein to a small forest ecosystem. The sites are first characterized in details, following the research scales, in chapters 2.1.1 to 2.1.3.

Schleswig-Holstein is one of the 16 German states and lies on the northernmost national border. The state connects to Denmark on the north and to three German states on the south; it borders the North Sea to the west and the Baltic Sea to the east. The main landscapes are Marsch, Hohe Geest, Vorgeest and Hügelland, which are mainly situated in the eastern part of Schleswig-Holstein.

The Bornhöved Lake District is an ensemble of agricultural and forest ecosystems around a catchment of five consecutively connected lakes. The district is located about 30 km south of Kiel (54°06'N, 10°14'E), in northern Germany. This area has been used as a study site for ecosystem research since 1989 (Fränzle et al., 2007a). It has been one of the continental waters or wetlands sites of the European Long Term Ecological Research Network program which aimed to assess environmental quality and pressures across Europe. Recent studies on ecosystem services regarding the structural and functional ecosystem components have been carried out based on the former studies by (Burkhard *et al.*, 2009, 2014; Kandziora *et al.*, 2013b).

2.1.1 Schleswig-Holstein

Schleswig-Holstein is located in at the northernmost part of Germany (Figure 3) with an area of 15.65×10^3 km^2. The central point of the state crowns at 54°28′12″ north altitude and 9°30′50″ east longitude. The North Sea and the Baltic Sea lay on the western and the eastern side of Schleswig-Holstein, respectively. The state borders Denmark to the north, and the German states of Lower Saxony, Hamburg and Mecklenburg-Vorpommern to the south. There are four separate urban districts and 11 rural districts in Schleswig-Holstein. The capital city is Kiel, being a middle-eastern coastal city at the Baltic Sea. There are 2.81 million inhabitants in Schleswig-Holstein and the population density is 179 inhabitants per km^2. Most of the population lives in the urban districts, especially in the areas surrounding Hamburg, e.g. in the districts of Pinneberg and Stormarn. Generally, the Schleswig-Holstein landscape is shaped by agriculture. However, the economic features are different due to spatial distributions, such as the Hamburg metropolitan region, the west coast and the port districts at the east coast. The economy comprises of engineering and services, agriculture, tourism and wind energy, trade, transport, shipbuilding and energy and infrastructure. Tourism in

Schleswig-Holstein accounts high for the national income (Wikipedia, 2016).

Volumes of glaciers in the quaternary ice ages were several times larger than now. Warmer and colder phases were alternately appearing in northern Germany during the Pleistocene and Holocene (Liedtke & Marcinek, 2002). The first glaciation reached northern Germany, and its tracks were cleared by the tertiary drilling (Stephan, 1995). Deep grooves resulted from erosion and meltwater streams appeared in the region of Schleswig-Holstein. Three glaciation phases of Saale-Elster-Weichsel, Saale and Elster moraines can be found in Geest. Weichsel moraines are basic elements of the Hügelland. These features are combined with the elements of the glacial series-Marsch being extend to North Sea (Stephan, 1995; Liedtke & Marcinek, 2002).

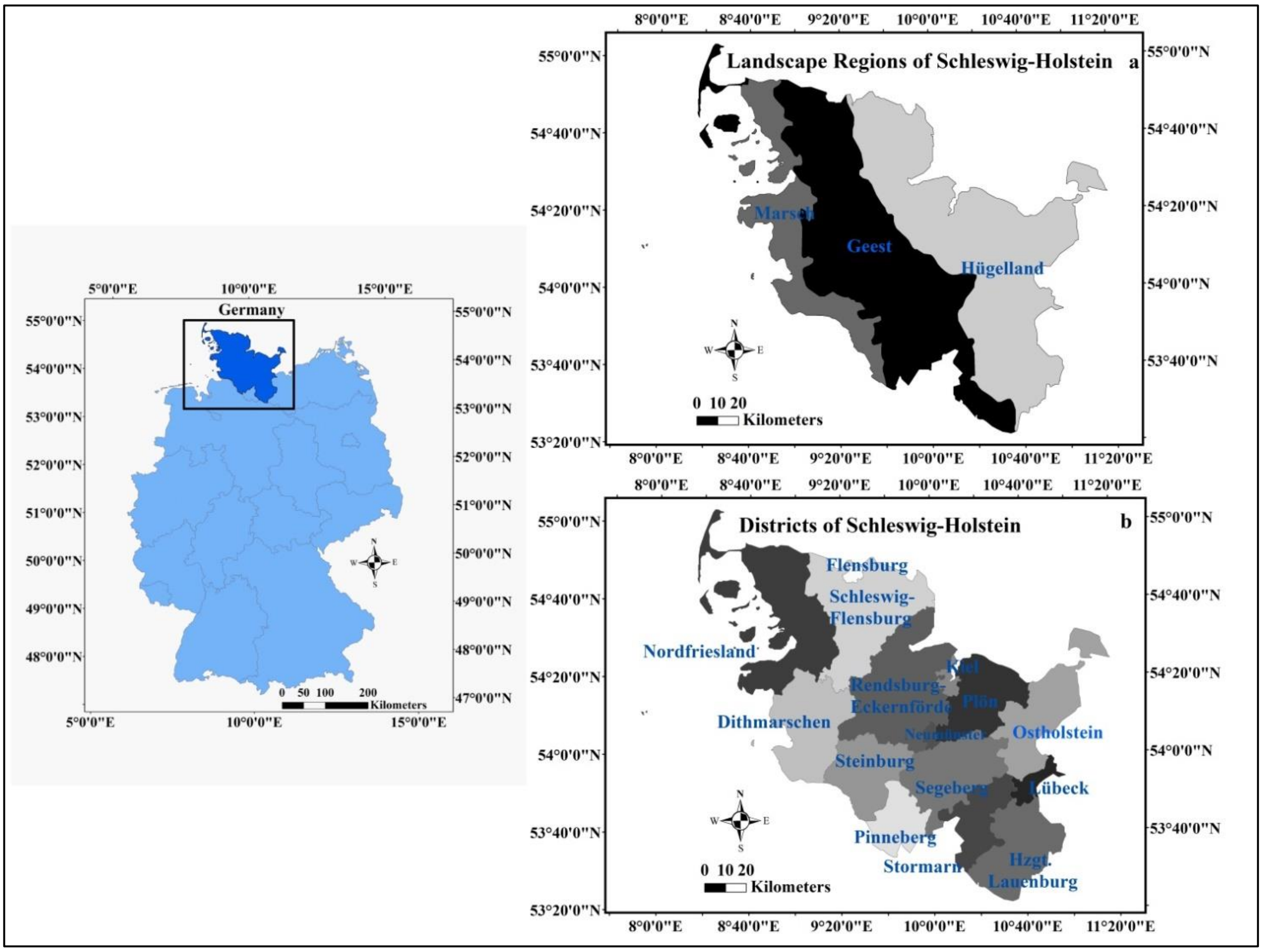

Figure 3. Landscape regions and districts of Schleswig-Holstein.

The natural landscape regions and the land cover classes in Schleswig-Holstein are multitudinous. The natural landscape regions are Marsch (extending into the western North Sea), sandy Geest (created by old moraine structures and sanders for the last ice age) in the middle and the hill region (emerged as moraine fields from the last ice age) which is called the Östliches Hügelland of Schleswig-Holstein. The elevation of the state decreases from the eastern part to the west. There is virtually no hill in the western part of the state. However, hills with the highest elevation of 168 meters exist on the eastern part. The landscape in the west of Schleswig-Holstein is more fragmented than the east of the state. Several islands are located at the western coast, which forms the Schleswig-Holstein's Wadden Sea National Park the largest national park in Central Europe. Natural parks and protection areas for flora and fauna are mainly distributed near the coastal areas of the Baltic See and areas occupied by lakes, rivers and forests.

Schleswig-Holstein is located in a flat landscape. 32 out of 44 CORINE land cover classes are found in Schleswig-Holstein. Figure 3 shows the locations of the main landscapes types of Schleswig-Holstein, which can affect the distributions of land cover classes and the ecosystem services on the land cover classes. Classifications and definitions of the land cover classes are based on the CORINE land cover nomenclature. Most areas of the state are distinctively characterized by artificial surfaces, agricultural areas and forest and semi natural areas.

The districts of the state that affect soil conditions due to the policies and management are presented in Figure 3. Moreover, the soil conditions are either affected by the geological development and geomorphological structures of the landscape regions, or they can be slightly influenced by the land cover classes. The soil types (Figure 4.) consist of Gleyic Calcaris Hovisol and Endogleyic Clayic Stagnosol and Thaptohistic Gleyic Stagnosol and Endogleyic Planosol in the western Schleswig-Holstein, Spodic Arenosol, Brownic Arenosol, Cambi Podzol, Podzol and Gleyic-Podzol in the middle part of the state, and Luvisol and Stagnosal and Luvisol and Gleyic Stagnosol in the east.

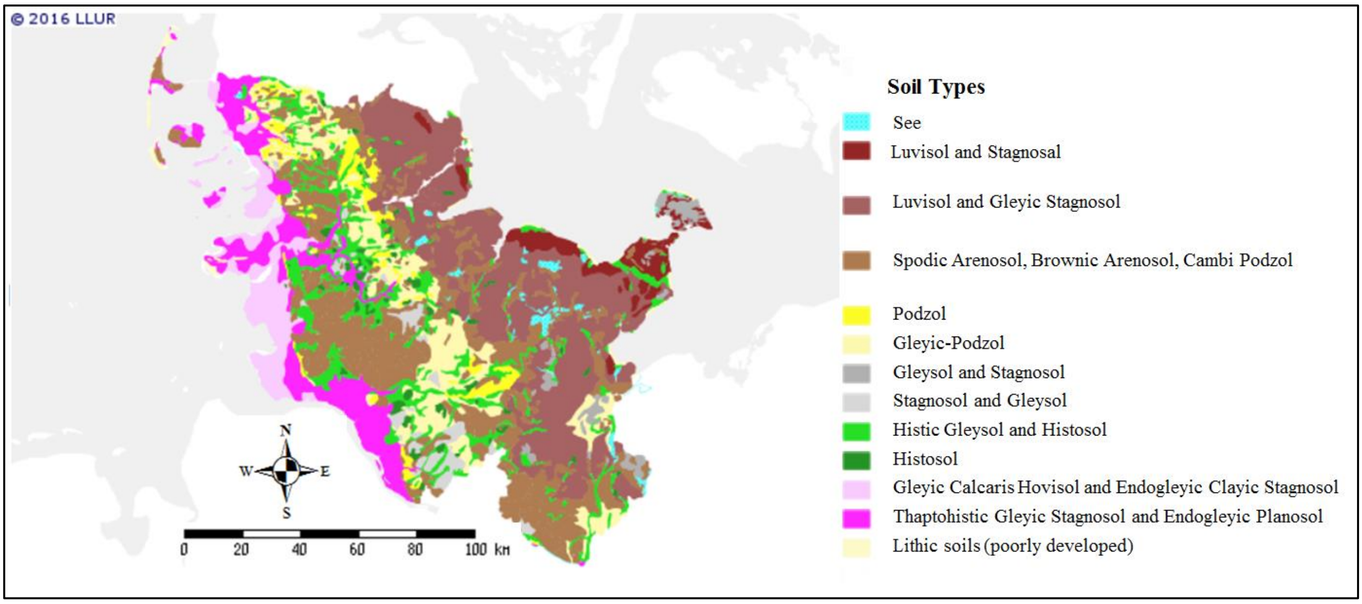

Figure 4. Soil types of Schleswig-Holstein. (Source:Agricultural and Environmental Atlas (Ministerium für Energiewende, Landwirtschaft, Umwelt und Ländliche Räume, 2016)).

2.1.2 Bornhöved Lakes District

The Bornhöved Lakes District is located in the middle-east of the Schleswig-Holstein (Figure 5). It was selected as a study site of a 12-year integrative ecological project and one of the study-sites of the Long Term Ecological Research program (Fränzle *et al.*, 2008; Müller *et al.*, 2010).

The landscape of the district is dominated by six consecutively connected lakes named Stolper See, Schierensee, Fuhlensee, Belauer See, Schmalensee and Bornhöveder See. The surface areas range between 1.13 km^2 and 0.27 km^2 (Kandziora *et al.*, 2013b). A complicated pattern of glacigenic, fluvioglacial, limnetic, organic and anthropogenic deposits characterized the Bornhöved Lakes District. The sedimentological progress of the deposits has been essential for forming the soils of the area (Blume *et al.*, 2007). The predominant till facies of the northern part vary based on the continuity or discontinuity of the lodgement process, the amount of water in the subglacial environment, syn-depositional processes, and the primary carbonate content. Furthermore, littoral wave action and deposition result in limnetic sediments comprising sand, silt, and detritus. Then, they comprise different minerogenic and minero-organogenic facies. The soils of the Bornhöved Lakes District represent loamy luvisols, stagnosols, cambic, arenosols and arenic umbisols. They have been influenced by the development of land cover classes, landscape features, and land cover patterns.

Agricultural areas, forest areas and settlements are the primarily dominating land cover classes of this watershed. The forest areas are mainly occupied by beech forest, mixed forest and alder carrs. Complex cultivation patterns and non-irrigated arable land, from which crops and fodder are harvested, compose the agricultural areas.

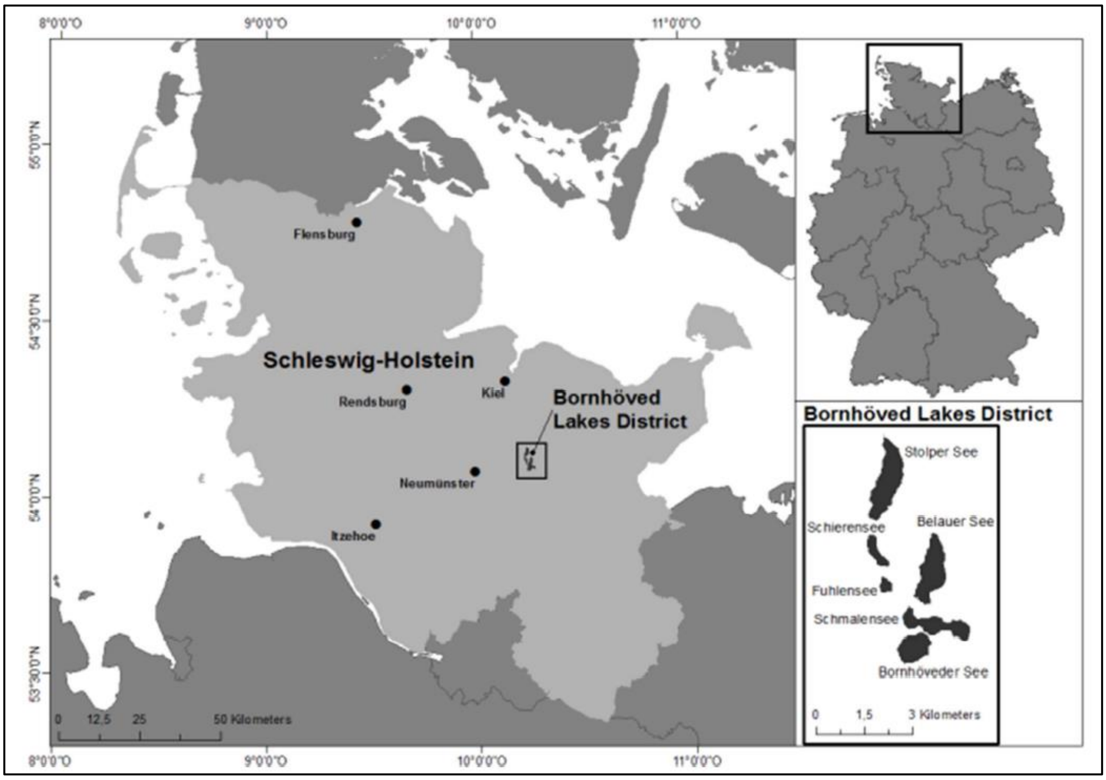

Figure 5. Study area location of Bornhöved Lakes District. (Source: Kruse et al., 2013).

2.1.3 Forest area around Lake Belau in the Bornhöved Lakes District

As a part of the LTER Europe, the local investigation on Forest Environmental Monitoring of the European Union has been executed since 1998 in the Bornhöved beech forest while several of the ecological studies had been carried out in Bornhöved since 1988 as components of the ecosystem research project (Fränzle et al., 2008; Kandziora et al., 2013b).

The forest areas in the Bornhöved Lake District are primarily situated around the five lakes, mainly constituted by beech forests around 120 years old, mixed forests 40 to 50 years old, and alder carrs that have experienced two facies since 1930 (Blume *et al.*, 2007). Most of the forest areas are surrounded by agricultural land (Kandziora *et al.*, 2013b). The beech forest (*Fagion Sylvaticae*) is an important and representative forest in this area. The herb layer of the beech forest is poorly developed and is herb layer is dominated by *Milum effusum*. The mixed forest comprises of the tree species *Pseudotsuga menziesii, Picea abies, Larix kaempferi, Quercus robur and Quercus rubra*. *Rubus fruticosus* primarily dominated the herb layer of the mixed forest areas. The shrub layer and the herb layer of the alder carr (*Carici elongatae*) strongly depends on the hydrological features of the locations of the communities (e.g. the drained site and wet eutrophic site) (Fränzle *et al.*, 2008).

2.2 Assessment methods and indicators

This section explains the methods used in the study, consisting of data sources, methods based on GIS, qualitative and quantitative ecosystem service assessments, and statistic methods. The reasons for choosing the methods, formulas and software or tools for the calculation will be illustrated in each sub-section.

2.2.1 Data sources

The CORINE land cover and CORINE land cover change maps were based on remote sensing data. They describe some of the prime land cover characteristics for whole Europe, allowing estimations of land cover and land cover changes. The maps of the CORINE land cover and land cover changes were derived from long-term investigation and advanced technologies on data calibration and mapping, which confirmed the reliability of these official and governmental data sources.

The CORINE land cover data had a minimum mapping unit of 25 hectares and a mapping width of 100 meters. However, the CORINE land cover change maps use a minimum mapping unit of 5 ha, and a minimum boundary displacement of 100 meters. The CORINE land cover data contains an inventory of 44 (Level 3 of CORINE Land Cover Classification) land cover classes, being available for the EU member states for the years 1990, 2000, 2006 and 2012 (Kandziora *et al.*, 2013b; Burkhard *et al.*, 2014). Meanwhile, the CORINE land cover change maps can be used from 1990 to 2000, from 2000 to 2006, and from 2006 to 2012. The databases were available for downloading as 100 m grids, 250 m grids and vector databases from the European Environmental Agency (EEA).

The CORINE land cover maps for 2012 were carried out within the program of global monitoring for environment and security initial operations. The maps included post- processing of space data and the automatic extraction of intermediate products, production of five high-resolution layers, a new CORINE land cover inventory, validation and quality control of products and collection of in-situ data. These methodology changes resulted in differences of understanding between 2006 and 2012. Distributions of land cover classes based on landscapes and districts in Schleswig-Holstein can be affected by the new approach (Büttner *et al.*, 2014).

The Amtliches Topographisch–Kartographisches Informations-System (Official Topographic-Cartographic Information System; ATKIS) (Authorities, Working Committee of the Surveying (AdV), 2006) is an official German topographic system that includes all federal German states. The map of German states was downloaded from this system. The Ministry of Energy Transition, Agriculture, Environment and Rural Areas of Schleswig-Holstein (Ministerium für Energiewende, Landwirtschaft, Umwelt und Ländliche Räume Schleswig-Holstein) is responsible for research related to energy transition, agriculture, and environment of Schleswig-Holstein. Maps of the borders of Schleswig-Holstein, districts, and landscape classifications were downloaded with a Geographic Information System (GIS: ArcGIS 10.3) to analyze the land cover distribution, Gross Primary Production (GPP) and Net Primary Production (NPP) distributions and storages, harvests, and the correlation among GPP, NPP and the harvest on the landscape regions and the districts.

The Moderate Resolution Imaging Spectroradiometer (MODIS) provides terrestrial satellite remote sensing images, aiming at observing parameters needed for global change research, including global carbon cycle analysis, ecosystem status assessment and environmental change monitoring (Justice *et al.*, 1998; Zhao *et al.*, 2005; Shim *et al.*, 2014). The MODIS GPP and NPP data are the main components of the MOD17 products that provide global vegetation productivity based on satellite images (Justice *et al.*, 2002). The maps of the annual total GPP and NPP with 1 km×1 km grids of Schleswig-Holstein for the years of 2000, 2006 and 2012, and maps of monthly GPP with 1 km×1 km grids of 2006 were retrieved from the database of MOD17A3 that was available at the Numerical Terradynamic Simulation Group of the University of Montana (Running & Zhao, 2015). They calculated the annual total GPP and the annual total NPP with formulas (1) to (3) (Running *et al.*, 2004; Zhao *et al.*, 2005; Running & Zhao, 2015):

Daily GPP was calculated by equation (7):

$$daily\ GPP = \varepsilon \times APAR \tag{7}$$

$$daily\ NPP = GPP - R\_m - R\_g \tag{8}$$

The annual total GPP or NPP was calculated by equation (9):

$$Annual\ total\ GPP\ or\ NPP = daily\ GPP\ or\ NPP * \frac{365}{100} \tag{9}$$

The daily GPP (kg C day^{-1}) was related to ε (kg C MJ^{-1}) and to the absorbed Photosynthetically Active Radiation (*APAR*). ε was a conversion efficiency parameter determined by vegetation types and climate conditions. The daily NPP (kg C day^{-1}) was affected by the annual growth respiration (R_g), and the live cells' annual maintenance respiration in woody tissue (*R_m*). The annual total GPP or NPP (Mg C ha^{-1} yr^{-1}) is based on the daily GPP or NPP.

The annual total stored GPP or NPP (Mg C yr^{-1}) means the GPP storage or the NPP storage on each land cover. The annual GPP or NPP which is stored by a certain land cover (CLC areas (ha)) and calculated by equation (10):

$$annual\ total\ stored\ GPP\ or\ NPP = annual\ total\ GPP\ or\ NPP \times CLCareas \tag{10}$$

The storage of Soil Organic Carbon (SOC (Mg C ha^{-1})) in agricultural soils plays a role as a main parameter of soil quality and as a strategy to offset CO_2 emission by C sequestration. The vector map of SOC storage in agricultural sites was downloaded from the European Environmental Agency (EEA). The EEA is an agency of the European Union, responsible for developing, adopting, implementing and evaluating environmental policy. They focus on research about air and climate, air pollution, nature (e.g. climate change, biodiversity of ecosystems, land cover and land use, soil, water and marine), sustainability and human well-being (e.g. waste and material resources, environment and health, policy instruments, noise), and economic sectors, such as agriculture, energy, industry and transport.

The Statistisches Amt für Hamburg und Schleswig-Holstein (Statistic Agency for Hamburg and Schleswig-Holstein) provided the statistical data of cereals, crops, winter rape and green corn for the average harvest of 2000 to 2004, for the harvest of 2006 and for the harvest of 2012. The retrieved data have been used to derive the following data: the statistical data of cereals, crops, winter rape and green corn about the average harvest and energy storage, related to GPP and NPP. Thereafter, correlations among GPP, NPP and the harvest data are analyzed.

2.2.2 GIS methods

2.2.2.1 Land cover distribution and land cover change detection

The CORINE land cover maps with 250×250 km m grids and vector maps with the land cover classes of Schleswig-Holstein (Table 5) for the years 1990, 2000, 2006 and 2012 were used to visualize the land cover distribution in Schleswig-Holstein using the Geographic Information System (GIS: ArcGIS 10.3). Vector data were used to analyze the number of polygons of each land cover class, for calculating the areas of each land cover class, and for deriving their percentages within Schleswig-Holstein.

The land cover areas and their percentage distributions in the landscape regions, the landscape regions' areas and the percentages of the land cover classes, the land covers' areas and their percentage for the districts, and the districts' land covers' areas and their percentage for the districts of Schleswig-Holstein for the years of 1990, 2000, 2006 and 2012 were mapped basing upon maps of the borders of the districts, the landscape classification, and the CORINE vector maps of Schleswig-Holstein. Afterwards, *LCALRp (%), LCADp (%), LRLCAp (%) and DLCAp (%)* were calculated with the equations below,

$$LCALRp = LCALR/LRA * 100\% \tag{11}$$

$$LCADp = LCAD/DA * 100\% \tag{12}$$

$$LRLCAp = LCALR/LRLCA * 100\% \tag{13}$$

$$DLCAp = LCAD/DLCA * 100\% \tag{14}$$

LCALRp means land cover area percentage of each landscape region, which is associated with the area of one land cover on one landscape region (LCALR), and the total area of one landscape region (LRA (ha)).

Similarly, the land cover area percentage of each district (LCADp) relates to the area of one land cover (LCAD (ha)) on one district, and the total area of one district (DA (ha)). LRLCAp is the percentage of landscape region area on one land cover, and LRLCA means the total area of one land cover class. DLCAp is the percentage of district area in one land cover, and DLCA (ha) means the total area of one land cover class.

Results were presented with figures produced using in Origin 8.0.

In this study, the land cover changes of Schleswig-Holstein from1990 to 2000, from 2000 to 2006 and from 2006 to 2012 were detected by mapping the CORINE land cover change and the map of border. Results for the land cover changes are shown in Table 5.

Table 5. CORINE land cover nomenclature and definitions associated with Schleswig-Holstein (based on Kosztra et al., 2014).

Level	Level 2	Level 3	Grid_code	Definition
1. Artificial surface	1.1 Urban fabric	1.1.1 Continuous urban fabric surfaces	1	Most of the land is covered by Buildings, roads and artificially surfaced area cover almost all the ground. Non-linear areas of vegetation and bare soil are exceptional.
		1.1.2 Discontinuous urban fabric	2	Most of the land is covered by structures. Buildings, roads and artificially surfaced areas associated with vegetated areas and bare soil, which occupy discontinuous but significant surfaces.
	1.2 Industrial, commercial	1.2.1 Industrial or commercial units and transport units	3	Artificially surfaced areas (with concrete, asphalt, tarmacadam, or stabilized, e.g. beaten earth) devoid of vegetation, occupy most of the area in question, which also contains buildings and/or vegetated areas
		1.2.2 Road and rail networks and associated land	4	Motorways, railways, including associated installations (stations, platforms, embankments). Minimum width to include: I 00 m.
		1.2.3 Port areas	5	Infrastructure of port areas, including quays, dockyards and marinas.
		1.2.4 Airports	6	Airport installations: runways, buildings and associated land.
	1.3 Mine, dump	1.3.1 Mineral extraction sites and construction sites	7	Areas with open-pit extraction of industrial minerals (sandpits, quarries) or other minerals (opencast mines). Includes flooded gravel pits, except for river-bed extraction.
		1.3.2 Dump sites	8	Landfill or mine dump sites, industrial or public.
		1.3.3 Construction sites	9	Spaces under construction development, soil or bedrock excavations, earthworks.
	1.4 Artificial non-agricultural	1.4.1 Green urban areas vegetated areas	10	Areas with vegetation within urban fabric. Includes parks and cemeteries with vegetation. 1.4.2. Sport
		1.4.2 Sport and leisure facilities	11	Camping grounds, sports grounds, leisure parks, golf courses, racecourses, etc. Includes formal parks not surrounded by urban zones.

Table 5. CORINE land cover nomenclature and definitions associated with Schleswig-Holstein (based on Kosztra et al., 2014).

Level	Level 2	Level 3	Grid_code	Definition
2. Agricultural areas	2.1 Arable land	2.1.1 Non-irrigated arable land	12	Cereals, legumes, fodder crops, root crops and fallow land. Includes flower and tree (nurseries) cultivation and vegetables, whether open field, under plastic or glass (includes market gardening). Includes aromatic, medicinal and culinary plants. Excludes permanent pastures.
	2.2Permanent crops	2.2.2 Fruit trees and berry plantations	16	Parcels planted with fruit trees or shrubs: single or mixed fruit species, fruit trees associated with permanently grassed surfaces. Includes chestnut and walnut groves.
	2.3 Pastures	2.3.1 Pastures	18	Dense, predominantly graminoid grass cover, of floral composition, not under a rotation system. Mainly used for grazing, but the fodder may be harvested mechanically. Includes areas with hedges (boscage).
	2.4Heterogeneous agricultural areas	2.4.2 Complex cultivation	20	Juxtaposition of small parcels of diverse annual crops, pasture and/or permanent crops.
		2.4.3 Land principally occupied by agriculture, with significant areas of natural vegetation	21	Areas principally occupied by agriculture, interspersed with significant natural areas.
3. Forests and semi-natural areas	3.1 Forests	3.1.1 Broad-leaved forest	23	Vegetation formation composed principally of trees, including shrub and bush understories, where broadleaved species predominate.
		3.1.2 Coniferous forest	24	Vegetation formation composed principally of trees, including shrub and bush understories, where coniferous species predominate.
		3.1.3 Mixed forest	25	Vegetation formation composed principally of trees, including shrub and bush understories, where broadleaved and coniferous species co-dominate.

Table 5. CORINE land cover nomenclature and definitions associated with Schleswig-Holstein (based on Kosztra et al., 2014).

Level	Level 2	Level 3	Grid_code	Definition
3. Forests and semi-natural areas	3.2 Shrub and/or herbaceous association	3.2.1 Natural grassland vegetation	26	Low productivity grassland. Often situated in areas of rough uneven ground. Frequently includes rocky areas, briars, and heathland.
		3.2.2 Moors and heathland	27	Vegetation with low and closed cover, dominated by bushes, shrubs and herbaceous plants (heath, briars, broom, gorse, laburnum, etc.).
		3.2.4 Transitional woodland shrub	29	Bushy or herbaceous vegetation with scattered trees. Can represent either woodland degradation or forest regeneration/ colonization.
	3.3 Open spaces with little or no vegetation	3.3.1 Beaches, dunes, and sand plains	30	Beaches, dunes and expanses of sand or pebbles in coastal or continental , including beds of stream channels with torrential regime.
		3.3.3 Sparsely vegetated areas	32	Includes steppes, tundra and badlands. Scattered high-attitude vegetation.
		5.2.2 Estuaries	43	The mouth of a river within which the tide ebbs and flows.
4. Wetlands	4.1 Inland wetlands	4.1.1 Inland marshes	35	Low-lying land usually flooded in winter, and more or less saturated by water all year round.
		4.1.2 Peatbogs	36	Peatland consisting mainly of decomposed moss and vegetable matter. May or may not be exploited.
	4.2 Coastal wetlands	4.2.1 Salt marshes	37	Vegetated low-lying areas, above the high-tide line, susceptible to flooding by sea water. Often in the process of filling in, gradually being colonized by halophilic plants.
		4.2.3 Intertidal flats	39	Generally unvegetated expanses of mud, sand or rock lying between high and low water-marks. On contour on maps.
5.Water bodies	5.1 Inland waters	5.1. 1. Water courses	40	Natural or artificial water-courses serving as water drainage channels. Includes canals. Minimum width to include: 100 m.
		5.1.2 Water bodies	41	Natural or artificial stretches of water.
	5.2 Marine waters	5.2.1 Coastal lagoons	42	Unvegetated stretches of salt or brackish waters separated from the sea by a tongue of land or other similar topography. These water
		5.2.2 Estuaries	43	The mouth of a river within which the tide ebbs and flows.

2.2.2.2 Land cover density of diversity

The spatial structures of landscapes can be decided by the composition and configuration of landscape elements. The spatial configuration and composition of landscape elements interact with the physiognomy of Schleswig-Holstein, as the ecosystem functions at different spatial and temporal scales (DG-Agriculture *et al.*, 2000). It is necessary to track and quantify the land cover changes based on the CORINE land cover database with the methods of Shannon's diversity index and land cover diversity index. The Shannon diversity index takes into account the number of land cover classes and the area evenness. The index increases following the increase of the number of different land cover classes, or the equitableness of the proportional distributions of the areas among the land cover classes (DG-Agriculture *et al.*, 2000). Moreover, the land cover diversity index associates with ecological and spatial aspects concerning land cover and ecosystem services. The reasons are that the land cover changes of states, such as Schleswig-Holstein, may be affected by economic factors, local policy-making, housing and transports associated to the Europe, Germany or State. Understanding the land cover changes is helpful to carry out feedback analysis of the economy and policies on land cover management.

(1) Shannon's Diversity Index (SHDI):

The number of different patch types and the proportional area distribution among patch types (the land cover classes in Schleswig-Holstein) constitute the Shannon Diversity Index quantifying the diversity of land cover in the study area. The Shannon Diversity Index has been calculated as equation (15) (DG-Agriculture *et al.*, 2000):

$$SHDI = -\sum_{i=0}^{m}(Pi * \ln Pi) \tag{15}$$

In this equation, *m* means the number of patch types, and *Pi* presents the proportion of area covered by patch types *i*. The CORINE land cover maps with 250m × 250m m grids of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012 were used for evaluating the *SHDI* for the four periods.

(2) Land Cover Diversity Index

One of the aims of this study is to produce georeferenced information in Schleswig-Holstein with the CORINE land cover maps for the different periods. The calculation of the land cover diversity index was carried out by the two steps below:

- Calculating the number of the CORINE land cover classed in one block of 3km × 3km (DG-Agriculture *etal.*, 2000).
- Finding the number of the land cover classes (Level 3 of the CORINE land cover classification) within each block, and join it to the cell locations in the corresponding blocks on an output raster.

2.2.2.3 Annual total GPP and annual total NPP classified by land cover

The MODIS GPP or NPP Project (MODIS 17) is one of the prime data provided by the Numerical Terradynamic Simulation Group (NTSG). NTSG is a research laboratory that tries to understand correlations between terrestrial vegetation responds and climate variability, energy, water and carbon cycles with new approaches. MODIS 17 is the first satellite-driven dataset to monitor vegetation productivity at a global scale. The dataset supports GPP and NPP data with the solution of 1km ×1 km for continents of the whole world. It is possible that deriving GPP and NPP data of Schleswig-Holstein from MODIS 17 products is useful for carbon cycle analysis and ecosystem assessment in this study. However, GPP and NPP data in artificial areas and water bodies are lacking because of the rare coverage of vegetation in artificial areas and non-terrestrial vegetation in water bodies (Running & Zhao, 2015). Therefore, GPP and NPP data are unavailable in artificial areas and water bodies.

The annual total GPP maps with 1km × 1km grids for the years 2000, 2006 and 2012 are used to visualize the GPP distribution in Schleswig-Holstein generated with ArcGIS 10.3. The original GPP maps with 1km × 1km grids have been resampled to maps with 250 m×250m grids to precede the same resolutions as the CORINE land cover maps. Then, the annual total GPP was computed and mapped based on 1) land cover classes, 2) landscape regions, 3) districts of Schleswig-Holstein, 4) union of land cover classes and landscape regions, and 5) union of land cover classes and districts of Schleswig-Holstein with ArcGIS 10.3. GPP storage which presents the storage of GPP on a certain land cover class, was calculated by uniting the annual total GPP maps and the maps of CORINE land cover, the landscape regions, the maps of the districts, the maps which combined land cover and landscape regions, and the maps which combined land cover and the districts for the three years. Then GPP storage was recalculated in the united maps. The correlation among the annual total GPP, the land cover areas and GPP storage of the land cover classes, was calculated using the software R (Kuhnert & Venables, 2005).

The same methods were used for mapping, computing and analyzing the annual total NPP data.

2.2.2.4 Differences between annual total GPP and annual total NPP

(1) Ratio between NPP and GPP

The annual total GPP and the annual total NPP maps have been produced based on the CORINE land cover classes were used for calculating the ratio between NPP and GPP of each land cover.

(2) Respiration by vegetation

Vegetation respiration was derived from the difference between the annual total GPP and the annual total NPP, based on the definition of the vegetation respiration from equations (8) and (9) in 2.2.1. Vegetation respiration based on the CORINE land cover classes was evaluated by deducting the annual total NPP from the annual total GPP using ArcGIS 10.3

2.2.2.5 Hotspots and cold spots for annual total GPP and annual total NPP

Analyses of hotspots and cold spots have been widely applied in socio-economic and ecological analyses (Li *et al.*, 2016a). Hotspots are statistically significant spatial clusters of high values, and cold spots are spatial clusters of low values (Li *et al.*, 2016a). They were used here to identify the locations of significant hotspots and cold spots of the annual total GPP and the annual total NPP in the study areas for the years 2000, 2006 and 2012. The data sources were derived from the raster data set of the MODIS annual total GPP and the MODIS annual total NPP. The raster patches were converted into polygons with the raster to polygon tool in ArcGIS. Afterwards, the Hot Spot Analysis (Getis-Ord Gi*) tool was used to identify the hotspots and cold spots of the annual total GPP and the annual total NPP. The p-value, being classified with typical probabilities of 0.01, 0.05 and 0.1 measure, is a probability. The Z-scores, being scored for 90%, 95% and 99% confidence levels with b<-1.65 or >+1.65, b<-1.96 or >+1.96 and b<-2.58 or >+2.58, are simply standard deviations. The p-value and Z-scores indicates spatially clustered areas with either high or low values.

2.2.2.6 Modelling the carbon storage of Schleswig-Holstein with InVEST

The InVEST model is an ecosystem service estimation tool operating at multiple scales. This tool relates ecosystem services to ecological production functions and economic valuation techniques. Ecosystem services can be quantified and estimated with this GIS friendly accessing tool (Delphin *et al.*, 2013). The aims of the tool are to enable managers to estimate quantified tradeoffs associated with alternative planning options, and to identify land cover classes which can enhance ecosystem services. InVEST 3.2.0 includes 18 models suited to terrestrial, freshwater and marine ecosystems. The carbon model can easily and reliably evaluate carbon storage (Sharp *et al.*, 2015a). It is regarded as a spatially explicit biophysical model, used in the studies of the terrestrial carbon cycle (Taoa *et al.*, 2015). The carbon model integrates information on the land cover and data on carbon storage in four carbon pools (above-ground, below-ground, soil organic carbon and litter). In order to assess the amount of carbon storage and carbon sequestration over time for a defined area, the current land cover map and the carbon storage in the four carbon pools are required (Sharp *et al.*, 2015a). The specific data input to the model in this study and the methods used to obtain the data are presented below.

⑴ Model input: Land cover map and carbon pools

- Current land cover

The current land cover was mapped within the border of Schleswig-Holstein and the CORINE land cover map with 250 m × 250m grids in 2006 according the land cover classes of Schleswig-Holstein in the first column of Table 5.

-Carbon pools

The method used to assess carbon storage is carried out based on the notion that not all pools need to be measured experimentally (Brown, 2002). It is a common practice to base on literature sources for obtaining values of carbon storage or using correlations between the carbon compartments to evaluate carbon storage and produce adequate assessments (Cruickshank *et al.*, 2000; Muñoz-Rojas *et al.*, 2011; Garrastazù *et al.*, 2015). Considering that the carbon equilibrium due to its long persistence based on the land cover classes, the data of carbon density were derived from the literatures (citations are below Table 6) between 2000 and 2013. The respective study areas (Bornhöved Lakes District) were a part of Schleswig-Holstein, the whole Germany or close to our case study areas (Ireland and Spain). They had similar climatic and phenological conditions as

Schleswig-Holstein. Furthermore, a comparison between the input data used in this study for the carbon storage of the four carbon pools and other studies has been carried out. It aimed at decreasing the uncertainty due to the limitation that InVEST does not have a built-in sensitivity analysis package or any procedure for consistency verification.

Schleswig-Holstein is a critical agricultural state in Germany, and is primarily occupied by agricultural areas, semi natural areas and wetlands. Furthermore, agricultural areas, semi natural areas and wetlands have higher potential carbon storage than other land cover classes. Therefore, carbon storage in the carbon pools of aboveground, belowground, litter and soil were evaluated in the land cover classes of agricultural areas, semi natural areas and wetlands in Schleswig-Holstein.

The carbon density which included the density of aboveground and belowground vegetation based on the CORINE land cover classes at level 3 was derived from literature. Data sources of carbon density in the carbon pools of above-ground, below-ground and litter, and the ratios of density between above-ground and below-ground can be found below Table 6. The carbon density of “pastures”, “peat bogs” and “intertidal flats “were assessed from carbon input data of a case study of agricultural landscapes in Schleswig-Holstein (Kruse *et al.*, 2013). The carbon density in broad-leaved forest, “coniferous forest” and “mixed forest” were derived from a statistic report on forest and wood carbon study of Schleswig-Holstein (Wördehoff *et al.*, 2012). We derived the carbon density of fruit trees and berry plantations, including above-ground an below-ground, from the investigation of Muñoz-Rojas (2011). The carbon density of the other 17 land cover classes were based on an estimation of carbon storage in the vegetation of Ireland (Cruickshank *et al.*, 2000).

The proportion of above-ground and below-ground carbon density of “deciduous forest”, “coniferous forest”, “mixed forest” and “grassland” correspond to the definition according Kruse (2013). Ratios of carbon storage between below-ground and above-ground for “non-irrigated arable land”, “complex cultivation patterns” and “land principally occupied by agriculture” were estimated from the ratios between maize and rapeseeds which were two significant types of agricultural areas in Schleswig-Holstein (Kruse *et al.*, 2013). The ratios between above-ground and below-ground carbon density for the land cover classes of “natural grasslands”, “sparsely vegetated areas”, “salt marshes” and “beaches, dunes, sands” were derived from 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Verchot *et al.*, 2006).

The carbon density of litter for “complex cultivation patterns”, “land principally occupied by agriculture”, “natural grasslands”, “beaches, dunes, sands”, “sparsely vegetated areas”, “salt marshes”, “grassland” and “non-irrigated arable land” were derived from the carbon density of litter published for Bornhöved Lakes District (Kruse *et al.*, 2013). The carbon density of litter for “deciduous forest”, “coniferous forest” and “mixed forest”, and the density on “fruit trees and berry plantations” and “transitional woodland-shrub” were derived from data published by Takahashi’s and Barth’s (1982; 2010).

Table 6. Carbon density of four carbon pools (above-ground, below-ground, soil organic carbon and litter) in each land cover class used in the InVEST model (data sources can be found below).

CORINE Land cover code	CORINE Land cover class	Aboveground (Mg C ha^{-1})	Belowground (Mg C ha$^{-1)}$	Litter (Mg C ha^{-1})	SOC medium (Mg C ha^{-1})	SOC maximum (Mg C ha^{-1})	SOC minimum (Mg C ha$^{-1)}$
111	**Continuous urban fabric**	0.00	0.00	0.00	0.00	0.00	0.00
112	**Discontinuous urban fabric**	0.00	0.00	0.00	0.00	0.00	0.00
121	**Industrial or commercial units**	0.00	0.00	0.00	0.00	0.00	0.00
122	**Road and rail networks and associated land**	0.00	0.00	0.00	0.00	0.00	0.00
123	**Port areas**	0.00	0.00	0.00	0.00	0.00	0.00
124	**Airports**	0.00	0.00	0.00	0.00	0.00	0.00
131	**Mineral extraction sites**	0.00	0.00	0.00	0.00	0.00	0.00
132	**Dump sites**	0.00	0.00	0.00	0.00	0.00	0.00
133	**Construction sites**	0.00	0.00	0.00	0.00	0.00	0.00
141	**Green urban areas**	0.00	0.00	0.00	0.00	0.00	0.00
142	**Sport and leisure facilities**	0.00	0.00	0.00	0.00	0.00	0.00
211	**Non-irrigated arable land**	1.71 a,b	0.49 a,b	0.00 a	92.62	288.22	20.65
222	**Fruit trees and berry**	5.53 b,c	15.47 b,c	0.08 d	89.91	126.58	53.24
231	**Pastures**	6.00 a	0.70 a	0.00 a	97.75	291.33	28.02
242	**Complex cultivation patterns**	1.25 a,b	0.35 a,b	2.05 a	93.22	288.22	21.69
243	**Land principally occupied by agriculture**	1.56 a,b	0.44 a,b	1.20 a	86.89	288.22	27.90
311	**Broad-leaved forest**	112.00 a,e	33.60a,e	7.50 f	79.48	271.40	20.65
312	**Coniferous forest**	87.00 a,e	21.75 a,e	5.11 f	85.05	273.70	28.02
313	**Mixed forest**	99.50 a,e	27.68 a,e	6.30 f	76.12	271.40	21.79
321	**Natural grasslands**	1.34 b,c	0.16 b,c	0.00 a	97.97	265.81	35.84
322	**Moors and heathland**	1.79 a,g	0.21 a,g	0.00 a	90.03	268.91	43.97
324	**Transitional woodland-shrub**	3.82 b,c	10.68 b,c	0.3605 d	81.00	265.41	33.11
331	**Beaches, dunes, sands**	0.30 b,c	1.20 b,c	0.00 a	9.34	15.68	4.98
333	**Sparsely vegetated areas**	0.16 b,c	0.64 b,c	0.00 a	89.39	225.73	49.68
411	**Inland marshes**	1.50 a,g	0.00 a,g	0.00 a	99.47	265.55	28.54
412	**Peat bogs**	1.75 a	0.00 a	0.00 a	134.27	288.22	34.16
421	**Salt marshes**	0.40 b,c	1.60 b,c	0.00 a	107.58	156.48	40.33
423	**Intertidal flats**	0.00 a	0.00 a	0.00 a	113.53	156.48	51.15
511	**Water courses**	0.00	0.00	0.00	0.00	0.00	0.00
512	**Water bodies**	0.00	0.00	0.00	0.00	0.00	0.00
521	**Coastal lagoons**	0.00	0.00	0.00	0.00	0.00	0.00
522	**Estuaries**	0.00	0.00	0.00	0.00	0.00	0.00

a. Kruse et al., 2013

b. Verchot et al., 2006

c. Cruickshank et al., 2000

d. Barth and Klemmedson, 1982

e. Wördehoff et al., 2012

f. Takahashi et al., 2010

g. Muñoz-Rojas et al., 2011

The SOC storage map was produced with the map of SOC storage of agricultural soils from EEA using ArcGIS 10.3. Moreover, the average, maximum and minimum SOC storage on each land cover class were calculated by ArcGIS 10.3. The average, maximum and minimum carbon storage of the four carbon pools in all the CORINE land cover classes are shown in Table 5. These data account for the carbon storage based on the CORINE land cover classification of Schleswig-Holstein. Data in Table 6 was used as inputs to the InVEST carbon model to evaluate the carbon storage of the whole state of Schleswig-Holstein.

(2) Carbon storage in each land cover of Schleswig-Holstein

The carbon pools of abov6e-ground, below-ground, average SOC and litter have been considered as the pools worthy of estimating. We summed up the carbon storage of the four carbon pools on each land cover as the carbon storage (CS). Following this calculation, the correlations between the annual total GPP, the annual total NPP, SOC, CS and GCR with the expert values from 0 to 5 of the global climate regulation after Burkhard et al. (2014) were analyzed with the program R.

2.2.3 Qualitative ecosystem service assessments

Qualitative assessments can be used to indicate state and trends that are the main advantages of qualitative ecosystem service estimation. The prime reason for the high applicability of the method is that the qualitative approach is flexible enough to combine a range of different methods, being usually applied to evaluate ecosystem services at large scales. Another reason is that the qualitative method makes the assessments available in situation with data scarcity. The procedures of qualitative assessments are correlated with a relatively high uncertainty that can be carried out rather fast, as they are primarily based on expert valuations, and they avoid the risk of over-interpreting data that is necessary for the quantitative evaluation (Busch *et al.*, 2011). Furthermore, the qualitative approach is much better applicable to large scale assessments than the quantitative method.

The matrix method is one of main qualitative approaches applied for ecosystem services analyses. The methods have been used in the assessments of evaluating various ecosystem services in different ecological systems (de Chazal *et al.*, 2008; Koschke *et al.*, 2012; Tengberg *et al.*, 2012). Burkhard and others have developed the matrix method with scales 0-5, linking 31 ecosystem services and seven ecological integrity indicators to 44 land cover classes (Burkhard *et al.*, 2009, 2014; Kroll *et al.*, 2012a). The matrix values are derived from different case studies that supply experiences. The cased studies in Schleswig-Holstein and northern Germany show an excellent data availability (Gee, 2010; Lange *et al.*, 2010; Kroll *et al.*, 2012a).

Therefore, the matrix values of ecosystem services and ecosystem integrity are used to map regulating, provisioning and culture services, and ecosystem integrity in this sub-section.

The potential ecosystem services features have been mapped with the qualitative indicators from the ecosystem service matrix (Tables 7-9). twenty out of 30 ecosystem services were chosen due to the characteristics of Schleswig-Holstein based on the CORINE land cover map of 2006 in ArcGIS 10.3. The attributes included regulating services (local climate regulation, global climate regulation, air quality regulation, water flow regulation, water purification, nutrient regulation, erosion regulation and natural hazard regulation), provisioning services (crops, biomass for energy, fodder, livestock, timber, wood fuel, wild foods and resources, freshwater and abiotic energy sources) and cultural services (recreation and tourism, landscape aesthetics and inspiration and natural heritage and natural diversity). Abiotic heterogeneity, biodiversity, biotic water flows, metabolic efficiency, exergy capture, reduction of nutrient loss and storage capacity indicated ecosystem integrity of Schleswig-Holstein. The chosen ecosystem services variables were mapped using the land cover classes of CORINE maps in 2006.

Ecosystem services assessments provide the possibility to understand the values of ecosystem services that have been estimated with matrix for all of the services (Burkhard *et al.*, 2014). However, mapping the services together with the land cover maps presents the ecosystem services of an area at one time too directly. It also notes the differences of ecosystem services resulting from land cover and land cover changes during a visible period. In this study of crops, ecosystem services of global climate regulation, landscape aesthetics and inspiration, crops and livestock (domestic) are critical services for Schleswig-Holstein because its important statues in agriculture and coastal landscapes. In this study of crops, global climate change, livestock and landscape aesthetics and inspiration are mapped using the land cover classes of CORINE maps in 2006 to identify potential changes of the provision of ecosystem services. Furthermore, maps of ecosystem service changes, and statistic changes being associated with land cover areas and their percentages of global climate regulation, landscape aesthetics and inspiration, crops and livestock (domestic) were calculated through overlaying of ecosystem service maps based on the matrix method in ArcGIS 10.3. This is because that understanding the ecosystem services of global climate regulation, landscape aesthetics and inspiration, crops and livestock in Schleswig-Holstein is meaningful because the state is an important agricultural area of Germany and has gorgeous landscapes especially in coastal areas.

Table 7. Matrix values of regulating service potential in Schleswig-Holstein (based on Burkhard et al., 2014).

CORINE Land cover code	CORINE Land cover class	Global climate	Local climate	Air quality	Water flow	Water purify-cation	Nutrient	Erosion	Natural hazard
111	Continuous urban fabric	0	0	0	0	0	0	2	0
112	Discontinuous urban fabric	0	0	0	0	0	0	1	0
121	Industrial or commercial units	0	0	0	0	0	0	2	0
122	Road and rail networks and associated land	0	0	0	0	0	0	1	0
123	Port areas	0	0	0	0	0	0	3	3
124	Airports	0	0	0	0	0	0	1	0
131	Mineral extraction sites	0	0	0	0	0	0	0	0
132	Dump sites	0	0	0	0	0	0	0	0
133	Construction sites	0	0	0	0	0	0	0	0
141	Green urban areas	2	2	2	2	2	2	2	1
142	Sport and leisure facilities	1	1	1	1	1	1	1	0
211	Non-irrigated arable land	1	2	1	2	0	1	0	1
222	Fruit trees and berry plantations	2	2	2	2	1	2	2	2
231	Pastures	2	2	0	1	0	1	1	1
242	Complex cultivation patterns	1	1	1	1	0	1	1	1
243	Land principally occupied by agriculture	2	2	2	2	2	2	2	1
311	Broad-leaved forest	5	5	5	3	5	5	5	4
312	Coniferous forest	5	5	5	3	5	5	5	4
313	Mixed forest	5	5	5	3	5	5	5	4
321	Natural grasslands	5	2	0	1	3	4	5	1
322	Moors and heathland	3	3	0	2	3	3	2	2
324	Transitional woodland-shrub	2	2	1	1	1	2	1	1
331	Beaches, dunes, sands	0	0	0	1	1	1	0	5
333	Sparsely vegetated areas	0	0	0	1	1	1	1	1
411	Inland marshes	2	2	0	3	2	4	1	4
412	Peat bogs	5	4	0	4	4	4	2	3
421	Salt marshes	1	1	0	1	1	2	1	4
423	Intertidal flats	1	1	0	1	1	1	1	5
511	Water courses	0	1	0	3	3	3	0	3
512	Water bodies	1	2	0	5	2	3	0	3
521	Coastal lagoons	1	1	0	4	2	3	0	4
522	Estuaries	1	0	0	3	3	3	0	3

Table 8. Matrix values of provisioning service potential in Schleswig-Holstein (based on Burkhard et al., 2014).

CORINE Land cover code	CORINE Land cover class	Crops	Biomass for energy	Fodder	Livestock	Timber	Wood fuel	Wild foods and resource	Fresh-water	Abiotic energy sources
111	**Continuous urban fabric**	0	0	0	0	0	0	0	0	1
112	**Discontinuous urban fabric**	1	0	0	0	0	0	0	0	1
121	**Industrial or commercial units**	0	0	0	0	0	0	0	0	1
122	**Road and rail networks and associated land**	0	0	0	0	0	0	0	0	0
123	**Port areas**	0	0	0	0	0	0	0	0	0
124	**Airports**	0	0	0	0	0	0	0	0	0
131	**Mineral extraction sites**	0	0	0	0	0	0	0	0	3
132	**Dump sites**	0	1	0	0	0	0	0	0	0
133	**Construction sites**	0	0	0	0	0	0	0	0	0
141	**Green urban areas**	0	0	0	0	0	0	0	0	0
142	**Sport and leisure facilities**	0	0	0	0	0	0	0	0	0
211	**Non-irrigated arable land**	5	5	5	0	0	0	1	0	2
222	**Fruit trees and berry plantations**	4	1	0	0	2	2	0	0	0
231	**Pastures**	0	1	5	5	0	0	2	0	5
242	**Complex cultivation**	4	2	2	1	0	1	1	0	1
243	**Land principally occupied by agriculture**	3	3	2	2	1	1	2	0	1
311	**Broad-leaved forest**	0	1	1	0	5	5	5	0	0
312	**Coniferous forest**	0	1	1	0	5	5	5	0	0
313	**Mixed forest**	0	1	1	0	5	5	5	0	0
321	**Natural grasslands**	0	1	2	3	0	0	5	0	2
322	**Moors and heathland**	0	1	1	1	0	2	2	0	0
324	**Transitional**	0	2	1	1	1	2	1	0	1
331	**Beaches, dunes, sands**	0	0	0	0	0	0	0	0	0
333	**Sparsely vegetated areas**	0	0	0	1	0	0	1	0	2
411	**Inland marshes**	0	0	4	2	0	0	1	0	0
412	**Peat bogs**	0	2	0	0	0	0	1	1	0
421	**Salt marshes**	0	0	2	2	0	0	1	0	0
423	**Intertidal flats**	0	1	0	0	0	0	1	0	0
511	**Water courses**	0	2	0	0	0	0	4	5	3
512	**Water bodies**	0	1	0	0	0	0	4	5	1
521	**Coastal lagoons**	0	1	0	0	0	0	4	0	0
522	**Estuaries**	0	2	0	0	0	0	4	0	1

Table 9. Matrix values of cultural service potential in Schleswig-Holstein (based on Burkhard et al., 2014).

CORINE Land cover code	CORINE Land cover class	Recreation and tourism	Landscape aesthetics and inspiration	Natural heritage and natural diversity
111	**Continuous urban fabric**	3	3	0
112	**Discontinuous urban fabric**	3	2	0
121	**Industrial or commercial units**	0	0	0
122	**Road and rail networks and associated land**	0	0	0
123	**Port areas**	1	2	0
124	**Airports**	0	0	0
131	**Mineral extraction sites**	0	0	0
132	**Dump sites**	0	0	0
133	**Construction sites**	0	0	0
141	**Green urban areas**	3	3	1
142	**Sport and leisure facilities**	5	1	0
211	**Non-irrigated arable land**	1	1	0
222	**Fruit trees and berry plantations**	3	2	1
231	**Pastures**	2	2	1
242	**Complex cultivation patterns**	2	2	0
243	**Land principally occupied by agriculture**	2	2	3
311	**Broad-leaved forest**	5	5	5
312	**Coniferous forest**	5	5	4
313	**Mixed forest**	5	5	5
321	**Natural grasslands**	3	4	3
322	**Moors and heathland**	4	4	4
324	**Transitional woodland-shrub**	2	3	2
331	**Beaches, dunes, sands**	5	4	2
333	**Sparsely vegetated areas**	1	1	1
411	**Inland marshes**	1	2	2
412	**Peat bogs**	3	2	4
421	**Salt marshes**	3	2	2
423	**Intertidal flats**	4	2	2
511	**Water courses**	4	4	3
512	**Water bodies**	5	4	3
521	**Coastal lagoons**	3	4	3
522	**Estuaries**	3	4	3

2.2.4 Quantitative ecosystem service assessments

Quantitative ecosystem service assessments can decrease uncertainties resulting from experts based assessments. Quantifying ecosystem services with the same indicators at different scales enhances the quality of comparison of ecosystem services between various scales. Mapping the comparison of qualitative and quantitative ecosystem services assessments allows the rapid access to the results and improves their readability.

As the important approach used for assessing ecosystem services, evaluations of the services and integrity with the qualitative indictors have been studied in sub-section 3.3.2. The quantitative approach is shown in this sub-section to indicate the ecosystem service of global climate regulation, which influences climate change and sustainability of ecosystems, with the quantitative indicators. The annual total GPP and NPP, SOC and CS are recommended indicators of evaluating global climate regulation because they reflect greenhouse gas storage in ecosystems which is the definition of the global climate regulation service (European Union, 2013; Kandziora *et al.*, 2013a; Burkhard *et al.*, 2014). These parameters can represent the abilities of carbon storage and its ecosystem services. Consequently, GPP, NPP, SOC and CS are chosen as the indicators of global climate regulation.

The annual total GPP and NPP of Schleswig-Holstein in 2000, 2006 and 2012, the distributions of the annual total GPP and NPP based on land cover, landscape regions and districts, monthly GPP in 2006, calculated respiration, ratio between NPP and GPP, and hotspots and cold spots for the annual total GPP and NPP are calculated in this sub-section. Afterwards, correlations among the indicators of the annual total GPP and NPP, SOC, CS and GCR are analyzed.

2.2.4.1 Map comparison and analysis of quantitative and qualitative indicators for global climate regulation

The annual total GPP, the annual total NPP, SOC and CS were assumed as quantitative indicators and the expert values from 0 to 5 of the global climate regulation after Burkhard et al. (2014) were assumed as qualitative indicators in this study. Furthermore, data normalization of the annual total GPP, the annual total NPP, SOC and CS, and comprising the normalized quantitative indicators and the qualitative indicators were done. The comparison identified the possible differences of ecosystem service assessments deriving from the distinct indicators.

(1) Mapping quantitative and qualitative indicators for global climate regulation

The values of the maps of the annual total GPP, the annual total NPP, SOC and CS with quantitative data in each land cover, presented the spatial distributions of global climate regulation defectively, were reclassified into six levels with equal interval classification in ArcGIS 10.3 in order to have the same classes of global climate regulation services as the qualitative indicator GCR. The maps of each indicator were visualized with 0-5 classes, which were comparable with the classes of the qualitative indicators, through equal interval classifications in ArcGIS 10.3.

(2) Map comparison statistics

The individual indicators of ecosystem services were analyzed for maps of the annual total GPP and NPP, SOC, CS and GCR to illustrating the distinctions of global climate regulation led by different indicators. Map Comparison Statistic (MCS) was the methods that summarized the relative differences in pair-wise comparisons (Schulp *et al.*, 2014)

$$MCS = \frac{\sum_{n=1}^{N}(|a-b|)/\max(a,b)}{N} \quad (16)$$

where *MCS* is the Map Comparison Statistic, *a* and *b* are the normalized values of two indicators for a particular land cover of two comparing maps, *N* is the number of land cover classes considered. The *MCS* indicates the average difference between any pair of indicator values. An *MCS* of 0.5 means the two maps were random, while, two opposing maps produce an *MCS* of 1 and two identical maps lead to an *MCS* of zero.

2.2.4.2 Methods of investigations at the Lake Belau in the Bornhöved Lake District

Meteorological and hydrological observations, such as free water capacity, available water capacity and non-plant available water capacity, were derived from a 35-m tower in the beech forest, from a 16-m telescope mast in the farmland, and from the German Meteorological Service (Kutsch *et al.*, 2001). Soil surveys, biocoenotic investigations (e.g. potential Cation Exchange Capacity (CEC), and measurement of effective CEC, SOC, soil nitrogen density (Nd) and hydrogen ion content (H^+)), element fluxes in air, water and the soil-vegetation complexes were carried out on the bases of sampling in the field and testing in laboratories (Fränzle *et al.*, 2008). Values of carbon density in biomass of a beech forest, spruce forest, mixed forest, grassland and arable land were derived from a publication reporting investigation results at Lake Belau in the Bornhöved Lake District (Kutsch *et al.*, 2001). Carbon storage in above-ground biomass, soil organic carbon (SOC), nitrogen density in soil, and water capacity were calculated, and correlations of the parameters were analyzed as well.

2.2.4.3 Methods of investigations of the Bornhöved Lake District

Besides the methods mentioned in the previous section, models have played a particular role in the fields of material and energetic fluxes, structure and functioning of the land cover classes in the research area (Fränzle *et al.*, 2008). Models on carbon storage and sequestration supported the assessment of the carbon storage and sequestration of each land cover in the Bornhöved Lake District (Kandziora *et al.*, 2013b). Research on carbon and energy balances, water relations, biocoenotic dynamics, transport processes in ecosystems, and ecosystem research and sustainable land use management were carried out in this area (Fränzle *et al.*, 2007b). The exiting studies at the Bornhöved Lake District are summarized and presented in chapter 3.2.

2.2.5 Statistical methods

Statistical data on cereals, crops, winter rape and green corn for 2006 were derived from the Statistisches Amt für Hamburg und Schleswig-Holstein (Statistic Agency for Hamburg and Schleswig-Holstein). See the website(https://www.destatis.de/GPStatistik/servlets/MCRFileNodeServlet/SHHeft_derivate_00001152/C_I_C_II_j_2006.pdf). They were used for mapping the harvests of the districts in Schleswig-Holstein. The annual GPP and NPP of the agricultural areas based on the CORINE land cover classification were calculated as GPPAgri and NPPAgri. Statistic data of cereals, crops, winter rape, green corn and the average amount of the four groups for the average harvest of 2006, together with the annual GPP, the annual NPP, GPPAgri, NPPAgri and the monthly GPP for the years of 2006 were used for analyzing the correlation among the harvest and the annual GPP, the annual NPP and the monthly GPP at the district scale (SPSS 17.0).

Chapter 3. Results

This study estimates local, regional and country-wide assessments on carbon storage in Schleswig-Holstein. The key research question is whether and how land cover dynamics affect carbon storage and ecosystem services. Especially, carbon storage is considered as a critical indicator of the ecosystem service of global climate change regulation. Therefore, this research is arranged to estimate land cover distributions and land cover changes, carbon storage in different carbon pools, and ecosystem services evaluated with qualitative and quantitative indicators.

The results will be illustrated in three sections: country-wide assessments, regional assessments and local assessments. The results on the land cover development based on CORINE land cover classifications for Schleswig-Holstein (SH), for the three landscape regions in SH and for 15 districts covering the years 1990, 2000, 2006 and 2012 are presented. Furthermore, the qualitative assessments of ecosystem services, and quantitative assessments of ecosystem service with various indicators relating to the overall carbon storage in Schleswig-Holstein are depicted in this section (chapter 3.1). The second section (chapter 3.2) aims to compare distinctions of carbon storage on local and regional scales and introduces includes the results of former studies on carbon storage and ecosystem services in the Bornhöved Lakes District. Carbon density in aboveground biomass, soil organic carbon (SOC) and correlated soil conditions that can affect SOC are presented in the first section (chapter 3.3). The estimations address carbon density in different carbon pools of five land cover classes according to the ATKIS (“beech forest”, “spruce forest”, “mixed forest”, “grassland” and “arable land” around the Lake Belau in the Bornhöved Lakes District).

3.1 Country-wide assessment

Results of the qualitative assessments (e.g. estimations of regulating services, provisioning services and cultural services) and quantitative assessments of ecosystem services on the scale of Schleswig-Holstein are presented in this section. They have been elaborated by mapping ecosystem services and are compared in qualitative and quantitative assessments.

The section includes three sub-sections. They are 1) land cover development as a basic regulating factor of ecosystem service provision, 2) qualitative assessments of ecosystem services, 3) quantitative assessments relating to carbon storage and the ecosystem service of global climate regulation.

The first sub-section depicts land cover distributions in for Schleswig-Holstein, land cover data for the landscape regions “Hügelland, Geest and Marsch” as well as data on the scale of districts for the years 1990, 2000, 2006 and 2012. The second sub-section presents results on the provision of regulating, provisioning and cultural services with qualitative indicators. The third sub-section shows results on the distribution of Gross Primary Production (GPP) and Net Primary Production (NPP), differences between the annual total GPP and NPP, hotspots and cold spots for the annual total GPP and NPP, carbon storage in vegetation and in soil, integrative model outputs, and comparisons of the different country-wide results.

3.1.1 Land cover development as a basic regulative actor of ecosystem services

Ecosystem services are sensitive to land cover and land cover changes. Studying the land cover development is critical to do research on ecosystem services. The CORINE land cover regional stations are produced for the years 1990, 2000, 2006 and 2012, and the documentations of land cover changes are available for periods from 1990 to 2000, from 2000 to 2006, and from 2006 to 2012. Beside land cover, landscape regions are classifications which can influence the land cover dynamics. Furthermore, classifications of districts affect land cover and land cover changes due to policies. This sub-section presents the land cover areas and land cover changes classified by the land cover classes, by the landscape regions and by the districts. The methods used for showing the land cover areas and land cover changes have been illustrated in chapter 2.2.2.1.

3.1.1.1 Land cover maps of Schleswig-Holstein in 1990, 2000, 2006 and 2012

Land cover maps show the land cover distributions directly. Figure 6 presents different land cover maps of Schleswig-Holstein for the years 1990 (Figurer 6a), 2000 (Figurer 6b), 2006 (Figurer 6c) and 2012 (Figurer 6d). There are 32 CORINE land cover classes (level 3) in Schleswig-Holstein for the four years out of 44 CORINE land cover classes in whole Europe (German Federal Environmental Agency, 2014).

3.1.1.2 Land cover areas in 1990, 2000, 2006 and 2012

Land cover maps present land cover distribution directly, but cannot show the relative or absolute share of each land cover on the overall area of the map. In order to clarify the land cover distribution in Schleswig-Holstein for the years 1990, 2000, 2006 and 2012, land cover areas and their percentages have been calculated in ArcGIS 10.3. Table 10 summarizes the area extents of selected land cover classes which occupy the largest and smallest areas in Schleswig-Holstein, including the areas and the percentages in Schleswig-Holstein for the years 1990, 2000, 2006 and 2012 (in Table 1 of the appendix A the results for all land cover classes presented). There are several differences to be highlighted concerning either the absolute areas or their relative shares (percentage) in the four years. “Non-irrigated arable land”, pastures” and “complex cultivation patterns” are clearly dominant, compared to other land cover classes for the years 1990, 2000 and 2006. “Non-irrigated arable land”, “pastures” and “discontinuous urban fabric” are the dominating land cover classes according the method used for the CORINE land cover mapping for 2012. Areas of “non-irrigated arable land” fluctuate from 670840 ha in 1990 to 666186 ha in 2006 then to 746016 ha in 2012. At the same time, areas of “pastures” convert from 454041 ha to 367189 ha and then to 441388 ha from 1990, 2006 until 2012. “Non-irrigated arable land”, “pastures” and “complex cultivation patterns” hold the highest percentages of areas of land cover classes for the years 1990, 2000 and 2006, and “Non-irrigated arable land”, “pastures” and “discontinuous urban fabric” are the major land cover areas in 2012. The percentages of areas of the land cover classes “non-irrigated arable land” and “pastures” decrease from 1990 to 2006, and then increase from 2006 to 2012. “Fruit trees and berry plantations”, “road and rail networks and associated land” and “construction sites” cover the smallest areas in Schleswig-Holstein for the years 1990, 2000 and 2006. So do “sparsely vegetated areas”, “construction sites” and “fruit trees and berry plantations” in 2012. The CORINE land cover classes, “non-irrigated arable land” and “pastures” are dominating for the years 1990, 2000, 2006 and 2012, though the areas of "non-irrigated arable land" and "pastures" vary from one year to the other.

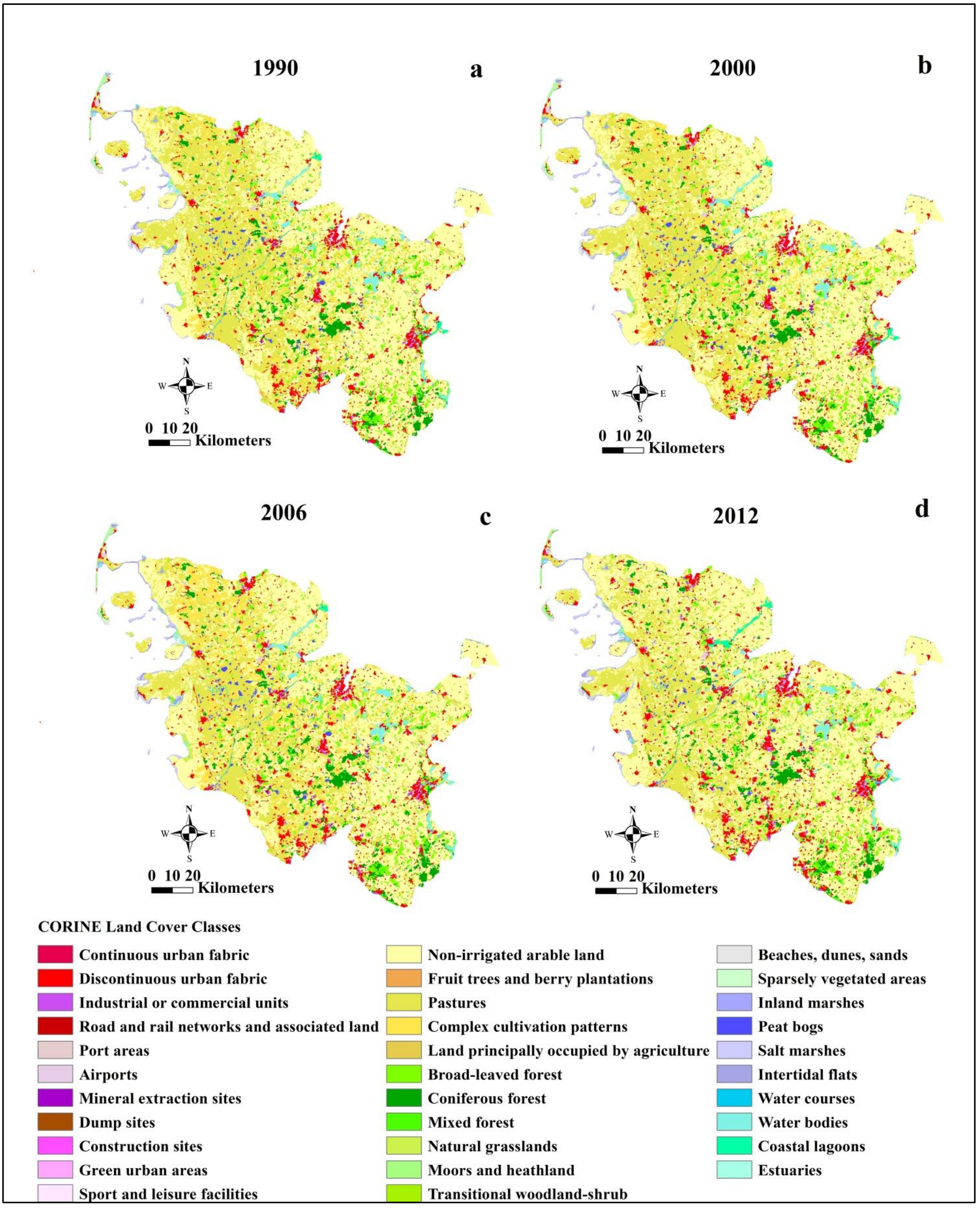

Figure 6. CORINE land cover maps of Schleswig-Holstein for the years 1990 (a), 2000(b), 2006(c), 2012(d).

Table 10. Chosen land cover areas and percentages of land cover classes of Schleswig-Holstein in 1990, 2000, 2006 and 2012. The land cover areas and percentages in all 32 land cover classes of Schleswig-Holstein can be found in Appendix A Table 1, bolded numbers mean the primary areas.

Land Cover Classes	1990		2000		2006		2012	
	Area (ha)	Percen-tage (%)	Area (ha)	Percen-tage (%)	Area (ha)	Percen-tage (%)	Area (ha)	Percen-tage (%)
Non-irrigated arable land	**670840**	**42.87**	**666449**	**42.59**	**666186**	**42.57**	**746016**	**47.67**
Pastures	**454041**	**29.01**	**452238**	**28.90**	**367189**	**23.46**	**441388**	**28.21**
Complex cultivation patterns	**95978**	**6.13**	**93850**	**6.00**	**164279**	**10.50**	743	0.05
Sparsely vegetated areas	1699	0.11	1321	0.08	1321	0.08	29	0.00
Fruit trees and berry	326	0.02	259	0.02	293	0.02	244	0.02
Road and rail networks and	303	0.02	338	0.02	486	0.03	472	0.03

3.1.1.3 Land coves areas of landscape regions in 1990, 2000, 2006 and 2012

Geest, Marsch and Hügelland are the main landscape regions in Schleswig-Holstein. The area distributions considering both land cover and landscape regions in the years 1990, 2000, 2006 and 2012 are evaluated in this part and shown in Tables 11-13 (Tables 2-4 of the appendix A show the full results). Not all CORINE land cover classes are represented in each landscape regions. No "construction sites" are found in Geest in 1990. In Marsch there is no "continuous urban fabric", "road and rail networks and associated land", "construction sites" and "green urban areas" in 1990. In 2000 Marsch excludes the land cover classes of "Continuous Urban Fabric", "road and rail networks and associated land", "construction sites", "green urban areas" and "coastal lagoons". Marsch does not include "continuous urban fabric", "road and rail networks and associated land", "green urban areas" and "coastal lagoons" in 2006. Finally in 2012 there is no "continuous urban fabric", "road and rail networks and associated land", "construction sites", "green urban areas", "sparsely vegetated areas" and "coastal lagoons" in the region Marsch. In 1990, 2000, 2006 the land cover classes "moors and heathland", "salt marshes", "intertidal flats" and "estuaries" are undistributed in Hügelland. There is no area of Hügelland occupying "moors and heathland", "sparsely vegetated areas", "salt marshes", "intertidal flats" and "Estuaries" in the COREINE data sets of 2012.

The areas of the landscapes are different among Geest, Marsch and Hügelland. The land cover areas and the percentage of CORINE land cover classes prevalent in the respective landscape regions are depicted in Table 11 and Table 12 (full results are depicted in Table 2 and Table 3 of the appendix A). The Tables reveal that 31 land cover classes in 1990 and 32 land cover classes in 2000, 2006 and 2012 are represented in Geest. 28 land cover classes in 1990 and 2006, 27 land cover classes in 2000 and 26 land cover classes in 2012 are existing in the March. There are 28 land cover classes in 1990, 2000 and 2006, and 26 land cover classes in 2012 in Hügelland. "Pastures" and "non-irrigated arable land" account for the largest areas (absolute and relative) in the landscape regions of Geest, Marsch and Hügelland for the years 1990, 2000, 2006 and 2012. "Complex cultivation patterns" occupy the third largest areas and percentage of areas in Geest and Marsch for the years 1990, 2000 and 2006. In 2012 "discontinuous urban fabric" takes the place of "complex cultivation patterns" to become the land cover which has the third largest areas and percentage of areas in Geest. "Salt marshes" displace "complex cultivation patterns" as the land cover with the third largest areas (absolute and relative) areas in Marsch from 1990, 2000 and 2006 to 2012. Moreover, “broad-leaved forest” is the third largest one in areas and percentage of areas in Hügelland for the years 1990, 2000, 2006 and 2012.

Table 11. Chosen land cover classes and their areas (ha) in landscape regions of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012. All land cover areas (ha) can be found in Appendix A Table 2, bolded numbers mean the primary areas.

Land Cover Classes	**1990**			**2000**			**2006**			**2012**		
	Geest	**Marsch**	**Hügel-land**	**Geest**	**Marsch**	**Hügel-land**	**Geest**	**Marsch**	**Hügel-land**	**Geest**	**Marsch**	**Hügel-land**
Non-irrigated arable land	**165783**	**99005**	**406052**	**164794**	**99629**	**402026**	**172535**	**101903**	**391748**	**240141**	**108932**	**396942**
Pastures	**289630**	**86855**	**77557**	**288057**	**86241**	**77939**	**218510**	**76682**	**71997**	**249821**	**84782**	**106785**
Complex cultivation	**52326**	**9262**	**34390**	**50692**	**8947**	**34211**	**105576**	**15252**	**43451**	362	205	176
Discontinuous urban fabric	40948	5841	33886	42338	6221	36013	44174	6725	37620	**50911**	7360	41906
Broad-leaved forest	16477	627	**43303**	16459	585	**43244**	16699	612	**45139**	22942	983	**57322**
Salt marshes	633	7603	0	726	7750	0	720	8014	0	1491	**10263**	0

Table 12. Percentages (%) of chosen land cover areas in landscape regions of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012. All percentage (%) can be found in Appendix A Table 3.

Land Cover Classes	**1990**			**2000**			**2006**			**2012**		
	Geest	**Marsch**	**Hügel-land**	**Geest**	**Marsch**	**Hügel-land**	**Geest**	**Marsch**	**Hügel-land**	**Geest**	**Marsch**	**Hügel-land**
Non-irrigated arable land	25.24	42.90	59.95	25.09	43.15	59.37	26.27	44.13	57.85	36.57	47.16	58.61
Pastures	44.09	37.63	11.45	43.85	37.35	11.51	33.27	33.21	10.63	38.04	36.71	15.77
Complex cultivation	7.97	4.01	5.08	7.72	3.87	5.05	16.07	6.61	6.42	0.06	0.09	0.03
Discontinuous urban fabric	6.23	2.53	5.00	6.45	2.69	5.32	6.72	2.91	5.56	7.75	3.19	6.19
Broad-leaved forest	2.51	0.27	6.39	2.51	0.25	6.39	2.54	0.26	6.67	3.49	0.43	8.46
Salt marshes	0.10	3.29	0.00	0.11	3.36	0.00	0.11	3.47	0.00	0.23	4.44	0.00

The landscape region areas and the percentages of the landscape region areas in the land cover classes in Schleswig-Holstein for the years 1990, 2000, 2006, and 2012 are presented in Table 11 and Table 13 (full results are depicted in Table 2 and Table 4 of appendix A). The distributions of Geest, Marsch and Hügelland in the land cover classes are different from one land cover to the other. “Non-irrigated arable” has greater areas than the other land cover classes for the years 1990, 2000, 2006 and 2012. Geest, Marsch and Hügelland account for about 25%, 15% and 60% of the total areas of “Non-irrigated arable land” during the four periods. However, Geest, Marsch and Hügelland account for about 60%, 20% and 20% of the total “pasture” areas for the four years. The areas of Geest, Marsch and Hügelland distribute different in the land cover classes of

Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Table 13. Percentages (%) of chosen landscape regions areas in land cover classes of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012. All percentage (%) can be found in Appendix A Table 4.

Land Cover Classes	1990			2000			2006			2012		
	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land
Non-irrigated arable land	24.71	14.76	60.53	24.73	14.95	60.32	25.90	15.30	58.80	32.19	14.60	53.21
Pastures	63.79	19.13	17.08	63.70	19.07	17.23	59.51	20.88	19.61	56.60	19.21	24.19
Complex cultivation	54.52	9.65	35.83	54.01	9.53	36.45	64.27	9.28	26.45	48.73	27.56	23.71
Discontinuous urban fabric	50.76	7.24	42.00	50.06	7.36	42.58	49.90	7.60	42.50	50.82	7.35	41.83
Broad-leaved forest	27.28	1.04	71.69	27.30	0.97	71.73	26.74	0.98	72.28	28.24	1.21	70.55
Salt marshes	7.68	92.32	0.00	8.57	91.43	0.00	8.25	91.75	0.00	12.69	87.31	0.00

3.1.1.4 Land cover areas of districts in 1990, 2000, 2006 and 2012

The area of prevalent land cover classes in the district and its percentage which equals to the area of each land cover of all 32 land cover classes in Schleswig-Holstein divided by the area of land cover in each district (see equation 12 in chapter 2) are shown in Table 14 and Table 15 (full results are depicted in Table 5 and Table 6 of the appendix A). Rendsburg-Eckernförde, Nordfriesland and Schleswig-Flensburg have larger areas, while Kiel, Neumünster, and Flensburg has smaller areas compared to other districts in Schleswig-Holstein. Land cover classes which have the largest areas in districts change in several areas. Land cover classes with the prime largest areas in the districts of Dithmarschen, Nordfriesland, Pinneberg, Rendsburg-Eckernförde, Schleswig-Flensburg, Segeberg, Steinburg and Stormarn are “non-irrigated arable land” and “pastures” for the years 1990, 2000, 2006 and 2012. “Non-irrigated arable land” in the districts of Ostholstein and Plön has larger areas compared to the other land cover classes for the four years. Simultaneously, Kiel, Neumünster, and Flensburg, the smaller areas have “discontinuous urban fabric” as the prime widely distributed land cover for the four years. Hzgt. Lauenburg is the district which takes “non-irrigated arable land” and “broad-leaved forest” as the land cover classes covering larger areas. “Non-irrigated arable land” and “discontinuous urban fabric” are the primarily occupying land cover classes in Lübeck. The percentage of the land cover areas in the districts follows the same orders of the land cover areas in the years 1990, 2000, 2006 and 2012. The areas of the land cover classes in districts are various among the different districts.

The percentage of the areas of districts in land cover classes is following the illustration of the area of prevalent land cover classes in districts and their percentage (Table 16, full results are depicted in Table 7 of appendix A). It is calculated with the area of each land cover in Schleswig-Holstein divided by the area of each land cover of each district (see the equation 14 in chapter 2). The distributions in 15 districts are different from one land cover to another. Taking “non-irrigated arable land” and “pastures” which are the land cover classes having more areas than the other land cover classes for example, areas of “non-irrigated arable land” in Schleswig-Flensburg, Rendsburg-Eckernförde, Nordfriesland and Ostholstein account for about 48% of the total "non-irrigated arable land" area for the years 1990 to 2012. Meanwhile, the areas of "pastures" in Dithmarschen, Nordfriesland, Rendsburg-Eckernförde, Schleswig-Flensburg and Steinburg cover more than 72% of the total "pasture" area for the four years. Schleswig-Flensburg, Rendsburg-Eckernförde, Plön, Nordfriesland and Pinneberg account for 71.19% of the total "pasture" area for 2000. Meanwhile, Nordfriesland, Rendsburg-Eckernförde, Dithmarschen, Schleswig-Flensburg and Steinburg account for 78.88%, 75.22% and 70.60% for the years 1990, 2006 and 2012 (the data in 2012 are in italic due to big distribution-differences compared to the data in the years of 1990, 2000 and 2006). Some districts do not contain one or several land cover classes. It means that the distributions of the land cover in the districts are not homogeneous, which may relate both to the landscape regions and to the land cover changes.

Table 14. Chosen land cover classes and their areas (ha) in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012. The data in all 32 land cover areas (ha) in the districts in Schleswig-Holstein can be found in Appendix A Table 5, bolded numbers mean the primary areas, numbers in italic are calculated with new technology.

Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg -Eckernför	Schleswig -Flensburg	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Non-irrigated arable land	**1990**	**50604**	**69074**	**58634**	**96843**	**16468**	**58365**	**83664**	**80389**	**64467**	**32920**	**47543**	2198	**7576**	1131	1717
	2000	**50976**	**67972**	**58651**	**96000**	**16158**	**57913**	**82977**	**81202**	**63185**	**32610**	**46823**	2135	**7197**	968	1618
	2006	**53548**	**65993**	**77566**	**77569**	**15406**	**57319**	**85368**	**86430**	**60394**	**31762**	**43994**	2117	**6287**	837	1547
	2012	***64026***	***61084***	***80864***	***91995***	***20893***	***62881***	***10,976***	***114853***	***61959***	***36160***	***39874***	*1787*	***4532***	*873*	*1545*
Pastures	**1990**	**61299**	7848	**100073**	8360	**22416**	11406	**71118**	**76526**	**30895**	**49155**	**9626**	1048	1834	1,066	1371
	2000	**60510**	8261	**99921**	8458	**22300**	11324	**70832**	**76075**	**30764**	**48977**	**9589**	1038	1900	979	1309
	2006	**52063**	8600	**72734**	8798	**20113**	11000	**56712**	**50240**	**27908**	**44459**	**9425**	975	2467	536	1158
	2012	***55547***	*15552*	***87294***	*14911*	***25290***	*17983*	***64042***	***57051***	***33336***	***47281***	***15185***	*1501*	*3429*	*1126*	*1590*
Discontinuous urban fabric	**1990**	5709	6258	7125	6584	7901	3652	7408	6289	6889	4764	5954	**3999**	**4161**	**1798**	**2181**
	2000	5966	6588	7879	6380	8116	4009	7883	6621	7514	4946	6332	**4033**	**4215**	**1880**	**2210**
	2006	6142	6654	8285	6695	8344	4202	8475	7176	7997	5187	6618	**4025**	**4297**	**2166**	**2253**
	2012	*6992*	*8227*	*8945*	*7490*	*9422*	*4719*	*10609*	*7800*	*9398*	*5517*	*7886*	***4207***	***4612***	***2237***	***2330***
Broad-leaved forest	**1990**	1041	**14974**	1115	8916	1769	7478	9077	3684	3167	1817	5205	428	1583	154	0
	2000	1040	**14947**	1073	8896	1768	7474	9063	3681	3165	1815	5202	428	1582	154	0
	2006	1100	**15039**	1099	9409	1660	7596	9208	4219	3567	1931	5359	428	1627	207	0
	2012	*1755*	***17557***	*1929*	*11225*	*1932*	*9816*	*13731*	*6180*	*5249*	*2397*	*6400*	*588*	*2494*	*226*	*137*

Table 15. Percentages (%) of chosen land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012. The respective data of all 32 land cover areas in the districts in Schleswig-Holstein can be found in Appendix A Table 6, bolded numbers mean the primary areas, numbers in italic are calculated with new technology.

Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg -Eckernför	Schleswig -Flensburg	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Non-irrigated arable land	**1990**	35.48	55.22	27.07	72.01	25.74	53.72	39.04	39.58	48.62	32.35	62.03	19.94	34.82	19.84	23.40
	2000	35.77	54.37	31.62	68.70	25.27	53.34	38.75	40.01	47.68	32.07	61.13	19.39	33.09	16.99	22.05
	2006	37.57	52.78	33.23	65.93	24.09	52.79	39.87	42.59	45.58	31.23	57.43	19.22	28.91	14.70	21.09
	2012	*44.92*	*48.90*	*41.11*	*65.44*	*32.68*	*57.98*	*47.64*	*56.62*	*46.85*	*35.59*	*52.06*	*16.26*	*20.84*	*15.31*	*21.06*
Pastures	**1990**	42.98	6.27	46.20	6.22	35.03	10.50	33.19	37.68	23.30	48.30	12.56	9.51	8.43	18.69	18.68
	2000	42.46	6.61	42.80	7.19	34.87	10.43	33.08	37.49	23.22	48.16	12.52	9.43	8.74	17.19	17.85
	2006	36.53	6.88	31.16	7.48	31.46	10.13	26.49	24.76	21.06	43.72	12.30	8.85	11.34	9.41	15.79
	2012	*38.97*	*12.47*	*37.58*	*12.43*	*39.55*	*16.63*	*29.92*	*28.14*	*25.16*	*46.49*	*19.89*	*13.66*	*15.76*	*19.73*	*21.67*
Discontinuous urban fabric	**1990**	4.00	5.00	3.29	4.90	12.35	3.36	3.46	3.10	5.20	4.68	7.77	36.29	19.12	31.54	29.71
	2000	4.19	5.27	3.37	5.42	12.69	3.69	3.68	3.26	5.67	4.86	8.27	36.62	19.38	32.99	30.12
	2006	4.31	5.32	3.55	5.69	13.05	3.87	3.96	3.54	6.03	5.10	8.64	36.55	19.76	38.02	30.71
	2012	*4.90*	*6.53*	*4.05*	*5.95*	*14.73*	*4.32*	*4.95*	*3.83*	*7.06*	*5.39*	*10.29*	*38.27*	*21.21*	*39.21*	*31.76*
Broad-leaved forest	**1990**	0.73	11.97	0.51	6.63	2.76	6.88	4.24	1.81	2.39	1.79	6.79	3.88	7.27	2.71	0.00
	2000	0.73	11.96	0.46	7.56	2.76	6.88	4.23	1.81	2.39	1.79	6.79	3.88	7.27	2.71	0.00
	2006	0.77	12.03	0.47	8.00	2.60	7.00	4.30	2.08	2.69	1.90	7.00	3.88	7.48	3.63	0.00
	2012	*1.23*	*14.02*	*0.82*	*9.51*	*3.02*	*8.96*	*6.40*	*3.01*	*3.92*	*2.36*	*8.29*	*5.35*	*11.48*	*3.96*	*1.86*

Table 16. Percentages (%) of districts areas in the land cover classes of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012. The respective data of all 32 land cover areas in the districts in Schleswig-Holstein can be found in Appendix A Table 7, bolded numbers mean the primary areas, numbers in italic are calculated with new technology.

Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Non-irrigated arable land	**1990**	7.53	10.29	**8.73**	**14.42**	2.45	8.69	**12.46**	**11.97**	9.60	4.90	7.08	0.33	1.13	0.17	0.26
	2000	7.65	10.20	**8.80**	**14.41**	2.42	8.69	**12.45**	**12.19**	9.48	4.89	7.03	0.32	1.08	0.15	0.24
	2006	8.04	9.91	**11.64**	**11.64**	2.31	8.60	**12.82**	**12.97**	9.07	4.77	6.60	0.32	0.94	0.13	0.23
	2012	*8.59*	*8.20*	***12.85***	***10.33***	*2.80*	*8.44*	***13.68***	***15.41***	*8.32*	*4.85*	*5.35*	*0.24*	*0.61*	*0.12*	*0.21*
Pastures	**1990**	**13.50**	1.73	**22.04**	1.84	4.94	2.51	**15.66**	**16.85**	6.80	**10.83**	2.12	0.23	0.40	0.23	0.30
	2000	**13.38**	1.83	**22.09**	1.87	4.93	2.50	**15.66**	**16.82**	6.80	**10.83**	2.12	0.23	0.42	0.22	0.29
	2006	**14.18**	2.34	**19.81**	2.40	5.48	3.00	**15.44**	**13.68**	7.60	**12.11**	2.57	0.27	0.67	0.15	0.32
	2012	***12.59***	*3.53*	***19.85***	*3.32*	*5.73*	*4.09*	***14.51***	***12.94***	*7.55*	***10.71***	*3.45*	*0.34*	*0.78*	*0.26*	*0.36*

3.1.1.5 Land cover changes of Schleswig-Holstein in 1990, 2000, 2006 and 2012

The land cover distributions are critical boundary conditions of the multiple cycles of material and energy in landscapes (Cebecauer & Hofierka, 2008; Muñoz-Rojas *et al.*, 2011). Land cover changes have significant effects on the land cover distributions due to transformations resulted from land cover changes. Therefore, appreciating processes of land cover changes is vital for studying effects on material and energy cycles taken by land cover.

Comparing statistic data about the CORINE land cover change maps from 1990 to 2000, from 2000 to 2006 and from 2006 to 2012 (see Table 8-10 of the appendix A), dynamics are detectable during these periods. The areas of land cover changes from 1990 to2000, from 2000 to 2006 and from 2006 to 2012 are 23929 ha, 125756 ha and 486,754 ha, which account for 1.50%, 8.04% and 31.10% of the land cover areas. Most areas of the land cover changes are among “non-irrigated arable land”, “pastures” and “complex cultivation patterns”.

Land cover changes have differences among the three periods. The land cover transformations are obvious from “non-irrigated arable land” to “complex cultivation patterns” and “pastures” from 1990 to 2000. It is found that 2994 ha of “non-irrigated arable land” change to “pastures”, accounting for 12.51% of the land cover change areas from 1990 to 2000. At the same time, land cover changes from “pastures” into “non-irrigated arable land” and “complex cultivation patterns” play the other important role during the period. 3547 ha and 1228 ha of “pastures” are transformed into “non-irrigated arable land” and “complex cultivation patterns”. In the second study period, from 2000 to 2006, major transformations are those from “pastures” to “non-irrigated arable land” and “complex cultivation patterns”. The areas of the transformations are 17936ha and 66961 ha, reach to 14.26% and 53.25% of the area of land cover changes. Other significant changes consist of transformations from “non-irrigated arable land” to “pastures” (3844 ha, 3.06% of the area of land cover changes) and to “complex cultivation patterns” (9378 ha, 7.46% of the area of land cover changes). Simultaneously, the prime changes include transformations from “complex cultivation patterns” to “non-irrigated arable land” and to” pastures” from 2006 to 2012. 92661ha (19.04% of the area of land cover changes from 2006 to 2012) of “complex cultivation patterns” transforms to “non-irrigated arable land”, and 62214 ha (12.78% of the area of land cover change from 2006 to 2012) of “complex cultivation patterns” transforms to “pastures”. At the same time, as another major land cover change from 2006 to 2012, 75106 ha (15.43% of the area of land cover change from 2006 to 2012) of “non-irrigated arable land” transforms to “pastures”.

Considering details, “non-irrigated arable land” takes the first place of land cover changes from 1990 to 2000. Its area is 10181 ha, occupying 0.65% of the total area of Schleswig-Holstein and 1.52% of the “non-irrigated arable land” area in 1990. The areas of land cover change into “pastures” (6741 ha), the second prime land cover change during 1990- 2000, takes 0.43% of the total area of Schleswig-Holstein and 1.48% of “pastures” area in 1990. The primary important land cover change between 2000 and 2006 is from “pastures” (89688 ha) to the other land cover classes, which accounts for 5.73% of the total area of Schleswig-Holstein and 19.83% of “pastures” area in 2000. The second major transformation is from “non-irrigated arable land”

(23063 ha) to others, involving in 1.47% of the total area of Schleswig-Holstein and 3.46% of “non-irrigated arable land” in 2000. A significant contrast of the largest area of land cover changes between the periods of 2006-2012 and 2000-2006 is that “complex cultivation patterns” affecting land cover changes as the most important land cover. The land cover change areas of “complex cultivation patterns” account for 10.49% of the total area of Schleswig-Holstein and 99.89% of “the complex cultivation patterns” (164095 ha) area in 2006. Besides “complex cultivation patterns”, “non-irrigated arable land” which has the second largest area of land cover change (103848 ha), accounts for 6.63% of the total area of Schleswig-Holstein and 15.59% of the “non-irrigated arable land” area in 2006. Additionally, 100% of areas on “construction sites” changes either from 2000 to 2006 or from 2006 to 2012.

Increase and decrease of the areas of land cover are different either based on the land cover classes or on the periods. The area of pastures during 1990-2000 is relatively steady. The area of “complex cultivation patterns” decreases 2061 ha and accepts 2123 ha from areas of the other land cover classes and converts 4184 ha into the other land cover classes from 1990 to 2000. Similarly to “complex cultivation patterns”, the area of “non-irrigated arable land” descends because the transformation from “non-irrigated arable land” to the other land cover classes (10181 ha, 0.65% of the total area of Schleswig-Holstein and 1.52% of the area of “non-irrigated arable land” in 1990) are more than the conversion from the other land cover classes to “non-irrigated arable land” (5412 ha). During the second land cover change period, 2000-2006, the area occupied by “pastures” decreases for achieving 4618 ha (6.00% of the total area of Schleswig-Holstein and 25.59% of the area of “pastures” in 2006) from areas of the other land cover classes, but converting 89688 ha into other land cover classes. However, the area of complex cultivation patterns increases because it accepts 76474 ha (4.88% of the total area of Schleswig-Holstein and 46.55% of the area of “complex cultivation patterns” in 2006) of land cover change, transferring 6047 ha into other land cover classes. Comparing the land cover changes of “pastures” and “complex cultivation patterns” during 2000-2006, the area of “non-irrigated arable land” is approximately steady. It converts 23063 ha into the other land cover classes, and regains 22815 ha from the other land cover from 2000 to 2006. For the period of 2006-2012, the area of “complex cultivation patterns” reduces for regaining 563 ha (0.04% of the total area of Schleswig-Holstein and 75.87% of the area of “complex cultivation patterns” in 2012) from areas of the other land cover classes, but converting 164,095 ha into the other land cover classes. The area of “non-irrigated arable land” rises, due to catching 183396 ha (11.72% of the total area of Schleswig-Holstein and 24.59% of the area of” non-irrigated arable land” in 2012) from the other land cover classes, transforming 103848 ha into the other land cover classes. The same trend appears on land cover of “pastures”, whose area increases during 2006-2012.

Land cover changes are distinct based on the analysis of the land cover transformations during the periods of 1990-2000, 2000-2006 and 2006-2012. The main land cover changes are among “pastures”, “non-irrigated arable land” and “complex cultivation patterns”. However, the transforming areas among the land cover classes are various during the three periods.

3.1.1.6 Land cover diversity

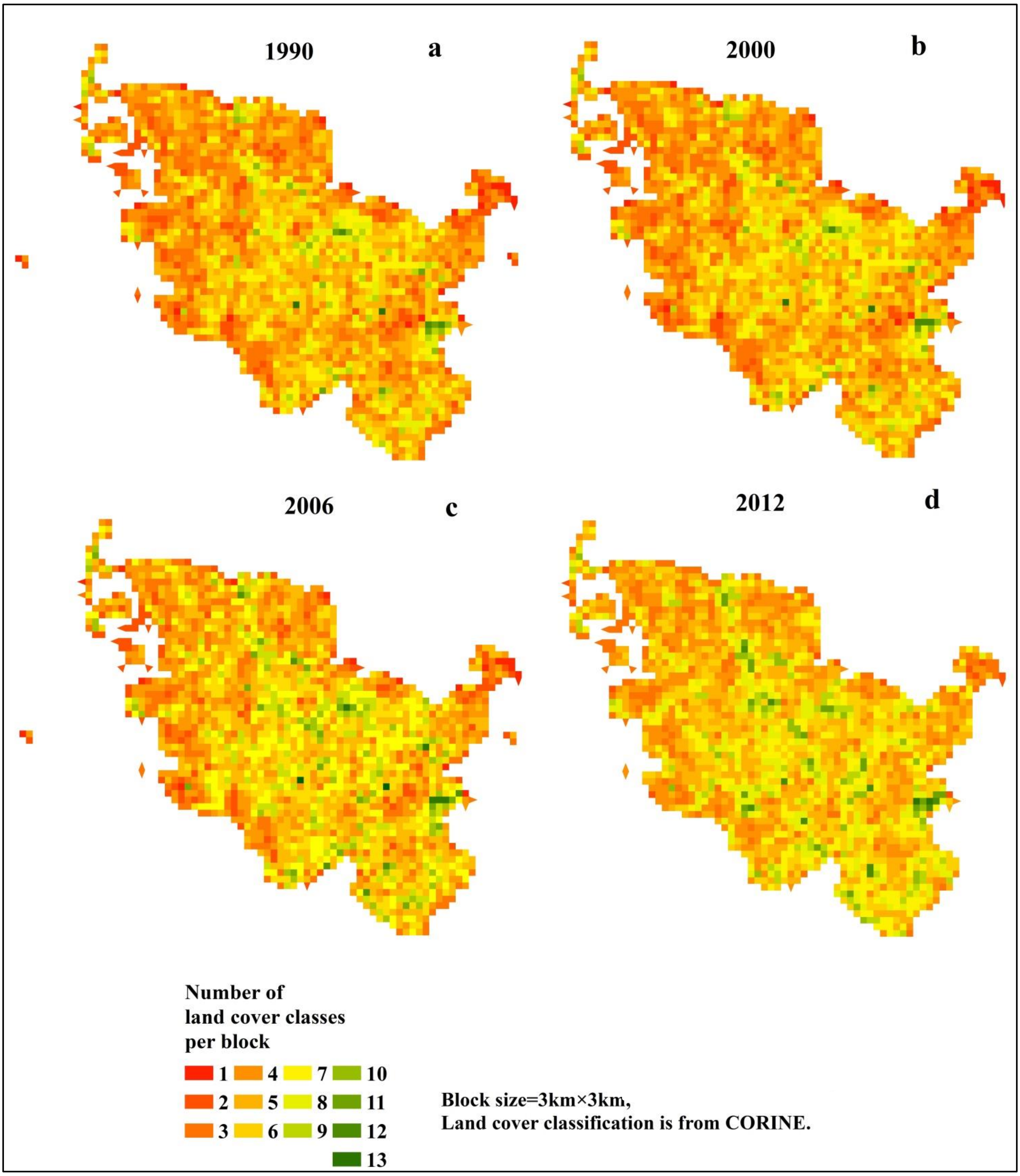

Figure 7. Land cover diversity index in Schleswig-Holstein for the years1990 (a), 2000 (b), 2006 (c) and 2012 (d).

Land cover diversity indicates a fragmental level of land cover in a certain area. Estimating the land cover diversity for Schleswig-Holstein clarifies land cover richness and evenness of the state. The Shannon diversity index is considered as a relative index which enables the comparison of different land cover types and the heterogeneity of their spatial distributions. Table 17 shows the Shannon diversity index based on the land cover classes for the years 1990, 2000, 2006 and 2012. The indexes in Schleswig-Holstein fluctuate during the four periods. The Shannon diversity index of Schleswig-Holstein in 2012 is the lowest one compared with the indexes for 1990, 2000 and 2006, while the index in 2006 is the highest. This pattern illustrates that the land cover is rather fragmentary in 2006 but less fragmented in 2012. Low fragment is a benefit for managing the land cover, for keeping the stability of ecosystems and material and energy cycles.

Table 17. Shannon diversity index based on land cover classes in Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

	Period			
Shannon Diversity Index	1990	2000	2006	2012
	1.756	1.775	1.850	1.615

The land cover diversity index also reveals an aggregation of land cover classes within each block which takes place as a unit on assessing the land cover diversity. The mapping results of the land cover diversity index for the years 1990, 2000, 2006 and 2012 are presented in Figure 7. Schleswig-Holstein includes 1957 blocks. The maximum number of different land cover classes per block is 13 due to the legend level 3 of the CORINE land cover classification. The number of CORINE land cover classes in each block fluctuates from 1 to 13 since 1990 until 2006, and fluctuates from 1 to 12 in 2012. Most of blocks have 5 different land cover classes for the years 1990, 2000 and 2006: there are 443 blocks (22.64% of the total), 457 blocks (23.35% of the total) and 448 blocks (28.89% of the total) with 5 land cover classes in the three years. 23.30% (456 blocks) of the total blocks were occupied with 4 land cover classes in 2012. The blocks, including 13 or 12 land cover classes, cover the least number of blocks in Schleswig-Holstein. The blocks located in the middle part of the state are much more various than the blocks in the east and west of Schleswig-Holstein, which might indicate higher fragmental in the middle of the state than the eastern and western parts. The areas of the former glaciation edges provide the highest diversity, thus the interval conditions can be seen in these maps. Also the agricultural areas can be observed as relative homogeneous landscapes.

3.1.2 Qualitative assessments of ecosystem services

The qualitative approach and the quantitative approach are the main methods used for assessing ecosystem services. The basic point is that ecosystem services are influenced by land cover. The land cover classes are the primary factors which affect the qualitative analysis of ecosystem services in this study.

The matrix method is one of main qualitative approaches applied for ecosystem services analyses. The methods have been used in the assessments of evaluating various ecosystem services in different ecological systems (de Chazal *et al.*, 2008; Koschke *et al.*, 2012; Tengberg *et al.*, 2012). Burkhard and others have developed the matrix method with scales 0-5, linking 31 ecosystem services and 7 ecological integrity variables to 44 land cover classes (Burkhard *et al.*, 2009, 2014; Kroll *et al.*, 2012a). The matrix values are derived from different case studies which supply experience and a multitude of expert valuations. The case studies in Schleswig-Holstein and northern Germany can provide an excellent data availability (Gee, 2010; Lange *et al.*, 2010; Kroll *et al.*, 2012a). Therefore, the matrix values of ecosystem services are used to map regulating, provisioning and cultural services in this sub-section.

The aim of the sub-section 3.1.2 is to show qualitative mapping results of ecosystem services. The land cover classes and their areas with no potential or with very high potential of ecosystem services: global climate regulation, crops, livestock (domestic), and landscape aesthetics and inspiration are presented in this section. Afterwards, changes of the potentials of ecosystem services induced by land cover changes for the years 1990, 2000, 2006 and 2012 are illustrated.

3.1.2.1 Regulating services

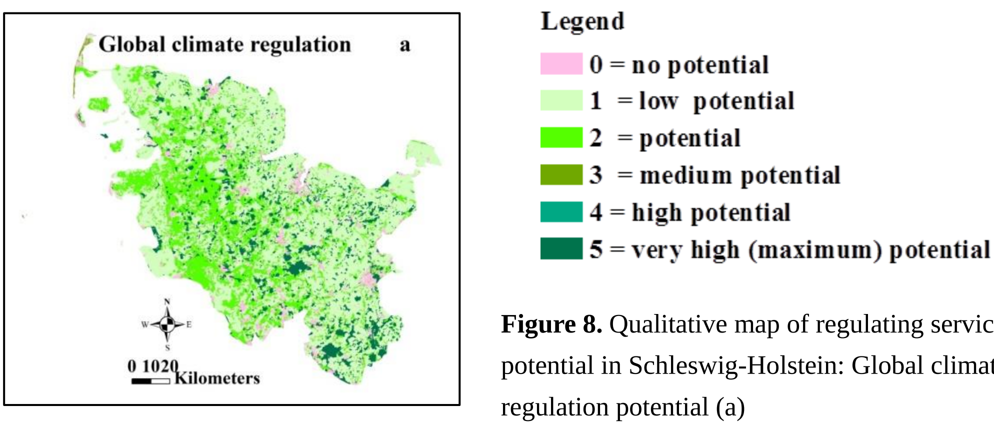

Figure 8. Qualitative map of regulating service potential in Schleswig-Holstein: Global climate regulation potential (a)

The focal map with the contribution of Schleswig-Holstein to global climate regulation delineated with the matrix method - mainly carbon storage - is shown in Figure 8 and Table 18, respectively. “Broad-leaved forest”, “coniferous forest”, “mixed forest” and “peat bog” are considered to have very high global climate regulation potentials. The land cover classes belong to the class 5 in the matrix method, occupying 155685 ha (9.95% of the total area of Schleswig-Holstein). Class 0 has an area of 116598 ha, taking 7.45% of the total land cover area, which includes “continuous urban fabric”, “industrial or commercial units”, “road and rail networks and associated land”, “port areas”, “airports”, “mineral extraction”, ‘dump sits”, “construction sites”, “beaches, dunes”, “sands”, ‘sparsely vegetated areas”, and “water coursed”. Kiel, Neumünster, Lübeck and Flensburg are the districts of metropolis where are manly composed of large areas of artificial surfaces, such as “continuous urban fabric”, “discontinuous urban fabric”, “industrial or commercial units”, “road and rail networks and associated land”, “port areas”, “airports”, “mineral extraction sites”, “dump sites” and “construction sites”. These land cover classes have been classified into class 0 leading to the mapping color in Kiel, Neumünster, Lübeck and Flensburg primarily consist of pink. Further maps depicting the potential to provide the ecosystem services: local climate regulation, erosion regulation, natural hazard regulation, nutrient regulation, air quality regulation, water potential regulation and water purification are shown in the appendix

B, Figure 1.

Table 18. Land cover areas and the percentages of regulating service (Global climate regulation) in Schleswig-Holstein in 2006.

Class 5			Class 0		
Land cover classes	**Area (ha)**	**Percentage (%)**	**Land Cover Classes**	**Area (ha)**	**Percentage (%)**
Broad-leaved forest	62450	3.99	**Continuous urban fabric**	1030	0.07
Coniferous forest	51759	3.31	**Discontinuous urban fabric**	88518	5.66
Mixed forest	22863	1.46	**Industrial or commercial units**	9076	0.58
Natural grasslands	9129	0.58	**Road and rail networks and associated land**	568	0.04
Peat bogs	9484	0.61	**Port areas**	965	0.06
			Airports	2438	0.16
			Mineral extraction sites	3504	0.22
			Dump sites	807	0.05
			Construction sites	334	0.02
			Beaches, dunes, sands	4433	0.28
			Sparsely vegetated areas	1321	0.08
			Water courses	3606	0.23
Total	155685	9.95	**Total**	116598	7.45

3.1.2.2 Provisioning services

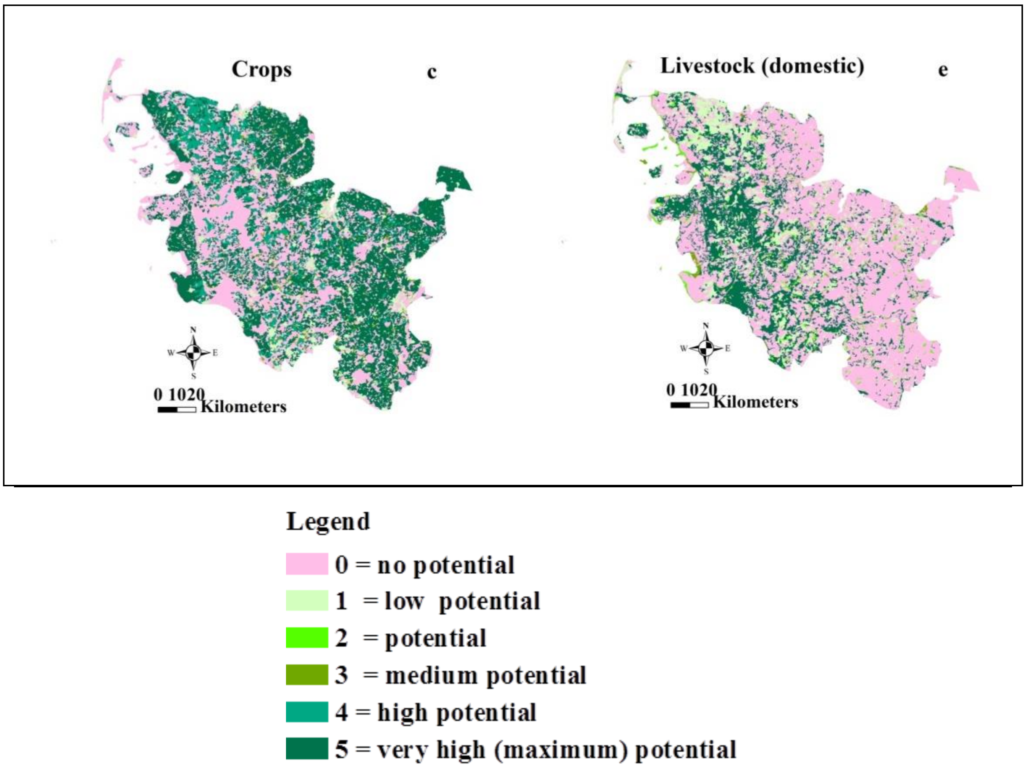

Figure 9. Qualitative maps of provisioning service potentials in Schleswig-Holstein: Crops potential (c) and Livestock (domestic) potential (e).

Provisioning services are the materials and goods provided by ecosystems. Figure 9, Table 19 and Table 20 present the spatial distributions and correlated area statistic for class 5 and class 0 of crops and livestock assessed with the matrix method. “Non-irrigated arable land” and “pastures”, covering 42.57% and 23.46% of the total land cover areas of Schleswig-Holstein, show very high potentials of the ecosystem services of “crop” and “livestock” according to the classification of the matrix method. The areas of “non-irrigated arable land” and “pastures” take high ratios in the qualitative maps of provisioning services (crop and livestock). However, “non-irrigated arable land” and “pastures” are classified in class 5 and class 0 in the qualitative maps of provisioning service crop, and are classified in 0 and class 5 in livestock. The classification results in color pink and clolr dark green become the prime colors in the map. Other provisioning services of energy sources, biomass for energy, fodder, wild foods and resources, timber, wood fuel and freshwater have been mapped with qualitative indicators in the appendix B Figure 2.

Table 19. Land cover areas and the percentages of provisioning service (Crops) in Schleswig-Holstein in 2006.

Class 5			**Class 0**		
Land cover classes	**Area (ha)**	**Percentage (%)**	**Land Cover Classes**	**Area (ha)**	**Percentage (%)**
Non-irrigated arable land	666186	42.57	**Continuous urban fabric**	1030	0.07
			Industrial or commercial units	9076	0.58
			Road and rail networks and associated land	568	0.04
			Port areas	965	0.06
			Airports	2438	0.16
			Mineral extraction sites	3504	0.22
			Dump sites	807	0.05
			Construction sites	334	0.02
			Green urban areas	1148	0.07
			Sport and leisure facilities	7100	0.45
			Pastures	367189	23.46
			Broad-leaved forest	62450	3.99
			Coniferous forest	51759	3.31
			Mixed forest	22863	1.46
			Natural grasslands	9129	0.58
			Moors and heathland	3015	0.19
			Transitional	2206	0.14
			Beaches, dunes, sands	4433	0.28
			Sparsely vegetated areas	1321	0.08
			Inland marshes	4480	0.29
			Peat bogs	9484	0.61
			Salt marshes	8735	0.56
			Intertidal flats	8130	0.52
			Water courses	3606	0.23
			Water bodies	29781	1.90
			Coastal lagoons	1117	0.07
			Estuaries	1344	0.09
Total	666186	42.57	**Total**	618009	39.49

Table 20. Land cover areas and the percentages of provisioning service (Livestock (domestic)) in Schleswig-Holstein in 2006.

Class 5			Class 0		
Land cover classes	**Area (ha)**	**Percentage (%)**	**Land Cover Classes**	**Area (ha)**	**Percentage (%)**
Pastures	367189	23.46	**Continuous urban fabric**	1030	0.07
			Discontinuous urban	88518	5.66
			Industrial or commercial units	9076	0.58
			Road and rail networks and associated land	568	0.04
			Port areas	965	0.06
			Airports	2438	0.16
			Mineral extraction sites	3504	0.22
			Dump sites	807	0.05
			Construction sites	334	0.02
			Green urban areas	1148	0.07
			Sport and leisure facilities	7100	0.45
			Non-irrigated arable land	666186	42.57
			Fruit trees and berry plantations	267	0.02
			Broad-leaved forest	62450	3.99
			Coniferous forest	51759	3.31
			Mixed forest	22863	1.46
			Beaches, dunes, sands	4433	0.28
			Peat bogs	9484	0.61
			Intertidal flats	8130	0.52
			Water courses	3606	0.23
			Water bodies	29781	1.90
			Coastal lagoons	1117	0.07
			Estuaries	1344	0.09
Total	367189	23.46	**Total**	976906	62.43

3.1.2.3 Cultural services

Landscape aesthetics and inspiration primarily contribute to the cultural services in Schleswig-Holstein. The map of landscape aesthetics and inspiration, and the land cover areas within class 5 and class 0 of landscape aesthetics and inspiration - based on the matrix method - are shown in Figure 10 and Table 21. “Broad-leaved forest”, “coniferous forest” and “mixed forest” are the land cover classes in class 5, covering 137071 ha (8.76%) of the total area of Schleswig-Holstein. “Industrial or commercial units”, “road and rail networks and associated land”, “airports”, “mineral extraction”, “dump sits”, “construction sites” are the land cover classes in class 0. Class 0 occupies 16727 ha (1.07% of the total land cover area). Besides the ecosystem services landscape aesthetics and inspiration, the ecosystem services of recreation and tourism, natural heritage and natural diversity are shown in appendix B Figure 3.

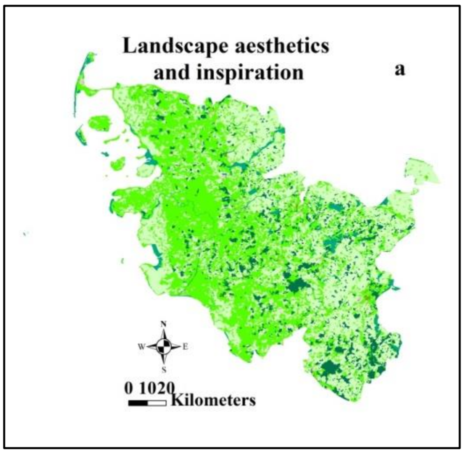

Figure 10. Qualitative map of cultural service potential in Schleswig-Holstein: Landscape aesthetics and inspiration (a).

Table 21. Land cover areas and the percentages of cultural service (Landscape aesthetics and inspiration) in Schleswig-Holstein in 2006.

Class 5			Class 0		
Land Cover Classes	**Area (ha)**	**Percentage (%)**	**Land Cover Classes**	**Area (ha)**	**Percentage (%)**
Broad-leaved forest	62450	3.99	**Industrial or commercial**	9076	0.58
Coniferous forest	51759	3.31	**Road and rail networks and associated land**	568	0.04
Mixed forest	22863	1.46	**Airports**	2438	0.16
			Mineral extraction sites	3504	0.22
			Dump sites	807	0.05
			Construction sites	334	0.02
Total	137071	8.76	**Total**	16727	1.07

3.1.2.4 Changes of the provision of ecosystem services induced by land cover changes

Land cover and land cover changes are the primary factors due to modified land management practices, which affect the potential of ecosystems to provide services. Respective changes in the periods 1990-2000, 2000-2006, and 2006-2012 are presented in the following section. The results on land cover changes are presented in Figures 11-14 and Tables 22-25, showing changes of the potentials of Schleswig-Holstein to provide ecosystem services (global climate regulation, landscape aesthetics and inspiration, crops and livestock) during the periods of 1990-2000, 2000-2006, and 2006-2012.

The ecosystem service change of global climate regulation primarily deduces during the period from 2006 to 2012 (Figure 11 and Table 22). The area of the ecosystem service's negative and positive changes are 195,500 ha and 169,181 ha from 1990 to 2012, respectively. However, there are a few areas included in negative and positive changed ecosystem service of global climate regulation during the period 1990-2000. The related areas during 1990-2012 are as 10 times and 25 times larger as those from the period 1990-2000. Most areas of the changes have the changed ecosystem service value 1 and -1, which represents that most areas of change of global climate regulation in Schleswig-Holstein are small.

The ecosystem service negative and positive changes of crops during 2006-2012, and positive changes during 2000-2006 mainly account for the ecosystem service changes during the period 1990-2012 (Figure 12 and Table 23). Most areas of change have the modified value 4 during 2000-2006, and areas of the changes focus on the changed value 1 and -5 during 2006-2012. Similarly to the ecosystem service changes of crops, the ecosystem service negative and positive changes of livestock during 1990-2012 mainly result from the periods 2000-2006 and 2006-2012 (Figure 13 and Table 24). Most areas of the negative changes have the changed value -4 during 2000-2006, and the areas of the negative and positive changes focus on the changed values -1, -5 and 5 during 2006-2012.

The ecosystem service changes of landscape aesthetics and inspiration during 1990 to 2012 are presented in Figure 14 and Table 25. The changes during 2006-2012 are the prime changes during the study period. Most areas of the negative and positive changes have the changed values -1 and 1 during 2006-2012, respectively. The value -1 is also the changed value that has the most occupation of the areas based on the ecosystem service changes of landscape aesthetics and inspiration.

The statistical analyzes about the ecosystem services potentials “global climate regulation”, “crops”, “livestock (domestic)” and “landscape aesthetics and inspiration” show the most obviously ecosystem service change based on land cover changes is in “landscape aesthetics and inspiration”, following with the services “livestock (domestic)”, “global climate regulation” and “crops” between 1990 and 2012. Furthermore, the areas with the negative ecosystem service changes are larger than the areas with the positive ecosystem service during the period from 1990 to 2012.

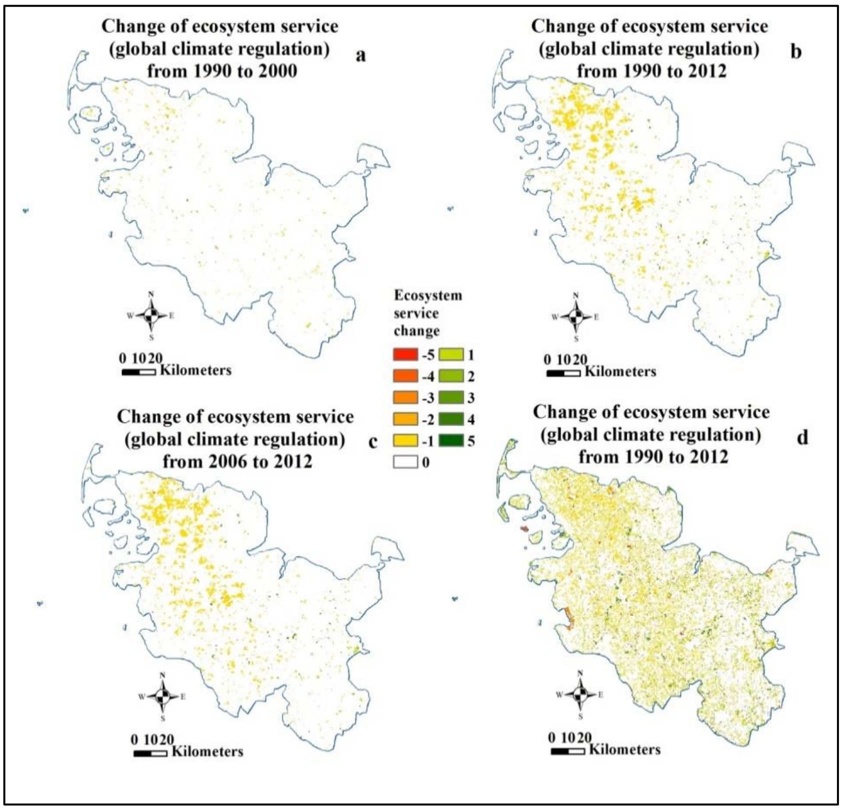

Figure 11. Maps of changes of global climate regulation potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Table 22. Statistical changes of global climate regulation potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Changed value	Area of change (ha)			
	1990- 2000	2000-2006	2006-2012	1990-2012
-5	63	175	2913	3000
-4	63	188	8144	7975
-3	900	538	13663	13644
-2	1569	2094	10181	13419
-1	11325	90994	100925	157463
1	5963	7931	152763	123994
2	131	263	8994	7331
3	425	1656	19263	19794
4	75	2331	13925	16238
5	13	169	1969	1825
Total negative changes（minus）	13919	93988	135825	195500
Total positive changes（plus）	6606	12350	196913	169181

Note: The numbers (-5 to 5) mean the changes of ecosystem services (based on the matrix method) on the land cover classes from one year to another.

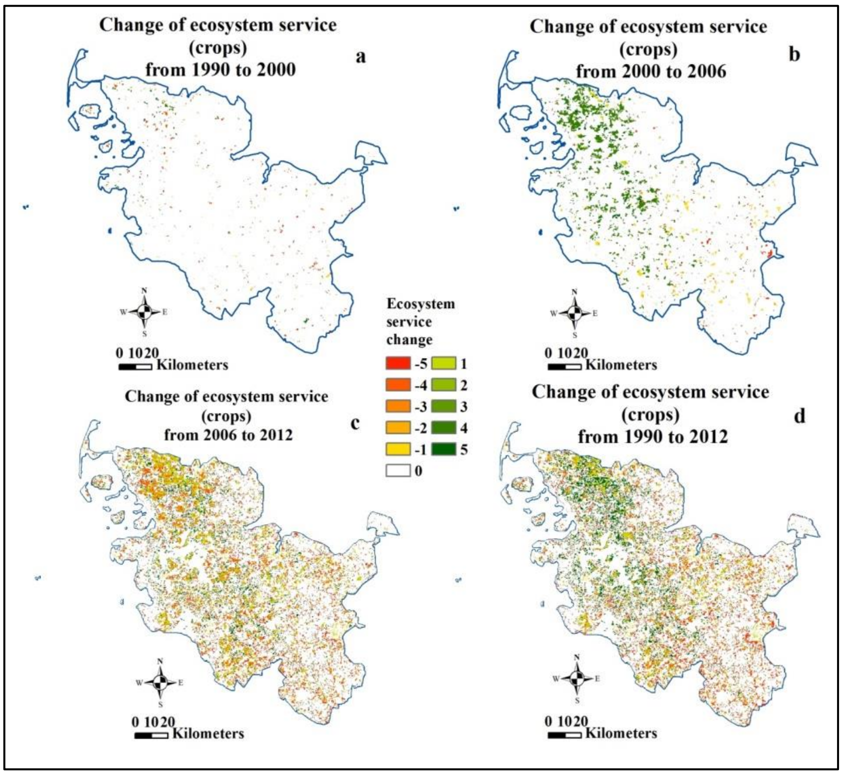

Figure 12. Maps of changes of crops potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Table 23. Statistical changes of crops potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Changed value	Area of change (ha)			
	1990- 2000	2000-2006	2006-2012	1990-2012
-5	6506	8700	91569	102463
-4	5238	3813	76606	49900
-3	413	719	21781	19338
-2	31	2181	3481	3488
-1	850	10688	11638	10788
1	2094	6069	104175	70069
2	0	31	7163	6119
3	0	1331	2006	2125
4	1344	67250	4488	3700
5	4100	18256	79650	128700
Total negative changes (minus)	13038	26100	205075	185975
Total positive changes (plus)	7538	92938	197481	42143

Note: The numbers (-5 to 5) mean the changes of ecosystem services (based on the matrix method) on the land cover classes from one year to another.

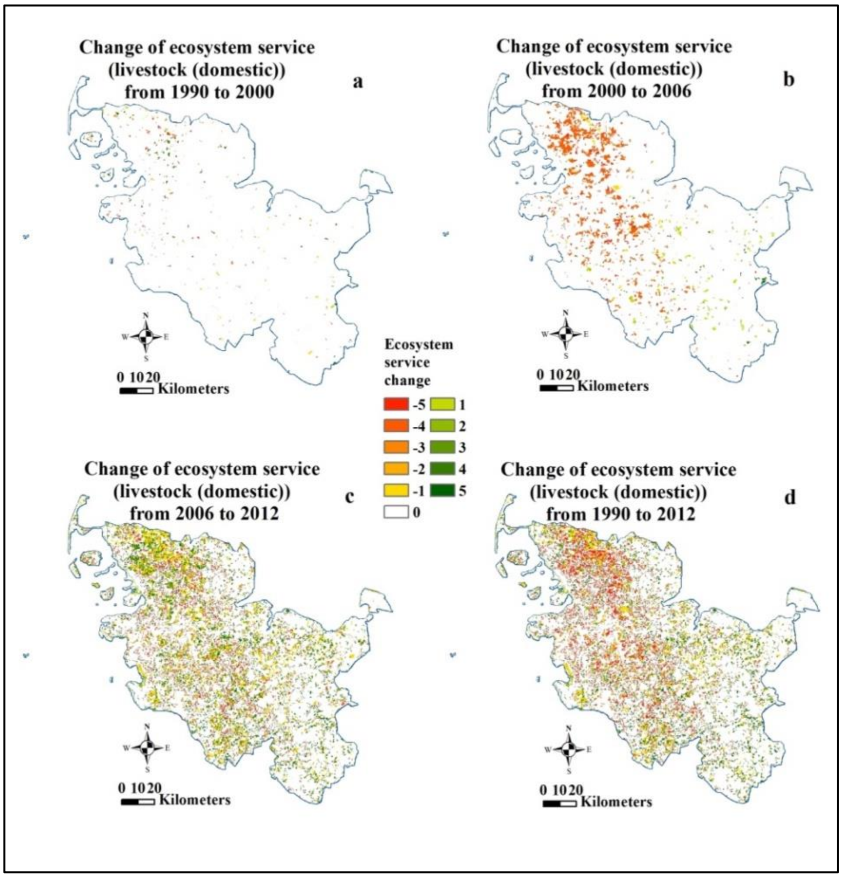

Figure 13. Maps of changes of livestock (domestic) potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Table 24. Statistical changes of livestock (domestic) potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Changed value	Area of change (ha)			
	1990- 2000	2000-2006	2006-2012	1990-2012
-5	5331	20944	86856	141200
-4	1256	67306	1069	1225
-3	50	1538	3550	4144
-2	206	381	18669	17588
-1	2206	6369	104925	67456
1	1913	10231	6550	6400
2	281	2488	9944	10425
3	63	131	15444	13788
4	2163	488	63063	31750
5	3000	4100	89156	90781
Total negative changes（minus）	9050	96538	215069	231613
Total positive changes（plus）	7419	17438	184156	153144

Note: The numbers (-5 to 5) mean the changes of ecosystem services (based on the matrix method) on the land cover classes from one year to another.

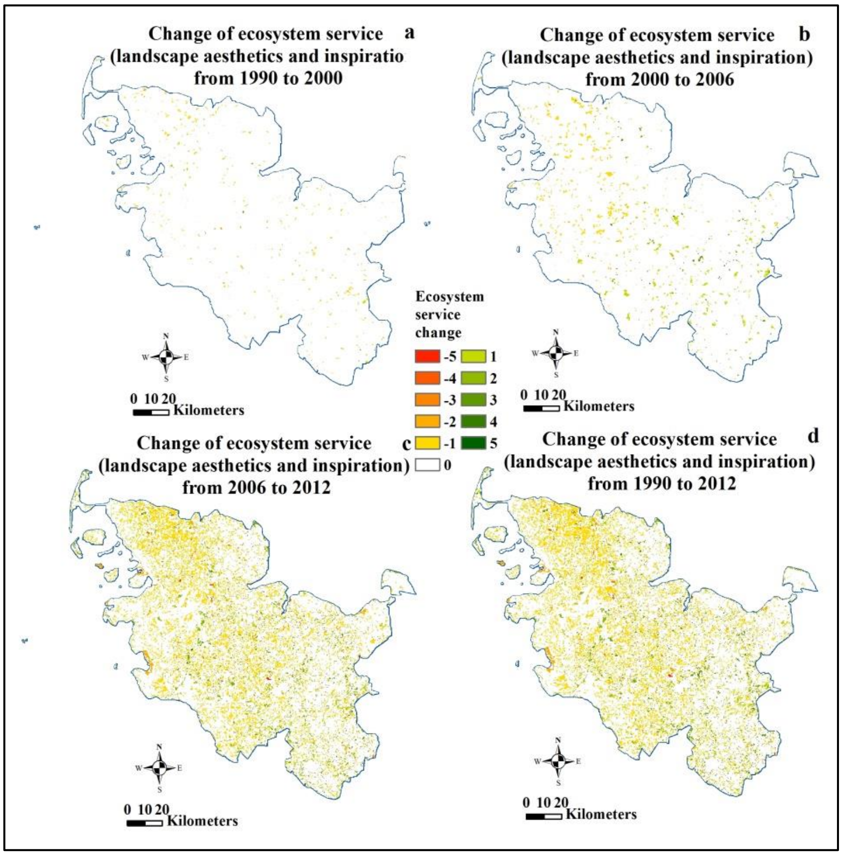

Figure 14. Maps of changes of landscape aesthetics and inspiration potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Table 25. Statistical changes of landscape aesthetics and inspiration potential in Schleswig-Holstein during 1990-2000 (a), 2000-2006 (b), 2006-2012 (c), and 1990 -2012 (d).

Changed value	Area of change (ha)			
	1990- 2000	2000-2006	2006-2012	1990-2012
-5	31	19	1038	1050
-4	50	163	6675	6556
-3	231	394	8456	8575
-2	1806	2594	15644	16850
-1	7475	24063	183275	197288
1	6888	19131	94544	102519
2	875	1525	13644	12431
3	150	931	18300	18456
4	81	2181	10175	12838
5	13	13	400	325
Total negative changes （minus）	9594	27231	215088	230319
Total positive changes（plus）	8006	23781	137063	146569

Note: The numbers (-5 to 5) mean the changes of ecosystem services (based on the matrix method) on the land cover classes from one year to another.

3.1.3 Quantitative assessments of global climate regulation

The aim of the sub-section 3.1.3 is to present quantitative results on the ecosystem service “global climate regulation”. The results for the indicators calculated in this study to quantify the potential of ecosystem to provide this service are: annual total Gross Primary Production (GPP), annual total Net Primary Production (NPP), Soil Organic Carbon (SOC), Carbon Storage (CS) and the qualitative indicator from the matrix evaluation (GCR). Furthermore, comparisons among the qualitative and quantitative indicators on assessments of global climate regulation are estimated as well.

Land cover is one of the important parameters which affect the algorithm using for producing the GPP and NPP products. The products have been produced with the MODIS land cover map (MOD12Q1) of 2004 (Running & Zhao, 2015). Figure 15 depicts the differences of the land cover distributions of CORINE land cover (Level 1) for the years of 1990, 2000, 2006 and 2012 and the land cover distributions of MODIS land cover in 2004 used for producing the annual total GPP and NPP for the years 2000, 2006 and 2012. The CORINE land cover classification in level 1 is similar to the classification of MODIS land cover. “Croplands”, “cropland/natural vegetation mosaic”, “mixed forest” and “urban and built-up”, occupying 94.2% of the total areas, are the main land cover classes in MODIS land cover (Figure 15 b). “Croplands”, “cropland/Natural vegetation mosaic” and “mixed forest” of MODIS land cover classes compose “agricultural areas” and “forest and semi natural areas” of CORINE land cover classes (Figure 15 a). “Urban and built-up” of MODIS land cover classes is grouped as “artificial areas” in the CORINE land cover classification. “Agricultural areas” and “forest and semi-natural areas” and “artificial areas” cover around 95.8% of the areas in

Schleswig-Holstein. Simultaneously, the areas of CORINE land cover among 1990, 2000, 2006 and 2012 are not changed much based on CORINE classification level 1 mentioned above, which indicates that the areas of the main MODIS land cover class areas. Consequently, the annual total GPP and NPP data for the years 2000, 2006 and 2012, and monthly GPP are used for analyzing the annual total GPP and NPP distributions, and monthly distributions in the CORINE land cover classes (Level 3) in my study. The aim of studying GPP and NPP distributions in the CORINE land cover classes level 3 is to clarify whether and how the detailed classification, such as CORINE land cover classes level 3, affect GPP and NPP distributions.

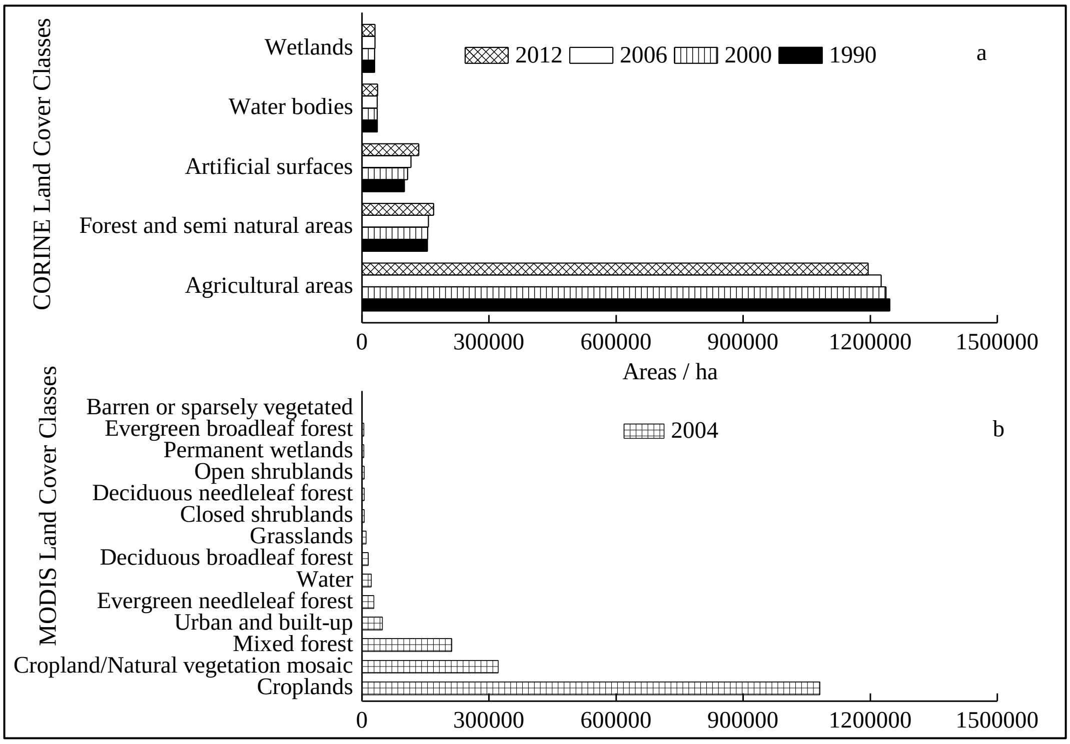

Figure 15. Comparison of CORINE land cover distributions (a) and MODIS land cover distributions (b) in Schleswig-Holstein.

3.1.3.1 Gross primary production

The indicator 'GPP denotes the total amount of carbon fixed in the process of photosynthesis by plants in an ecosystem' (IPCC, 2000, page 10). Results on the distribution of GPP have been calculated in this study at the scales of the whole Schleswig-Holstein, landscape regions and districts, and the methods used for calculating are presented in sub-chapter 2.2.2.3.

(1) GPP of Schleswig-Holstein in 2000, 2006 and 2012

GPP can be considered as a focal factor which shows the ability of ecosystems for carbon storage (Haines-Young, Roy; Potschin, 2010). It is closely associated with species vegetation in the different land cover classes (Verchot *et al.*, 2006). The annual total GPP of Schleswig-Holstein for the years 2000, 2006 and 2012 is estimated with the solution of 1km × 1km in Figure 16. The annual total GPP for these three years is presented within six classes. The annual total GPP in 2000 has a larger amount compared to the annual total

GPP in 2012 and in 2006. 2006 is the year which had the smallest annual total GPP in these three years. The annual total GPP fluctuates during 2000, 2006 and 2012. The pixels with the high annual total GPP are mainly on the land cover classes of “pastures” and “coniferous forest”, which principally locate in Marsch. The red pixels indicate areas with low annual total GPP, which primarily locate in “beaches, dunes and sands” and “intertidal falts”, being parts of Geest and Hügelland.

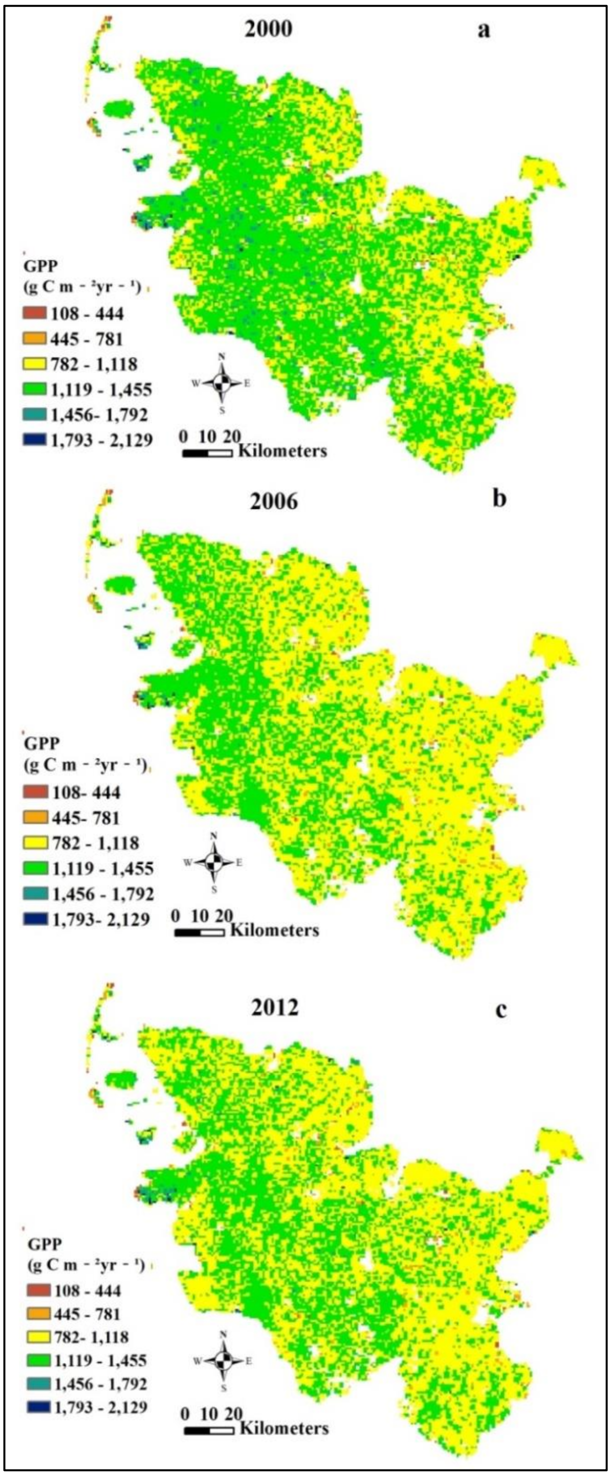

Figure 16. Annual total Gross Primary Production (GPP) of Schleswig-Holstein for the years 2000 (a), 2006 (b), 2012 (c).

⑵ *GPP based on land cover classes in 2000, 2006 and 2012*

The annual total GPP presents carbon stored within a certain spatial and temporal unit (g C m^{-2} yr^{-1}), while the annual total stored GPP shows carbon stored in a certain temporal unit (Mg C yr^{-1}) due to reflecting spatial areas. The annual total GPP and the annual total stored GPP of Schleswig-Holstein for the years 2000, 2006 and 2012 are shown in Figure 17. The land cover class which has the largest annual total GPP is “coniferous forest” in 2000, followed by “pastures”, “peat bogs’, “mixed forest” and “broad-leaved forest”. The land cover classes which have the largest annual total GPP in 2006 are the same ones as in 2000. However, the amounts of the annual total GPP of the five land cover classes in 2006 are less than those in 2000. “Coniferous forest”, “mixed forest”, “pastures”, “broad-leaved forest” and “complex cultivation patterns” constitute the land cover classes having the largest annual total GPP in 2012.

The annual total stored GPP for the years 2000, 2006 and 2012 has been calculated as 17518.48 Mg C yr^{-1}, 16211.26 Mg C yr^{-1} and 16374.11 Mg C yr^{-1}. “Non-irrigated arable land”, “pastures”, “complex cultivation patterns”, and “broad-leaved forest” are the land cover classes that have the large amounts of the annual total GPP among the 17 land cover classes for the years 2000 and 2006. “Coniferous forest” replaces “complex cultivation patterns” as one of the top five land cover classes containing large amounts of annual total stored GPP in 2012.

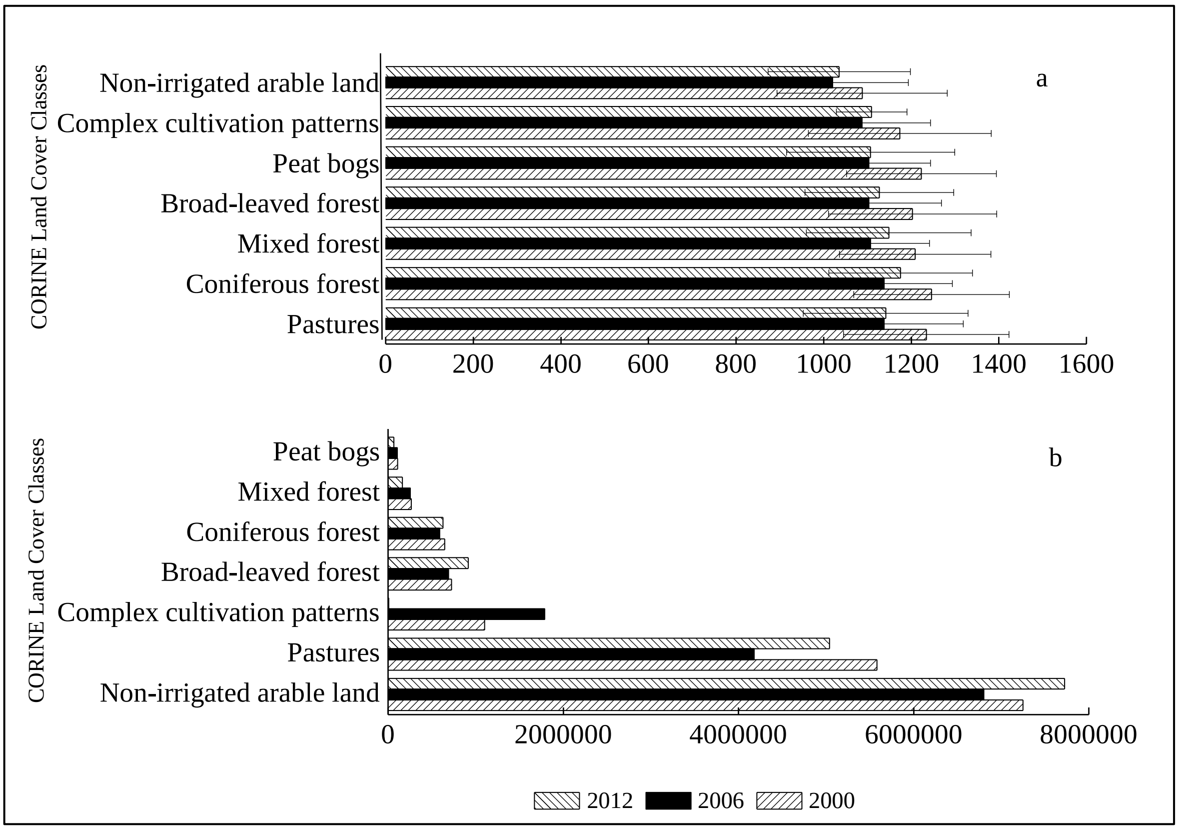

Figure 17. Annual total GPP（g C m^{-2} yr^{-1}）(a) and stored GPP（Mg C yr^{-1}）(b) based on chosen land cover classes of Schleswig-Holstein for the years 2000, 2006 and 2012. The annual total GPP and stored GPP based on 17 land cover classes of Schleswig-Holstein for the years 2000, 2006 and 2012 can be found in Appendix C Figure 5 and Figure 6.

Two potential factors which may influence the annual total stored GPP are the annual total GPP and the land cover areas. Table 26 shows the correlations among these three factors, the annual total stored GPP is significantly affected by the annual total GPP and the land cover areas. The influence from the land cover area reaches to 1.00, meaning that the land cover area has the most important effect to the annual total stored GPP. The annual total GPP and the annual total stored GPP are distinct from one land cover to another. The distributions of the annual total GPP and the annual total stored GPP in different years are various as well.

Table 26. Correlations among annual total GPP (g C m^{-2} yr^{-1}), land cover areas (ha) and annual total stored GPP based on land cover (Mg C yr^{-1}).

	GPP	Land Cover Area	Stored GPP Based on Land Cover
GPP	1.00	0.24*	0.26*
Land Cover Area		1.00	1.00**
Stored GPP Based on Land Cover			1.00

*Correlation is significant at the 0.05 level, **Correlation is significant at the 0.01 level.

(3) GPP based on landscape regions in 2000, 2006 and 2012

Table 27. Annual total GPP and stored GPP based on landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012.

Landscape regions	GPP (g C m^{-2} yr^{-1})						Stored GPP (Mg C yr^{-1})		
	2000		2006		2012		2000	2006	2012
	Mean	STD	Mean	STD	Mean	STD			
Geest	1001.40	282.97	984.57	251.24	1057.88	258.05	7170441	6458067	7013307
Marsch	1120.73	280.32	1068.63	260.90	1068.21	265.94	2562424	2466619	2593825
Hügelland	758.46	248.74	832.10	222.82	827.37	232.50	6621647	6149528	6517420

Table 27 shows the annual total GPP and the annual stored GPP based on the landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012. The annual total GPP in the three landscape regions in 2000 is relative high, and then decreases in 2006, afterwards increases again in 2012. The annual total GPP of the region Marsch exceeds the annual total GPP of the regions Geest and Hügelland, while the region Hügelland shows the lowest annual total GPP in the years 2000, 2006 and 2012. Marsch and Hügelland are the regions with the highest and lowest annual total GPP. Trends of the annual total stored GPP are different from the trends of the annual total GPP for the years 2000, 2006 and 2012. Geest has the highest value of the annual total stored GPP, and Marsch has the lowest value of the annual total stored GPP for this three years. The landscape regions of Geest, Marsch and Hügelland have distinct abilities to store the annual total GPP.

The results of the annual total GPP based on land cover of landscape regions (Table 28) shows that “broad-leaved forest”, “coniferous forest”, “mixed forest”, “pastures” and “fruit trees and berry plantations” are the land cover classes having exceeding high annual total GPP values in Geest for the years 2000, 2006 and 2012. Nevertheless, the land cover classes with the high annual total GPP in Marsch in 2000 and 2006 are partially different from the land cover classes in 2012. “Sparsely vegetated areas”, “inland marshes”, “broad-leaved forest”, “coniferous forest” and “mixed forest” have higher annual total GPP values than the other land cover classes for the years 2000 and 2006. In 2012, “broad-leaved forest”, “coniferous forest”, “mixed forest”, “natural grassland” and “complex cultivation patterns” are the land cover classes fixing much the annual total GPP. Similarly to Geest, the land cover classes in Hügelland that contain the high annual total GPP are “broad-leaved forest”, “coniferous forest”, “mixed forest”, “pastures” and “peat bogs” in 2000. “Peat bogs”, “coniferous forest”, “inland marshes”, “broad-leaved forest”, “mixed forest” and “pastures” are the land cover classes containing higher annual total GPP than the other land cover classes in 2006. The annual total GPP in “coniferous forest”, “mixed forest”, “peat bogs” is larger than the annual total GPP in the other land cover classes.

Table 28. Annual total GPP (g C m^{-2}) based on land cover classes within landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover Classes	2000			2006			2012		
	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland
Non-irrigated arable land	1120.93	1128.84	1068.27	1022.96	1103.28	1002.61	1168.38	1176.09	1073.08
Fruit trees and berry plantations	1264.60	1220.93	1142.85	1060.10	1043.63	986.57	1251.60	1238.85	1174.50
Pastures	1241.52	1263.79	1168.48	1130.27	1220.06	1070.67	1232.55	1262.31	1152.18
Complex cultivation patterns	1178.35	1202.59	1153.97	1084.19	1174.85	1061.06	1218.41	1267.38	1173.50
Land principally occupied by agriculture	1203.67	1283.16	1118.83	1075.26	1118.49	1032.63	1138.85	1242.10	1129.74
Broad-leaved forest	1244.75	1364.73	1172.95	1127.21	1207.49	1084.61	1248.61	1352.07	1169.27
Coniferous forest	1257.30	1354.30	1217.08	1150.03	1201.20	1103.47	1246.88	1342.35	1226.49
Mixed forest	1241.16	1310.24	1169.59	1113.90	1113.59	1083.71	1250.35	1302.65	1224.29
Natural grasslands	1139.22	1157.67	1073.95	1043.59	1061.26	998.85	1233.83	1249.18	1059.97
Moors and heathland	924.34	1129.10	0.00	892.43	1026.40	0.00	914.26	1099.30	0.00
Transitional woodland-shrub	1201.53	1156.98	1115.70	1107.61	1060.40	1060.15	1110.91	1070.33	960.06
Beaches, dunes, sands	364.20	498.63	464.20	316.28	472.35	424.53	323.26	485.62	447.60
Sparsely vegetated areas	859.88	990.20	808.33	743.20	887.90	710.11	905.36	0.00	0.00
Inland marshes	982.12	1311.33	1092.53	891.53	1223.81	1090.24	907.59	1110.73	1061.34
Peat bogs	1151.70	1227.85	1191.68	1107.43	1160.54	1136.50	1141.32	1235.50	1213.29
Salt marshes	990.32	1112.24	0.00	894.84	1046.46	0.00	986.19	1105.14	0.00
Intertidal flats	663.65	679.52	0.00	626.79	665.05	0.00	605.52	620.03	0.00
Average	1001.40	1120.73	758.46	984.57	1068.63	832.10	1057.88	1068.21	827.37

The correlation analysis among the annual total stored GPP, the land cover areas and the annual total GPP illustrates that land cover area has the most important effect to the annual total stored GPP. The annual total stored GPP based on land cover classes of landscape regions (Table 29) confirms the importance of the land cover classes on the annual total GPP storing again. “Pasture” and “non-irrigated arable land” have the highest annual total stored GPP due to the wide distribution in Geest, Marsch or Hügelland. The land cover classes which have the lowest annual total stored GPP are the ones occupying the least areas in Geest, Marsch or Hügelland.

Table 29. Annual total stored GPP (Mg C yr^{-1}) based on land cover classes within landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover Classes	2000			2006			2012		
	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland
Non-irrigated arable land	184722	1124652	4294739	176496	1124272	3927696	280575	1281142	4259516
Fruit trees and berry plantations	319	2337	489	276	1997	747	392	1775	817
Pastures	357629	1089909	910706	246976	935567	770844	307915	1070210	1230358
Complex cultivation patterns	597336	107601	394779	1144641	179187	461039	4408	2593	2066
Land principally occupied by agriculture	146264	5462	130729	143955	4906	142863	35400	558	37669
Broad-leaved forest	204872	7986	507235	188238	7388	489577	286460	13286	670250
Coniferous forest	467537	820	177221	428581	727	159242	485593	2408	172593
Mixed forest	123497	49	140953	119292	41	131666	109477	692	67247
Natural grasslands	26630	61274	18999	21061	55151	19122	52382	24236	35330
Moors and heathland	27967	344	0	26631	313	0	40270	797	0
Transitional woodland-shrub	16094	3515	5521	14662	3178	6174	22435	2777	15890
Beaches, dunes, sands	7066	12996	494	6136	11270	452	3411	3879	797
Sparsely vegetated areas	9032	1387	1054	7807	1243	926	259	0	0
Inland marshes	6988	16263	25735	6806	15735	26498	3755	36761	10670
Peat bogs	89570	1240	12719	91901	1210	12290	57991	4567	14218
Salt marshes	7194	86198	0	6446	83868	0	14706	113425	0
Intertidal flats	14037	39831	0	13231	40032	0	11419	34717	0
Total	717044	2562424	6621647	645806	2466619	6149528	701330	2593825	6517420

(4) GPP based on districts in 2000, 2006 and 2012

The classifying of districts influences the annual total GPP and the annual Stored GPP even though it connects with artificial effects. The annual total GPP and the annual stored GPP are presented in Figure18. Steinburg, Dithmarschen, Nordfriesland and Rendsburg-Eckernförde are the districts which have the largest annual total GPP compared to the other districts of Schleswig-Holstein. Meanwhile, the annual total GPP of Lübeck, Neumünster, Flensburg and Kiel are less than the annual total GPP of the other districts. The lowest annual total GPP of the 15 districts (Kiel in 2000, Neumünster in 2006, Neumünster in 2012) only reach to 59.21%, 57.80% and 61.00% of the highest annual total GPP of the 15 districts (Steinburg in 2000, Nordfriesland in 2006, Steinburg in 2012) for the years 2000, 2006 and 2012.

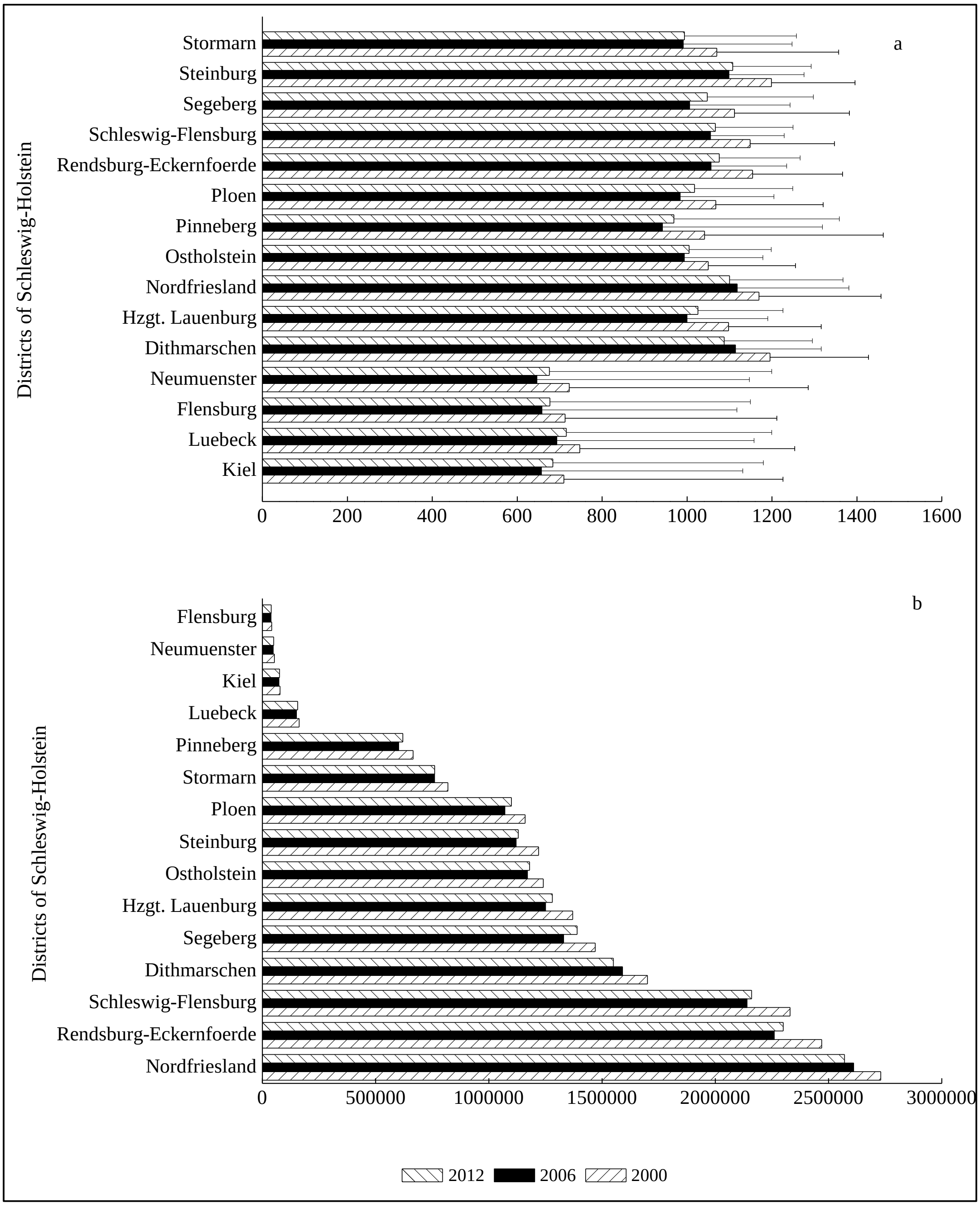

Figure 18. Annual total GPP（g C m^{-2} yr^{-1}）(a) and stored GPP（Mg C yr^{-1}）(b) based on districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

The Figure 18 b shows that the annual total stored GPP of districts which have the largest amounts are Nordfriesland, Rendsburg-Eckernförde, Schleswig-Flensburg, and Dithmarschen. The annual total stored GPP of the districts mentioned above have similar amounts in 2006 and 2012, which are less than the annual total stored GPP in 2000. Lübeck, Kiel, Neumünster and Flensburg are the districts which have the lower annual total stored GPP. The annual total stored GPP in Flensburg which holds the least, reaches only 1.5% of the district (Nordfriesland) having the most annual total stored GPP.

The Annual total GPP based on land cover classes of the districts (Table 30) shows that the districts are quite similar. However, the annual total GPP of Kiel, Lübeck, Flensburg and Neumünster in the different land cover classes are less than the annual total GPP of the other districts. The distances are averagely 21.26 g C m^{-2} yr^{-1} between the districts having the highest annual total GPP and the districts holding the lowest annual total GPP. “Broad-leaved forest”, “coniferous forest”, “mixed forest”, “pastures”, “non-irrigated arable land” and “complex cultivation patterns” have the high annual total GPP in each district. However, Kiel, Lübeck, Flensburg and Neumünster have less annual total GPP than the other land cover classes in “broad-leaved forest”, “coniferous forest”, “mixed forest” “natural grasslands” and “pastures”. The annual total GPP in “moors and heathland”, “transitional woodland-shrub”, “inland marshes” and “peat bogs” are also high even though not all the districts have the land cover classes due to the landscape conditions.

The annual total stored GPP determined mainly by the areas of land cover. Table 31 shows the annual total stored GPP of each district in the 17 land cover classes. “Non-irrigated arable land” is the land cover containing the most annual total GPP compared to the other land cover classes in the districts of Kiel, Lübeck, Neumünster, Hzgt. Lauenburg, Plön, Rendsburg-Eckernförde, Schleswig-Flensburg, Segeberg and Stormarn. At the same time, “pastures” in Flensburg, Dithmarschen, Nordfriesland, Pinneberg and Steinburg have a higher annual total GPP than the other land cover classes. “Broad-leaved forest” is the prime land cover contributing to the annual total stored GPP in Ostholstein.

Table 30. Annual total GPP based on land cover classes within the districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	GPP of districts (g C m^{-2} yr^{-1})														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Non-irrigated arable land	2000	1136.97	1166.11	1166.59	1137.52	1139.36	1155.90	1156.98	1175.61	1154.43	1142.70	1147.27	1111.30	1122.37	1113.00	1106.88
	2006	1051.63	1072.47	1046.44	1064.89	1051.33	1063.92	1059.35	1036.40	1047.05	1042.88	1043.64	1024.56	1058.41	1013.82	1031.93
	2012	1087.63	1078.53	1099.41	1081.83	1095.55	1075.55	1060.36	1056.31	1053.25	1058.55	1067.79	1049.10	1072.24	1054.24	1050.65
Fruit trees and berry plantations	2000	0.00	0.00	0.00	1122.75	1120.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	0.00	1000.50	1020.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	1060.10	1043.63	0.00	0.00	0.00	0.00	1053.20	0.00	0.00	0.00	0.00	0.00
Pastures	2000	1272.01	1254.36	1265.68	1265.38	1274.80	1269.43	1272.75	1282.30	1277.50	1256.71	1267.42	1251.95	1254.77	1250.48	1267.47
	2006	1163.15	1142.83	1168.64	1165.17	1157.27	1155.71	1116.61	1124.14	1128.46	1140.45	1144.60	1116.52	1115.46	1119.69	1112.96
	2012	1179.78	1178.97	1190.59	1177.57	1176.82	1177.66	1171.81	1180.83	1179.98	1167.54	1173.86	1154.29	1157.22	1144.31	1140.40
Complex cultivation patterns	2000	1137.19	1144.36	1137.75	1141.56	1145.65	1140.15	1149.65	1142.21	1141.90	1150.51	1152.19	1141.35	1138.80	1134.05	1121.70
	2006	1041.10	1045.26	1060.83	1070.03	1074.66	1057.29	1045.39	1046.97	1034.76	1046.29	1052.76	1032.87	1036.20	1015.25	1027.82
	2012	1072.60	0.00	1178.60	0.00	1070.47	1070.20	1084.50	1063.07	1064.11	1070.27	0.00	0.00	0.00	0.00	0.00
Land principally occupied by agriculture	2000	1185.71	1188.25	1106.74	1146.70	1195.22	1154.81	1188.12	1197.68	1190.42	1113.69	1161.47	1137.42	1131.61	0.00	0.00
	2006	1045.70	1023.59	1025.22	1013.18	1004.11	1004.00	1016.23	1001.02	1019.28	1015.93	973.61	988.36	994.20	0.00	0.00
	2012	1068.40	1071.36	1031.39	1013.88	1039.16	1022.47	1055.16	1030.56	1069.15	1016.55	1048.62	0.00	1015.63	0.00	1048.30
Broad-leaved forest	2000	1205.90	1221.37	1251.45	1253.48	1237.22	1271.43	1230.11	1220.54	1208.97	1208.09	1207.92	1197.72	1196.44	1191.05	0.00
	2006	1064.84	995.54	1083.11	1085.88	1035.14	1070.59	1045.22	1028.53	1026.44	1028.24	1039.29	1016.90	1011.24	1018.07	0.00
	2012	1139.86	1138.36	1140.25	1133.23	1136.60	1127.39	1127.82	1123.05	1133.82	1131.01	1140.50	1125.53	1121.19	1124.13	1115.90
Coniferous forest	2000	1219.47	1233.07	1248.88	1231.35	1223.39	1238.01	1222.02	1247.97	1226.50	1239.02	1243.73	0.00	1209.55	1205.65	1208.65
	2006	1166.41	1108.87	1142.47	1114.72	1157.80	1114.46	1125.14	1128.37	1134.02	1149.28	1150.69	0.00	1127.99	1103.30	1112.90
	2012	1181.90	1191.79	1195.81	1164.56	1173.34	1166.61	1187.45	1193.58	1181.24	1197.00	1191.17	0.00	1171.22	1176.33	1710.10
Mixed forest	2000	1203.41	1200.80	1238.94	1214.44	1196.10	1244.80	1236.60	1230.70	1220.05	1234.18	1238.59	0.00	1222.98	1189.75	1212.63
	2006	1070.74	966.08	1076.63	1054.80	1071.45	1059.09	1066.08	1059.16	1062.50	1052.81	1051.99	0.00	1049.82	1055.30	1052.67
	2012	1163.52	1165.92	1138.63	1179.73	1159.62	1172.98	1149.16	1152.58	1152.94	1155.37	1140.79	1143.55	1147.58	0.00	1138.40
Natural grasslands	2000	1120.71	0.00	1151.31	1112.70	1114.88	1112.73	1129.86	1139.72	1156.33	1124.30	1137.50	0.00	0.00	1069.87	0.00
	2006	1022.29	0.00	1026.12	1039.44	1042.00	991.00	1041.90	1038.67	1041.60	1033.00	1021.80	0.00	0.00	983.17	0.00
	2012	1054.84	1064.97	1061.58	1062.98	1051.22	1075.90	1061.07	1060.55	1095.84	1082.19	0.00	0.00	1025.68	0.00	0.00

Table 30. Annual total GPP based on land cover classes within the districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	GPP of districts (g C m^{-2} yr^{-1})														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Moors and heathland	2000	0.00	0.00	935.75	0.00	952.80	0.00	933.40	920.40	931.30	949.90	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	868.37	0.00	861.02	0.00	864.60	853.50	869.40	861.60	0.00	0.00	0.00	0.00	0.00
	2012	0.00	903.50	917.97	902.30	0.00	902.40	919.75	0.00	915.40	911.20	0.00	0.00	905.69	0.00	0.00
Transitional woodland-shrub	2000	1198.72	0.00	1210.25	1206.50	1184.48	0.00	1209.50	1200.28	1222.70	1233.45	1216.25	0.00	0.00	0.00	0.00
	2006	1091.68	1069.78	1093.82	1082.55	1098.30	0.00	1111.15	1076.86	1015.18	1073.62	1089.50	0.00	0.00	0.00	0.00
	2012	1142.10	1137.50	1154.48	1124.18	1113.87	1121.60	1146.30	1142.56	1129.38	1131.64	1120.03	1115.00	1100.79	1106.20	0.00
Beaches, dunes, sands	2000	0.00	0.00	632.95	634.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	504.69	500.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	417.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	389.24	391.24	0.00	0.00
Sparsely vegetated areas	2000	0.00	0.00	906.20	918.33	0.00	0.00	825.70	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	778.42	884.53	0.00	0.00	832.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	894.51	0.00	0.00	0.00	0.00	0.00
Inland marshes	2000	1125.60	1166.80	1145.36	1110.31	0.00	1148.12	1139.36	1155.20	0.00	1167.15	1177.40	1109.87	1078.70	0.00	0.00
	2006	1112.66	1149.98	1075.65	1021.95	0.00	991.41	1028.07	1066.60	0.00	1032.70	1051.70	1009.37	1019.00	0.00	0.00
	2012	1161.30	0.00	1110.38	1089.10	1078.90	1072.41	1108.31	1100.00	0.00	1112.61	1111.20	1065.90	0.00	0.00	0.00
Peat bogs	2000	1203.35	0.00	1232.67	0.00	1219.03	1234.80	1214.35	1202.12	1223.13	1227.19	1229.70	0.00	0.00	0.00	1198.30
	2006	1079.17	0.00	1076.65	0.00	1013.26	1020.60	1015.86	1035.34	1024.62	1103.48	1116.55	0.00	0.00	0.00	1023.42
	2012	1104.45	1082.25	1092.40	1080.08	1111.53	1111.85	1056.36	1057.33	1073.81	1060.10	1094.10	0.00	0.00	0.00	1038.60
Salt marshes	2000	1168.50	0.00	1172.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	1128.43	0.00	1135.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	1075.02	0.00	1080.54	0.00	0.00	0.00	0.00	0.00	0.00	1038.80	0.00	0.00	0.00	0.00	0.00
Intertidal flats	2000	573.78	0.00	607.76	0.00	599.65	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	532.21	0.00	575.67	0.00	560.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	558.62	0.00	591.80	0.00	0.00	0.00	0.00	0.00	0.00	595.55	0.00	0.00	0.00	0.00	0.00

Table 31. Annual total stored GPP based on land cover classes within the districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	Stored GPP of districts (Mg C yr^{-1})														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Non-irrigated arable land	2000	579582	792628	684217	1092019	184098	669416	960027	954619	729427	372634	537186	23726	80777	10774	17909
	2006	563127	707755	811682	826025	161968	609828	904346	895761	632355	331240	459139	21690	66542	8486	15964
	2012	696366	658809	889027	995230	228893	676317	1081313	1213204	652583	382772	425771	18747	48594	9204	16233
Fruit trees and berry plantations	2000	0	0	0	483	2432	0	0	0	0	0	0	0	0	0	0
	2006	0	0	0	760	1949	0	0	0	0	0	0	0	0	0	0
	2012	0	0	0	742	1231	0	0	0	0	600	0	0	0	0	0
Pastures	2000	769693	103623	1264680	107026	284280	143750	901514	975510	393010	615499	121533	12995	23841	12242	16591
	2006	605571	98283	849999	102512	232762	127128	633252	564768	314931	507033	107879	10886	27518	6002	12888
	2012	655332	183353	1039314	175587	297618	211779	750451	673675	393358	552025	178251	17326	39681	12885	18132
Complex cultivation patterns	2000	100061	32774	147953	41781	103762	145084	167734	199042	69782	31317	17421	5821	1173	2699	5934
	2006	148024	36919	376138	56701	118202	136866	254845	376721	95912	77823	30151	4937	1067	6457	6999
	2012	1062	0	377	0	1381	621	607	808	1213	1381	0	0	0	0	0
Land principally occupied by agriculture	2000	10932	33164	8610	22808	27490	18592	52551	28193	28177	24546	20314	2832	5941	0	0
	2006	9579	31383	8684	22239	27824	19006	50273	26887	27765	23559	24691	2886	4673	0	0
	2012	1538	11196	2434	5262	5092	5583	10246	6410	6265	5652	3597	0	2153	0	1698
Broad-leaved forest	2000	12541	182558	13428	111510	21874	95027	111485	44928	38264	21927	62836	5126	18928	1834	0
	2006	11713	149719	11903	102170	17183	81322	96244	43394	36613	19855	55696	4352	16453	2107	0
	2012	20005	199862	21995	127205	21959	110665	154861	69404	59514	27110	72992	6618	27962	2541	1529
Coniferous forest	2000	25950	151532	54589	11833	21630	9025	70022	42631	159568	49239	27797	0	12616	989	834
	2006	24028	135615	49492	10712	20273	8124	65033	38635	148908	45155	25821	0	11709	905	768
	2012	28732	138605	50487	9363	23924	9566	74227	44700	165858	50992	25134	0	8550	1306	906
Mixed forest	2000	10458	54516	5129	9983	2428	24933	77658	28688	19008	19648	10070	0	3461	999	2583
	2006	9305	45348	5125	8976	2175	21330	68410	23556	20559	18277	8679	0	3611	623	2242
	2012	5887	47313	4110	6477	3734	4211	27683	10869	14735	19595	17283	286	2272	0	1218
Natural grasslands	2000	34865	0	28564	11238	2943	2159	8090	8388	4452	922	2070	0	0	2546	0
	2006	30965	0	24740	10498	2751	1923	6616	9088	2948	847	1860	0	0	1593	0
	2012	17215	2354	19767	10513	1903	1614	18346	12037	6213	6688	0	0	3354	0	0

Table 31. Annual total stored GPP based on land cover classes within the districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	Stored GPP of districts (Mg C yr^{-1})														
		Dithmarschen	Hzgt. Lauenburg	Nordfriesland	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neumünster
Moors and heathland	**2000**	0	0	23927	0	1324	0	373	1519	689	779	0	0	0	0	0
	2006	0	0	21848	0	1197	0	346	1408	643	707	0	0	0	0	0
	2012	0	136	38252	379	0	108	855	0	320	465	0	0	562	0	0
Transitional woodland-shrub	**2000**	1247	0	5083	1472	237	0	2419	5653	1406	7117	1253	0	0	0	0
	2006	1135	1391	4430	996	373	0	4378	5072	1543	4434	1122	0	0	0	0
	2012	2284	1729	3706	2698	2083	729	12105	5107	3117	3191	3875	624	1849	1504	0
Beaches, dunes, sands	**2000**	0	0	28774	583	0	0	0	0	0	0	0	0	0	0	0
	2006	0	0	21833	365	0	0	0	0	0	0	0	0	0	0	0
	2012	0	0	7739	0	0	0	0	0	0	0	0	27	43	0	0
Sparsely vegetated areas	**2000**	0	0	10893	670	0	0	289	0	0	0	0	0	0	0	0
	2006	0	0	10559	5254	0	0	291	0	0	0	0	0	0	0	0
	2012	0	0	0	0	0	0	0	0	0	259	0	0	0	0	0
Inland marshes	**2000**	2915	1365	21315	10903	0	5396	4763	1640	0	1564	542	1210	1629	0	0
	2006	3216	2081	20201	6070	0	4660	4297	1472	0	1683	536	1100	1539	0	0
	2012	13448	0	24062	1514	2719	3571	3125	2508	0	356	422	1013	0	0	0
Peat bogs	**2000**	20204	0	10663	0	1950	790	32047	20941	10861	5743	2312	0	0	0	3032
	2006	18206	0	9345	0	2746	653	26951	20065	10820	5363	2322	0	0	0	2589
	2012	12988	790	4938	3024	2634	967	13807	18355	6421	5014	1028	0	0	0	1142
Salt marshes	**2000**	23802	0	75468	0	0	0	0	0	0	0	0	0	0	0	0
	2006	22625	0	76445	0	0	0	0	0	0	0	0	0	0	0	0
	2012	27058	0	99042	0	0	0	0	0	0	738	0	0	0	0	0
Intertidal flats	**2000**	5250	0	42871	0	48	0	0	0	0	0	0	0	0	0	0
	2006	4870	0	41494	0	45	0	0	0	0	0	0	0	0	0	0
	2012	4586	0	39307	0	0	0	0	0	0	191	0	0	0	0	0

(5) *Monthly GPP in 2006*

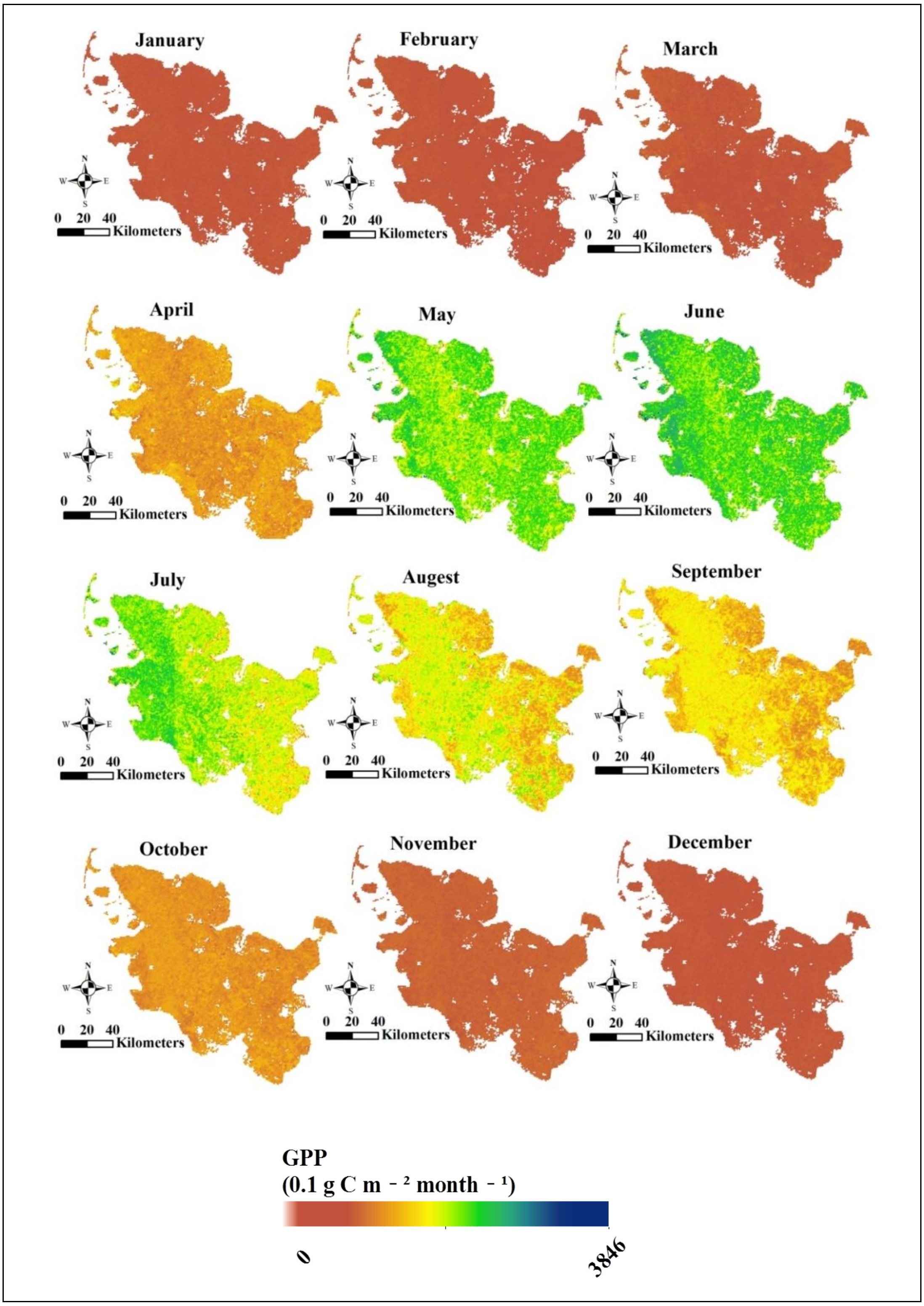

Figure 19. Monthly GPP of Schleswig-Holstein in 2006.

The monthly GPP clarifies the fluctuation of GPP following month-transformation. In addition, data sources of the monthly GPP in 2006 have the high quality. The monthly GPP distributions are analyzed in this part.

The monthly GPP distributions of Schleswig-Holstein in 2006 are illustrated in Figure19. The results show that the largest monthly GPP occur between May and September in 2006. The temporal GPP patterns vary greatly on the regional basis because of the various land cover classes. The monthly GPP of the regions in the western and eastern parts of Schleswig-Holstein are higher than the monthly GPP in the middle part during May and June. Meanwhile, from July to September, the regions in the middle have stronger abilities of fixing solar energy than the regions in the west and east. From November to March is the period while rare energy is absorbed from atmosphere. Differences of monthly GPP are obvious among the 12 month in 2006.

(6) Monthly GPP based on landscapes in 2006

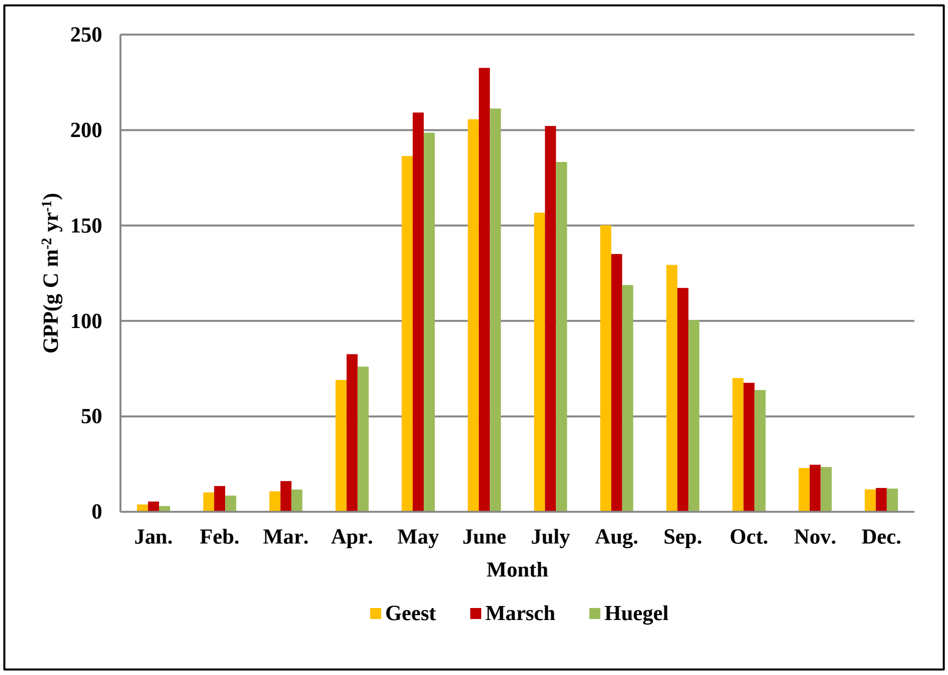

Figure 20. Monthly GPP in landscape regions (Geest, Marsch and Hügelland) of Schleswig-Holstein in 2006.

The fixation of CO_2 fluctuates monthly in the different landscape types of Schleswig-Holstein in 2006 (Figure 20). June is the month which has the highest GPP, followed by May, July, August, September, April, October, and November. The GPP values in December, February and March are similar to each other. January has the lowest GPP during the 12 months. The vegetation in Marsch absorbs the most CO_2 from March to July and from November to December. The vegetation of Geest absorbs the least GPP for the same periods as the vegetation on Marsch does. Geest takes the first place and Hügelland plays the third role on GPP from August to October. The vegetation on Marsch accounts more on GPP absorbing compared to the vegetation on Geest and on Hügelland for the months January and February.

(7) Monthly GPP based on districts in 2006

The monthly GPP based on districts in 2006 is shown in Figure 19 and Table 32. Vegetation assimilates more energy in June than in May, July, August and September in the 15 districts. Dithmarschen is the district fixing the most CO_2 in June, July, August and January. Nordfriesland is the one the most GPP in February, March and September. The highest monthly GPP in April, May, November and December appears in the district of Ostholstein. Steinburg has the highest ability of assimilating energy in October compared to other districts.

The annual total GPP, and the annual total stored GPP based on land cover, landscape regions and districts of Schleswig-Holstein for the years 2000, 2006 and 2012 have been shown in sub-section 3.1.3.1. The different land cover classes, landscape regions or districts have distinct abilities of storing the annual total GPP and the annual total stored GPP. Furthermore, the annual total GPP has strong relationships with the area of each land cover. The monthly GPP fluctuates from one month to another and the differences of monthly GPP among landscape regions and districts mainly result from vegetation species on the regions and districts. Estimating GPP makes it possible to denote the materials and energy absorbed by vegetation.

Table 32. Monthly GPP in the districts of Schleswig-Holstein in 2006.

Month	Monthly GPP (g C m^{-2})														
	Kiel	Lübeck	Flensburg	Neumün-ster	Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg-Eckernförde	Schleswig-Flensburg	Segeberg	Steinburg	Stormarn
Jan.	1.66	1.84	1.85	2.45	5.36	2.50	5.24	2.79	2.25	2.92	4.03	3.61	3.29	4.56	2.80
Feb.	4.37	4.93	5.78	5.75	12.60	7.62	13.71	8.84	7.57	7.21	10.00	10.59	8.54	11.27	7.46
Mar.	5.86	7.66	7.84	6.62	11.45	10.56	17.24	14.08	9.32	11.13	10.48	12.91	9.28	11.20	10.04
Apr.	40.34	48.71	42.93	42.91	72.03	73.20	81.73	83.44	60.98	74.94	72.78	74.21	70.04	75.82	77.17
May	120.83	136.48	127.22	122.90	200.74	198.53	203.45	203.68	164.77	200.18	195.96	194.90	193.09	196.44	196.97
June	137.11	150.16	146.57	138.00	230.53	208.48	223.75	217.59	181.33	211.79	212.74	210.31	210.71	215.63	208.62
July	108.68	105.36	121.70	113.22	210.76	144.74	200.66	155.14	156.60	157.45	177.32	182.86	164.59	194.97	155.16
Aug.	95.33	101.09	99.35	97.32	144.53	130.21	141.20	104.96	136.35	117.07	144.88	139.41	136.26	155.49	124.97
Sep.	77.29	86.44	83.62	83.00	125.78	111.34	127.09	90.05	112.30	99.91	120.58	121.22	115.33	128.83	103.97
Oct.	40.79	51.23	45.26	45.54	69.16	71.31	70.36	61.56	62.21	61.98	68.57	67.03	68.03	71.45	67.10
Nov.	12.99	18.51	14.46	13.24	24.51	27.29	25.01	25.09	20.03	22.37	22.69	22.70	22.69	23.02	23.30
Dec.	6.78	9.73	7.39	6.87	12.44	13.95	12.69	13.22	10.18	11.71	11.70	11.60	11.76	11.76	12.01

3.1.3.2 Net primary production and respiration

NPP has been defined as ‘the reduction of GPP after autotrophic respiration’ (Zhang et al., 2009, page 280), which therefore means production of living organic matter by vegetation (IPCC, 2000). The distribution of NPP based on the three scales of the whole Schleswig-Holstein, landscape regions and districts are presented. Methods on the calculation and assessment techniques have been depicted in sub-chapter 2.2.2.3.

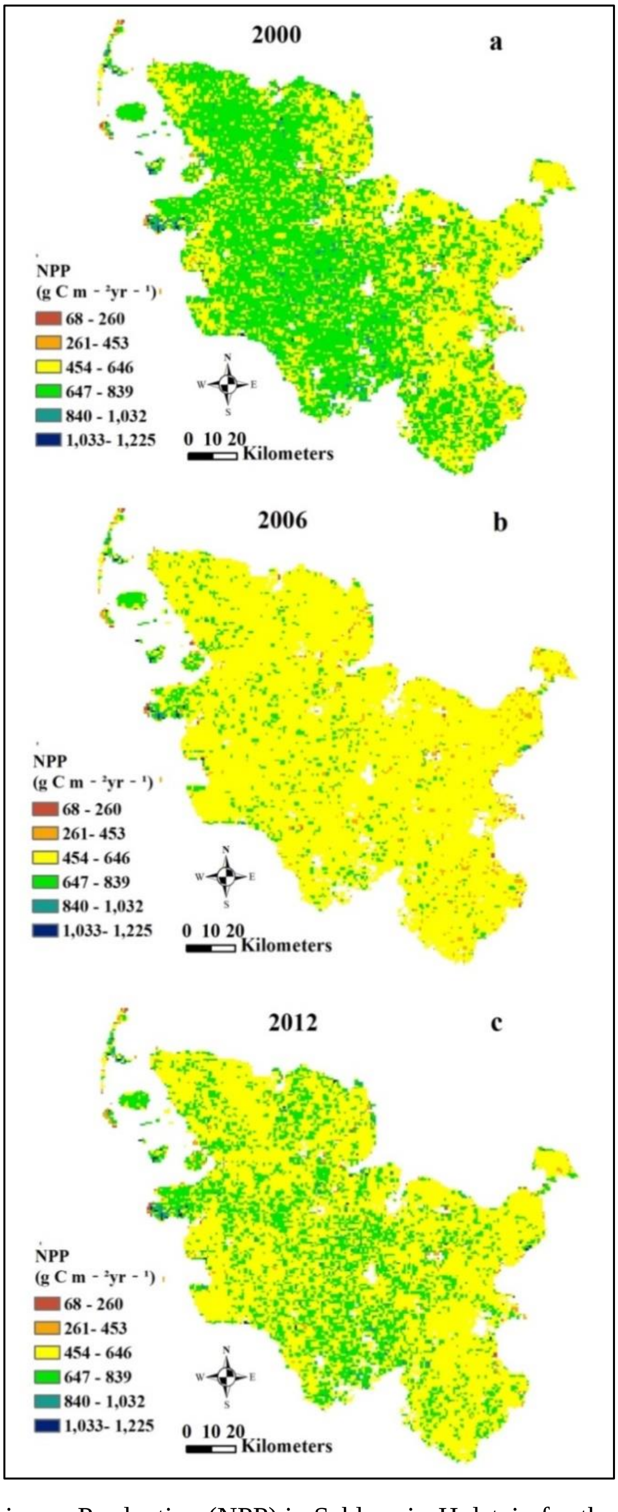

Figure 21. Annual total Net Primary Production (NPP) in Schleswig-Holstein for the years 2000 (a), 2006 (b), 2012 (c).

(1) NPP of Schleswig-Holstein in 2000, 2006 and 2012

The annual total NPP represents NPP stored in biomass within special unit in one year, and the annual total stored NPP are the amount of NPP in one land cover classes, one landscape region or district. The annual total NPP maps of Schleswig-Holstein in 2000, 2006 and 2012 are presented with the solution of 1km × 1km in Figure 21. Six classes have been distinguished for evaluating NPP for these three years in order to be comparable with the classes of the qualitative matrix method. The annual total NPP in 2000 is larger compared to the annual total NPP in 2012 and 2006. The annual total NPP in 2006 shows the smallest amount among the three years. The dark blue pixels represent high annual total NPP, locating in Marsch on “pastures” and in Geest “mixed forest”. The red pixels with the low annual total GPP are mainly on the land cover classes of “beaches, dunes and sands” and “intertidal falts”, which can be primarily found in Geest and Hügelland.

(2) NPP based on land cover classes in 2000, 2006 and 2012

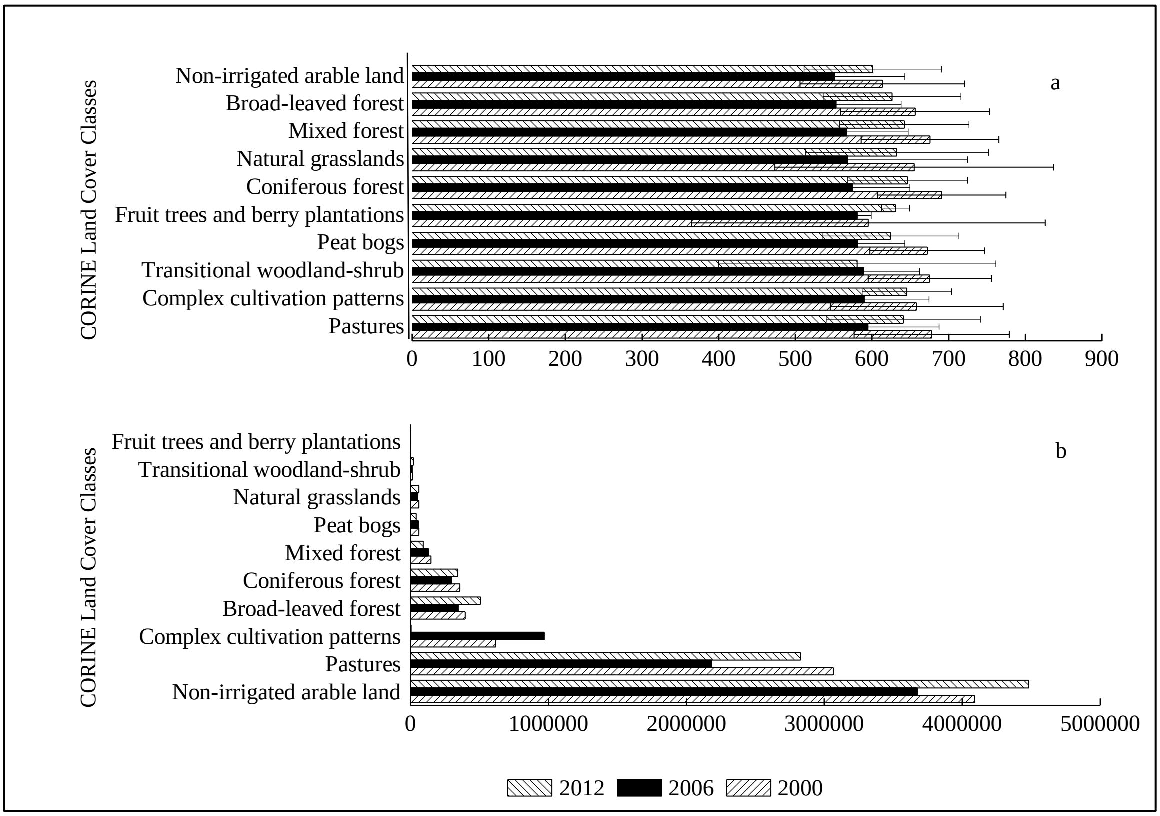

Figure 22. Annual total NPP (g C m^{-2} yr^{-1}) (a) and stored NPP (Mg C yr^{-1}) (b) based on chosen land cover classes of Schleswig-Holstein for the years 2000, 2006 and 2012. Annual total NPP and stored NPP based in all 17 land cover classes of Schleswig-Holstein for the years 2000, 2006 and 2012 can be found in the Appendix C Figure 7 and Figure 8.

The carbon stored in vegetation within a certain spatial and temporal unit is denoted by the annual total NPP. Figure 22 presents the annual total NPP and the annual total stored NPP of Schleswig-Holstein for the years 2000, 2006 and 2012. “Pastures”, “mixed forest”, “transitional woodland-shrub” and “peat bogs” have the largest annual total NPP in 2000. “Pastures”, “complex cultivation patterns”, “transitional woodland-shrub”, “peat bogs” and “fruit trees and berry plantations” and “coniferous forest” are the land cover classes having high capabilities to produce the annual total NPP in 2006. “Coniferous forest”, “complex cultivation patterns”, “mixed forest”, “pastures” and “natural grasslands”, constitute the land cover classes having large annual total

NPP in 2012.

The annual total stored NPP for the years 2000, 2006 and 2012 are 9814.92 Mg C yr-[1], 8667.40 Mg C yr^{-1} and 9394.52 Mg C yr^{-1}. Ratios of the annual total NPP to the annual total GPP for the years 2000, 2006 and 2012 are 0.56, 0.53 and 0.57. The land cover classes which have the largest amounts of the annual total NPP in the land cover classes are “non-irrigated arable land”, “pastures”, “complex cultivation patterns”, and “broad-leaved forest” for the years 2000 and 2006. “Coniferous forest” takes the position of “complex cultivation patterns” as one of the top five land cover classes containing large amounts of the annual Stored NPP in 2012.

The annual total NPP and the land cover areas are two important factors influencing the annual total stored NPP. The potential factors which might influence the annual total stored NPP are analyzed with correlation analysis. Table 33 presents the correlation among the factors. The result is that the annual total NPP and the land cover area significantly affect the annual total stored NPP. The influence from the land cover area is 1.00, which means the land cover area has the most important significance for the annual total stored NPP. The land cover classes lead to the distinctions of the annual total NPP and the annual total stored NPP, and the distributions of the annual total NPP and the annual total stored NPP in different years.

Table 33. Correlations among annual total NPP (g C m^{-2} yr^{-1}), land cover areas (ha) and annual total stored NPP based on land cover (Mg C yr^{-1}).

	NPP	Land Cover Area	Stored NPP Based on Land Cover
NPP	1.00	0.24*	0.25*
Land Cover Area		1.00	1.00**
Stored NPP Based on Land Cover			1.00

(3) NPP based on landscape regions in 2000, 2006 and 2012

Table 34. Annual total NPP and stored NPP based on the landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012.

Landscape regions	NPP (g C m^{-2} yr^{-1})						Stored NPP (Mg C yr^{-1})		
	2000		2006		2012		2000	2006	2012
	Mean	STD	Mean	STD	Mean	STD			
Geest	567.46	150.29	510.34	129.63	563.76	139.38	3979342	3299149	3637413
Marsch	624.29	150.26	558.87	131.39	565.58	142.39	1408918	1254264	1356095
Hügelland	432.16	137.80	437.01	118.59	446.12	129.92	3709724	3295894	3575808

Landscape regions influence the annual total NPP due to their effects on biotic and abiotic conditions of the study areas. Table 34 presents the annual total NPP and the annual total stored NPP based on the three landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012. The annual total NPP in Marsch and Hügelland are the highest and lowest annual total NPP for the years 2000, 2006 and 2012. Trends of the annual total stored NPP for 2000, 2006 and 2012 are different form the trends of the annual total NPP. Geest has the highest value of the annual total stored NPP, while Marsch has the lowest value for these three years.

Table 35. Annual total NPP (g C m^{-2} yr^{-1}) based on land cover classes within the landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover Class	2000			2006			2012		
	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland
Non-irrigated arable land	628.01	637.73	599.18	504.60	579.11	544.79	607.17	608.56	594.36
Fruit trees and berry plantations	665.58	687.64	601.50	541.45	591.16	503.61	630.92	635.87	621.50
Pastures	680.16	681.39	658.94	586.21	590.41	579.72	637.87	656.69	628.89
Complex cultivation patterns	656.08	665.90	644.55	568.72	613.28	563.09	626.09	644.97	598.15
Land principally occupied by agriculture	671.33	688.20	636.71	563.43	583.65	553.82	614.29	643.50	597.01
Broad-leaved forest	678.47	741.24	641.69	557.56	616.64	532.75	632.01	702.09	619.68
Coniferous forest	697.09	708.48	670.30	575.99	658.53	555.70	648.16	672.63	642.07
Mixed forest	689.17	689.60	660.02	574.29	586.10	563.67	642.92	660.76	630.91
Natural grasslands	633.31	675.88	631.25	550.33	556.74	516.51	640.56	644.34	620.50
Moors and heathland	535.79	672.35	0.00	494.08	519.68	0.00	464.97	528.66	0.00
Transitional woodland-shrub	687.79	667.80	625.79	621.96	589.09	563.61	589.65	587.66	531.62
Beaches, dunes, sands	231.99	319.84	316.98	191.55	263.88	250.10	216.97	282.51	270.31
Sparsely vegetated areas	421.34	478.43	407.75	490.02	409.91	386.48	492.02	0.00	0.00
Inland marshes	554.06	684.39	643.59	491.79	594.54	535.42	543.52	624.92	599.24
Peat bogs	621.40	675.45	668.05	577.59	592.22	579.83	618.68	677.54	629.75
Salt marshes	625.07	634.44	0.00	562.49	603.89	0.00	591.83	618.69	0.00
Intertidal flats	345.06	360.58	0.00	123.69	252.04	0.00	317.15	394.61	0.00
Average	567.46	624.29	432.16	510.34	558.87	437.01	565.58	563.76	446.12

The results of the annual total NPP based on the land cover classes within the landscape regions (Table 35) depicts that “broad-leaved forest”, “coniferous forest”, “mixed forest”, and “pastures” are the land cover classes having exceeding high annual total NPP in Geest for the years 2000 and 2012. However, the annual total NPP in “sparsely vegetated areas”, “transitional woodland-shrub”, “pastures” and “peat bogs” in Geest for 2006 are higher than the annual total NPP in the other land cover classes of Geest. “Broad-leaved forest”, “coniferous forest” and “sparsely vegetated areas” are the land cover classes having the highest annual total NPP than the other land cover classes for the years 2000, 2006 and 2012 in Marsch. The land cover classes with the high annual total NPP in Hügelland in 2000 and 2012 are partially different from the land cover classes in 2006. “Coniferous forest”, “mixed forest” and “pastures” have the highest values in 2000 and 2012. In 2006, “Peat bogs”, “pastures”, “sparsely vegetated areas”, “mixed forest” and “complex cultivation patterns” are the land cover classes with the optimum annual total NPP.

The annual total stored NPP based on the land cover classes of landscape regions (Table 36) confirms the importance of the land cover classes for the annual total stored NPP. “Pasture” and “non-irrigated arable land” which extensively distribute in Geest, Marsch or Hügelland, have the highest annual total stored NPP. The land cover classes covering least areas in Geest, Marsch or Hügelland have the lowest annual total stored NPP.

Table 36. Annual total stored NPP (Mg C yr^{-1}) based on land cover classes within the landscape regions of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover Class	2000			2006			2012		
	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland	Geest	Marsch	Hügelland
Non-irrigated arable land	1050949	625675	2408868	870605	590126	2134207	1458066	662921	2359270
Fruit trees and berry plantations	168	1316	258	141	1131	381	198	911	432
Pastures	1959241	587641	513574	1280923	452739	417376	1593542	556751	671558
Complex cultivation patterns	332582	59581	220505	600433	93537	244669	2265	1320	1053
Land principally occupied by agriculture	81577	2930	74396	75433	2560	76620	19095	289	19906
Broad-leaved forest	111667	4338	277496	93110	3773	240478	144997	6899	355215
Coniferous forest	259219	429	97603	214655	399	80194	252425	1207	90354
Mixed forest	68573	26	79542	61503	22	68484	56292	351	34654
Natural grasslands	14804	35773	11167	11106	28932	9888	27195	12501	20682
Moors and heathland	16211	205	0	14744	159	0	20480	383	0
Transitional woodland-shrub	9213	2104	2986	8233	1766	3282	11908	1525	8799
Beaches, dunes, sands	4501	8336	338	3716	6296	266	2289	2257	481
Sparsely vegetated areas	4426	670	532	5147	714	504	141	0	0
Inland marshes	3942	8487	15160	3754	7644	13013	2249	20683	6025
Peat bogs	48327	682	7130	47932	617	6270	31435	2505	7380
Salt marshes	4541	49168	0	4052	48398	0	8825	63499	0
Intertidal flats	7298	21136	0	2611	15171	0	5981	22095	0
Total	3979342	1408918	3709724	3299149	1254264	3295894	3637413	1356095	3575808

(4) NPP based on districts in 2000, 2006 and 2012

The annual total NPP and the annual stored NPP are shown in Figure 23. Steinburg, Rendsburg-Eckernförde, Schleswig-Flensburg and Dithmarschen are the districts which have the largest annual total NPP compared to the other districts of Schleswig-Holstein in 2000. Nordfriesland, Steinburg, Dithmarschen and Schleswig-Flensburg have the largest annual total NPP in 2006. Steinburg, Nordfriesland, Rendsburg-Eckernförde, Dithmarschen are the ones that have the largest annual total NPP in 2012. Meanwhile, the annual total NPP of Lübeck, Neumünster, Flensburg and Kiel are less than the annual total NPP of the other districts. Neumünster is the district having the lowest annual total NPP for the years 2000, 2006, and 2012. The annual total NPP of Neumünster in 2000, 2006 and 2012 only reaches to 61.36%, 60.75%, and 62.45% of the highest annual total NPP of the 15 districts for the years 2000, 2006 and 2012.

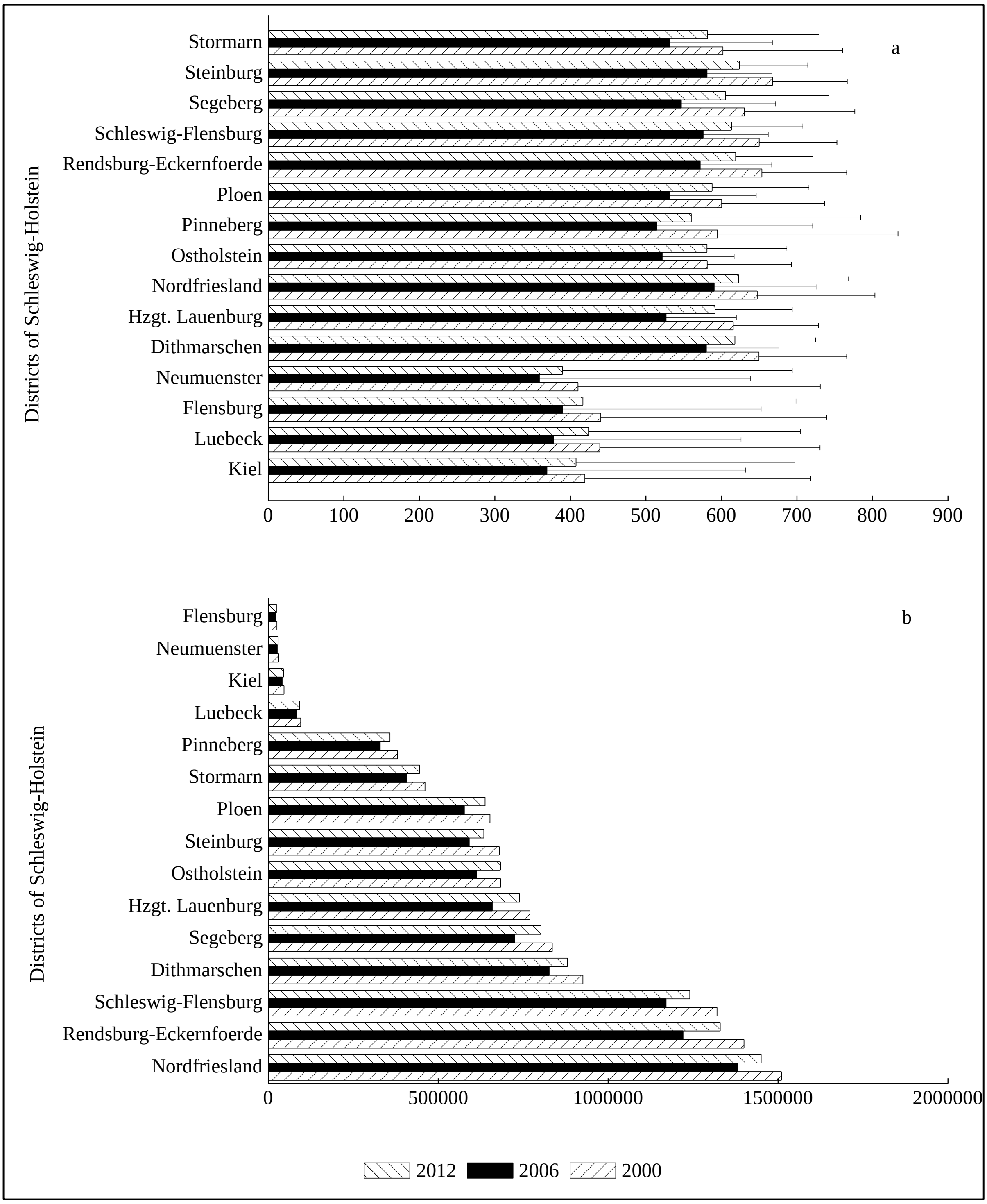

Figure 23. Annual total NPP (g C m^{-2} yr^{-1}) (a) and stored NPP (Mg C yr^{-1}) (b) based on districts in Schleswig-Holstein for the years 2000, 2006 and 2012.

The annual total stored NPP of the districts which have the largest amounts in all districts fluctuate among the years 2000, 2006 and 2012. The annual total stored NPP in districts with high abilities on storing are Nordfriesland, Rendsburg-Eckernförde, Schleswig-Flensburg, and Dithmarschen. The annual total stored NPP decreases from 2000 to 2006, and then increases from 2006 to 2012. The districts which have the lowest annual total stored NPP are Lübeck, Kiel, Neumünster and Flensburg. The annual total stored NPP in Flensburg which holds the smallest range reaches 1.6% of the district (Nordfriesland) having the highest annual total NPP.

The annual total NPP based on land cover classes of the districts in Table 37 shows that the annual total NPP of Kiel and Lübeck is around 10.58 g C m^{-2} yr^{-1} less than the annual total NPP of the other districts. The annual total NPP values of each district in “broad-leaved forest”, “coniferous forest”, “mixed forest”, “natural grasslands”, “pastures”, “complex cultivation patterns” and “non-irrigated arable land” are higher than the other land cover classes. However, Kiel, Lübeck, Flensburg and Neumünster have less of the annual total NPP than the other land cover classes in “broad-leaved forest”, “coniferous forest”, “mixed forest” and “natural grasslands”. The annual total NPP in “moors and heathland”, “transitional woodland-shrub”, “inland marshes” and “peat bogs” are also high although not all the districts have the land cover classes.

The annual total stored NPP is primarily affected by the areas of land cover. The annual total stored NPP of each district in the 17 land cover classes are depicted in Table 38. “Non-irrigated arable land” is the land cover containing most of the annual total NPP compared to the other land cover classes in the districts of Kiel, Lübeck, Flensburg, Neumünster, Plön, Rendsburg-Eckernförde, Schleswig-Flensburg, Segeberg and Stormarn. Simultaneously, “pastures” in Dithmarschen, Hzgt. Lauenburg, Nordfriesland, Ostholstein, Pinneberg and Steinburg have higher the annual total NPP values than the other land cover classes.

Table 37. Annual total NPP based on land cover classes within districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	NPP of districts (g C m^{-2} yr^{-1})														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Non-irrigated arable land	2000	629.88	600.76	646.84	569.05	596.66	605.40	637.21	629.24	613.93	654.47	589.02	602.04	608.29	616.30	628.57
	2006	577.84	522.28	605.07	517.19	524.47	539.83	566.66	567.12	541.01	574.42	526.87	517.43	519.03	550.45	555.24
	2012	606.23	578.79	625.97	573.66	573.23	601.24	617.13	610.43	603.30	613.31	574.69	570.59	574.73	574.82	594.12
Fruit trees and berry plantations	2000	0.00	0.00	0.00	630.92	640.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	0.00	541.45	591.16	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	601.50	613.30	0.00	0.00	0.00	0.00	615.63	0.00	0.00	0.00	0.00	0.00
Pastures	2000	675.82	649.77	692.78	632.29	656.38	653.64	684.57	679.21	666.84	678.76	666.94	649.73	645.91	641.98	646.45
	2006	594.88	560.75	628.93	549.66	564.61	566.54	594.62	598.13	576.08	589.17	585.28	561.78	544.47	551.54	585.81
	2012	645.38	618.51	669.25	617.54	611.70	627.33	640.46	637.74	632.06	637.22	622.32	611.43	621.44	608.14	631.69
Complex cultivation patterns	2000	665.23	648.34	686.39	622.02	643.28	646.23	664.37	673.55	660.24	689.40	642.05	643.01	646.03	637.79	633.71
	2006	592.86	562.76	620.39	551.99	539.57	568.44	590.19	594.61	568.92	606.72	576.34	552.73	556.17	556.45	547.38
	2012	654.04	0.00	667.43	604.29	611.24	614.09	636.52	661.02	594.11	631.17	0.00	0.00	0.00	0.00	0.00
Land principally occupied by agriculture	2000	671.28	649.43	686.56	621.78	667.24	615.86	677.65	693.57	658.50	691.83	640.10	658.62	623.46	0.00	0.00
	2006	578.50	553.71	607.02	546.66	575.71	548.00	587.66	616.72	532.49	599.47	538.96	565.05	548.50	0.00	0.00
	2012	643.16	608.31	675.54	590.54	571.27	594.85	619.02	648.67	619.38	641.33	626.55	0.00	606.01	0.00	533.92
Broad-leaved forest	2000	697.09	645.35	707.78	626.15	701.05	642.90	677.92	677.60	654.47	694.69	642.43	654.50	634.93	677.81	0.00
	2006	606.73	526.28	615.73	545.46	590.76	558.00	568.56	586.19	560.03	576.86	539.21	565.33	579.15	543.32	0.00
	2012	644.11	616.58	657.70	615.95	671.29	617.02	637.20	643.07	628.17	642.70	607.77	621.48	618.59	611.08	632.70
Coniferous forest	2000	716.17	669.46	735.99	655.99	698.58	654.73	693.91	700.00	691.24	705.98	675.39	0.00	655.15	638.72	644.78
	2006	609.82	550.18	637.08	534.90	558.33	557.28	580.82	589.30	575.76	584.10	550.63	0.00	556.12	572.41	566.03
	2012	662.05	635.93	684.15	640.10	651.38	637.57	656.66	645.80	639.05	658.34	640.47	0.00	620.92	631.80	619.52
Mixed forest	2000	696.38	665.15	657.59	664.07	679.15	655.06	673.99	681.35	671.61	688.10	667.95	0.00	627.89	631.74	635.37
	2006	583.78	576.33	573.76	567.69	560.89	558.14	575.03	604.94	572.78	582.20	575.91	0.00	566.50	586.32	576.45
	2012	660.53	633.15	640.09	638.18	632.97	630.03	651.86	644.34	635.93	645.16	640.99	636.55	625.76	0.00	628.28
Natural grasslands	2000	662.96	0.00	672.34	653.96	665.40	667.33	686.42	678.27	663.18	652.09	657.63	0.00	0.00	652.48	0.00
	2006	599.60	0.00	610.73	591.70	608.30	597.38	607.65	590.32	588.02	586.28	588.74	0.00	0.00	586.94	0.00
	2012	638.22	622.57	648.33	628.97	631.01	629.19	643.41	629.72	627.35	623.56	620.83	0.00	613.31	0.00	0.00

Table 37. Annual total NPP based on land cover classes within districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	NPP of districts (g C m^{-2} yr^{-1})														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Moors and heathland	2000	0.00	0.00	518.59	0.00	556.41	0.00	544.22	546.35	550.27	558.06	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	465.57	0.00	468.67	0.00	467.10	457.20	465.52	465.79	0.00	0.00	0.00	0.00	0.00
	2012	0.00	503.50	526.51	546.85	0.00	502.40	510.72	0.00	528.41	522.90	0.00	0.00	515.69	0.00	0.00
Transitional woodland-shrub	2000	678.72	0.00	672.56	671.02	674.48	0.00	665.71	672.04	675.38	669.08	667.90	0.00	0.00	0.00	0.00
	2006	570.61	560.77	556.11	562.55	560.30	0.00	566.10	566.19	561.39	563.39	567.34	0.00	0.00	0.00	0.00
	2012	618.75	606.06	606.72	606.08	611.72	605.57	605.46	605.88	616.17	613.81	613.93	618.76	603.79	608.93	0.00
Beaches, dunes, sands	2000	0.00	0.00	284.09	276.98	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	264.00	245.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	227.57	216.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	207.84	0.00	0.00
Sparsely vegetated areas	2000	0.00	457.51	456.54	441.66	0.00	0.00	417.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	424.96	411.35	0.00	0.00	392.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	432.02	0.00	0.00	0.00	0.00	0.00
Inland marshes	2000	689.32	685.17	687.34	695.19	0.00	691.67	683.85	690.27	0.00	684.71	688.16	682.21	678.91	0.00	0.00
	2006	585.45	581.02	584.32	582.96	0.00	590.48	591.52	592.74	0.00	589.87	590.39	539.49	533.52	0.00	0.00
	2012	635.50	0.00	631.42	630.31	637.33	637.53	638.53	628.12	0.00	632.61	629.15	615.41	0.00	0.00	0.00
Peat bogs	2000	687.10	0.00	686.84	0.00	685.63	682.99	681.83	681.49	686.26	688.59	686.75	0.00	0.00	0.00	693.30
	2006	594.73	0.00	586.90	0.00	587.98	587.81	586.57	587.82	586.35	587.67	588.47	0.00	0.00	0.00	582.52
	2012	625.05	623.69	628.70	628.06	619.53	617.61	618.59	616.52	622.00	625.00	629.30	0.00	0.00	0.00	623.55
Salt marshes	2000	637.64	0.00	632.25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	580.65	0.00	581.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	601.72	0.00	601.27	0.00	0.00	0.00	0.00	0.00	0.00	636.79	0.00	0.00	0.00	0.00	0.00
Intertidal flats	2000	371.83	0.00	377.69	0.00	391.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	316.77	0.00	342.42	0.00	360.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	330.62	0.00	351.42	0.00	0.00	0.00	0.00	0.00	0.00	338.55	0.00	0.00	0.00	0.00	0.00

Table 38. Annual total stored NPP based on land cover classes within districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	Stored NPP of districts (Mg C yr^{-1})														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Non-irrigated arable land	2000	321088	408349	379378	546288	96408	350605	528738	510955	387912	213423	275797	12854	43779	5966	10170
	2006	309422	344668	469329	401179	80800	309425	483746	490162	326738	182447	231791	10954	32631	4607	8590
	2012	388145	353548	506184	527739	119765	378066	629324	701097	373799	221773	229152	10196	26047	5018	9179
Fruit trees and berry plantations	2000	0	0	0	271	1390	0	0	0	0	0	0	0	0	0	0
	2006	0	0	0	412	1129	0	0	0	0	0	0	0	0	0	0
	2012	0	0	0	421	724	0	0	0	0	351	0	0	0	0	0
Pastures	2000	408939	53677	692233	53479	146373	74018	484895	516709	205147	332436	63953	6744	12272	6285	8462
	2006	309712	48225	457446	48359	113560	62319	337221	300501	160772	261939	55163	5477	13432	2956	6784
	2012	358489	96191	584215	92081	154699	112813	410163	363837	210704	301284	94499	9178	21309	6848	10044
Complex cultivation patterns	2000	58534	18568	89258	22766	58262	82233	96932	117373	40347	18765	9708	3279	665	1518	3352
	2006	84293	19877	219972	29250	59347	73585	143877	213953	52733	45128	16506	2642	573	3539	3728
	2012	647	0	214	302	788	356	356	502	677	814	0	0	0	0	0
Land principally occupied by agriculture	2000	6189	18126	5341	12367	15347	9915	29972	16327	15587	15248	11195	1640	3273	0	0
	2006	5299	16977	5141	11999	15953	10374	29072	16565	14505	13902	13668	1650	2578	0	0
	2012	926	6357	1594	3065	2799	3248	6011	4035	3630	3566	2149	0	1285	0	865
Broad-leaved forest	2000	7250	96460	7594	55702	12395	48050	61440	24942	20714	12609	33419	2801	10045	1044	0
	2006	6674	79147	6767	51322	9807	42386	52353	24731	19976	11139	28896	2420	9423	1125	0
	2012	11304	108253	12687	69140	12969	60567	87494	39742	32973	15406	38897	3654	15428	1381	867
Coniferous forest	2000	15240	82270	32170	6304	12351	4773	39761	23912	89930	28056	15095	0	6833	524	445
	2006	12562	67287	27598	5140	9776	4063	33571	20178	75603	22949	12356	0	5773	469	391
	2012	16094	73959	28885	5146	13282	5228	41048	24185	89729	28045	13514	0	4533	701	328
Mixed forest	2000	6052	30198	2722	5459	1379	13121	42327	15882	10464	10955	5430	0	1777	531	1353
	2006	5073	27053	2731	4831	1139	11241	36900	13454	11083	10107	4751	0	1949	346	1228
	2012	3342	25693	2311	3504	2038	2262	15703	6076	8127	10942	9711	159	1239	0	672
Natural grasslands	2000	20625	0	16681	6605	1757	1295	4915	4992	2553	535	1197	0	0	1553	0
	2006	18162	0	14725	5976	1606	1159	3859	5165	1664	481	1072	0	0	951	0
	2012	10416	1376	12072	6221	1142	944	11125	7147	3557	3854	615	0	2006	0	0

Table 38. Annual total stored NPP based on land cover classes within districts of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Year	Stored NPP of districts (Mg C yr^{-1})														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Moors and heathland	2000	0	0	13260	0	773	0	218	901	407	458	0	0	0	0	0
	2006	0	0	11714	0	651	0	187	754	344	382	0	0	0	0	0
	2012	0	76	21940	230	0	60	475	0	185	267	0	0	320	0	0
Transitional woodland-shrub	2000	706	0	2825	819	135	0	1331	3165	777	3861	688	0	0	0	0
	2006	593	729	2252	518	191	0	2230	2667	853	2327	584	0	0	0	0
	2012	1238	921	1948	1455	1144	394	6394	2708	1701	1731	2124	347	1014	828	0
Beaches, dunes, sands	2000	0	0	12915	255	0	0	0	0	0	0	0	0	0	0	0
	2006	0	0	11421	179	0	0	0	0	0	0	0	0	0	0	0
	2012	0	0	4219	331	0	0	0	0	0	0	0	0	23	0	0
Sparsely vegetated areas	2000	0	0	5488	322	0	0	146	0	0	0	0	0	0	0	0
	2006	0	0	5108	2443	0	0	137	0	0	0	0	0	0	0	0
	2012	0	0	0	0	0	0	0	0	0	125	0	0	0	0	0
Inland marshes	2000	1785	802	12791	6827	0	3251	2858	980	0	918	317	744	1025	0	0
	2006	1692	1052	10974	3463	0	2775	2473	818	0	961	301	588	806	0	0
	2012	7359	0	13683	876	1606	2123	1801	1432	0	202	239	585	0	0	0
Peat bogs	2000	11536	0	5941	0	1097	437	17993	11872	6094	3223	1291	0	0	0	1754
	2006	10033	0	5094	0	1593	376	15562	11392	6192	2856	1224	0	0	0	1474
	2012	7351	455	2842	1759	1468	537	8085	10703	3720	2956	592	0	0	0	686
Salt marshes	2000	12989	0	40711	0	0	0	0	0	0	0	0	0	0	0	0
	2006	11642	0	39106	0	0	0	0	0	0	0	0	0	0	0	0
	2012	15145	0	55112	0	0	0	0	0	0	452	0	0	0	0	0
Intertidal flats	2000	3402	0	26642	0	31	0	0	0	0	0	0	0	0	0	0
	2006	2898	0	24682	0	29	0	0	0	0	0	0	0	0	0	0
	2012	2714	0	23341	0	0	0	0	0	0	108	0	0	0	0	0

3.1.3.3 Differences between annual total GPP and annual total NPP

The calculated respiration and the ratio between NPP and GPP are evaluated for Schleswig-Holstein for the years 2000, 2006 and 2012 in this study in order to support evidence of ecosystem productivity.

The calculated respiration by green plants per unit time and space has been defined as the difference between the annual total GPP and NPP. The respiration maps based on the CORINE land cover of Schleswig-Holstein for the years 2000, 2006 and 2012 are shown in Figure 24 and Table 39. The respiration of 2006 is higher than the respiration in 2000 and 2012. The year of 2012 has the lowest respiration among the three years. The respiration ranges from 556.73 g C m^{-2} yr^{-1} to 182.33 g C m^{-2} yr^{-1} in 2000, from 563.34 g C m^{-2} yr^{-1} to 188.34 g C m^{-2} yr^{-1} in 2006, and from 529.20 g C m^{-2} $yr^{-1}$to 101.56 g C m^{-2} yr^{-1} in 2012. The lowest calculated respiration appears in “intertidal flats” and “beaches, dunes, sands” with color red in Figure 24. By contrast, the ratio between respiration and GPP in 2006 is lower than in 2000 and 2012. The ratios of the land cover class of “intertidal flats” are 33.24%, 36.08% and 32.52% for the years 2000, 2006 and 2012. “Intertidal flats” is the land cover class which has the lowest ratio between respiration and GPP. “Beaches, dunes, sands” (48.50%), “broad-leaved forest” (49.88%) and “sparsely vegetated areas” (80.61%) have the peak ratios for the years 2000, 2006 and 2012. This indicates that more energy has been fixed by autotrophs in “intertidal flats” than in “beaches, dunes, sands”, “broad-leaved forest” or “sparsely vegetated areas”.

The ratio between the annual total NPP and GPP based on the land cover classes for the years 2000, 2006 and 2012 present fluctuations (Figure 25 and Table 39). Average ratios of the annual NPP/GPP are 0.5647, 0.5350 and 0.5573. A distance between the minimum and the maximum of the ratios of the annual total NPP/GPP in 2006 is larger than the distance in 2000, but smaller than the distance in 2012. “Intertidal flats” have the maximum of the annual NPP/GPP (0.6675 in 2000, 0.6391 in 2006 and 0.6748 in 2012). “Beaches, dunes, sands” (in 2000), “broad-leaved forest” (in 2006) and “sparsely vegetated areas” (in 2012) have the minimum of the ratio with color red in Figure 25. The land cover classes having the minimum and maximum values of the annual NPP/GPP ratio are the same as the land cover classes which have the lowest and highest ratio between respiration and GPP. The calculated respiration and the ratios of the annual NPP/GPP are different from one land cover class to another in Schleswig-Holstein for the years 2000, 2006 and 2012.

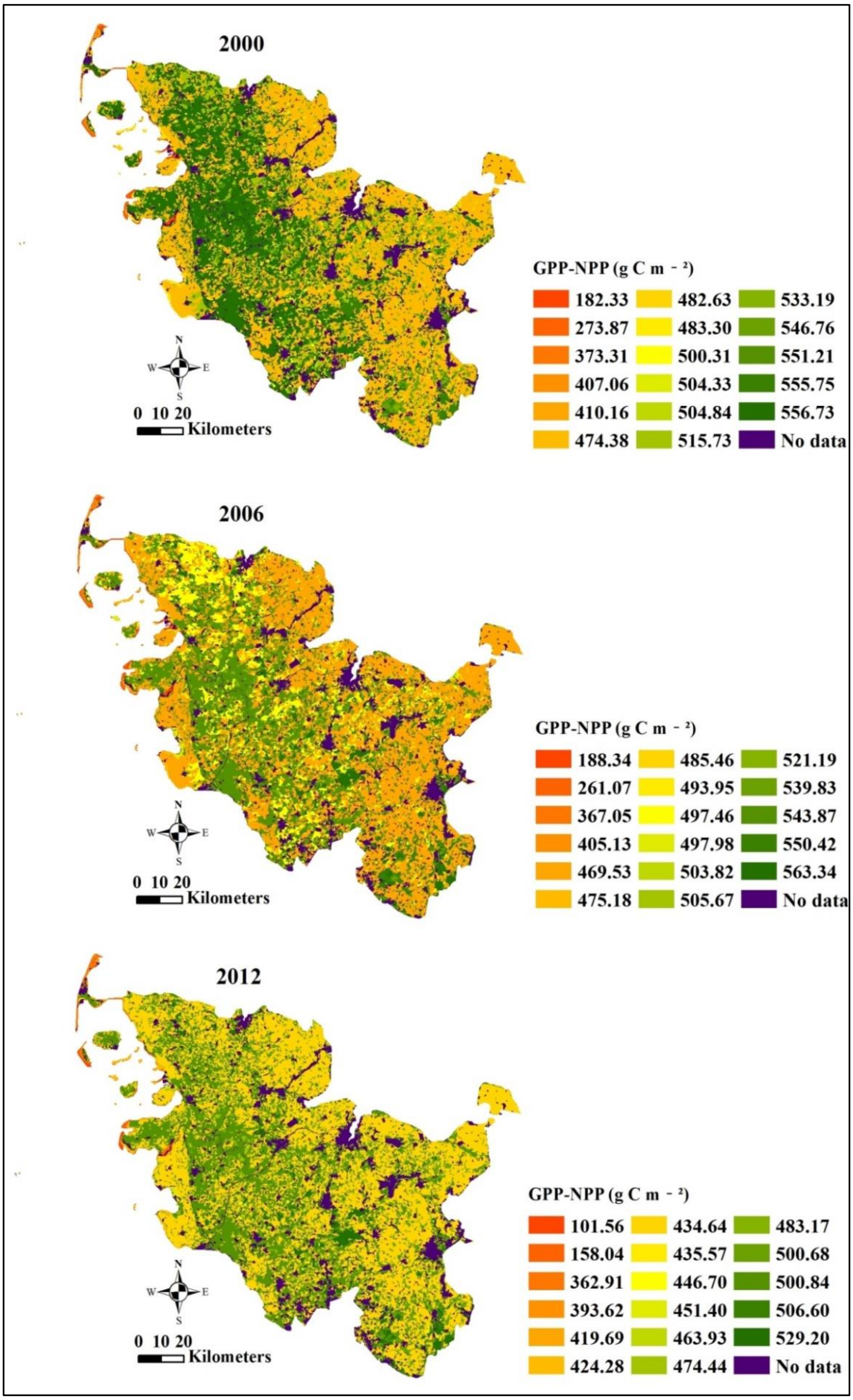

Figure 24. Maps of calculated respiration based on land cove classes of Schleswig-Holstein for the years 2000 (a), 2006 (b) and 2012 (c).

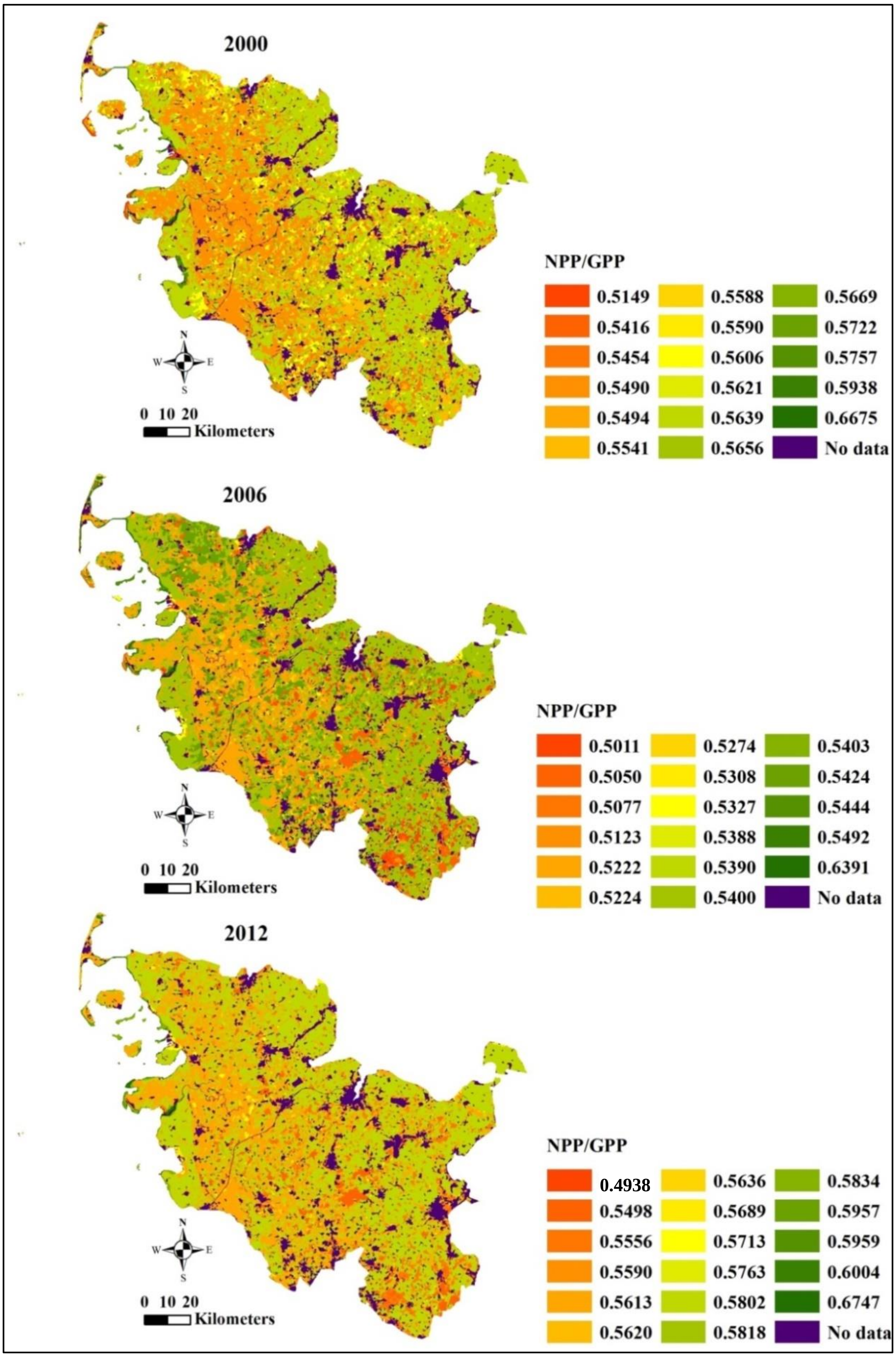

Figure 25. Maps of ratio between annual total NPP and GPP based on land cover classes of Schleswig-Holstein for the years 2000 (a), 2006 (b) and 2012 (c).

Table 39. Calculated respiration and ratios between annual total NPP and GPP based on land cove classes of Schleswig-Holstein for the years 2000, 2006 and 2012.

Land Cover classes	Calculated respiration between GPP and NPP (GPP-NPP) (g C m^{-2} yr^{-1})			Ratios between GPP and NPP (NPP/GPP)		
	2000	2006	2012	2000	2006	2012
Non-irrigated arable land	474.38	469.53	434.64	0.5639	0.5400	0.5802
Fruit trees and berry plantations	407.06	493.95	419.69	0.5938	0.5403	0.6004
Pastures	556.73	543.87	500.84	0.5490	0.5222	0.5613
Complex cultivation patterns	515.73	497.46	463.93	0.5606	0.5424	0.5818
Land principally occupied by agriculture	500.31	485.46	446.70	0.5669	0.5388	0.5763
Broad-leaved forest	546.76	550.42	500.68	0.5454	0.5011	0.5556
Coniferous forest	555.75	563.34	529.20	0.5541	0.5050	0.5498
Mixed forest	533.19	539.83	506.60	0.5588	0.5123	0.5590
Natural grasslands	482.63	497.98	474.44	0.5757	0.5327	0.5713
Moors and heathland	410.16	405.13	362.91	0.5621	0.5492	0.5620
Transitional woodland-shrub	504.84	503.82	393.62	0.5722	0.5390	0.5959
Beaches, dunes, sands	273.87	261.07	101.56	0.5149	0.5077	0.5957
Sparsely vegetated areas	373.31	367.05	435.57	0.5416	0.5308	0.4938
Inland marshes	504.33	505.67	451.40	0.5590	0.5224	0.5689
Peat bogs	551.21	521.19	483.17	0.5494	0.5274	0.5636
Salt marshes	483.30	475.18	424.28	0.5656	0.5444	0.5834
Intertidal flats	182.33	188.34	158.04	0.667	0.6391	0.6747

3.1.3.4 Identifying hotspots and cold spots for annual total GPP and annual total NPP of Schleswig-Holstein

Estimating the spatial distributions of the hotspots and cold spots for the annual GPP and NPP within Schleswig-Holstein presents core detrition areas of the annual total GPP and NPP. The temporal distributions of the hotspots and cold spots for the annual GPP and NPP for the years 2000, 2006 and 2012 show differences of the annual total GPP and NPP see Figure 26.

Statistic significant spatial clusters, high values (hotspots) and low values (cold spots) of the annual total GPP and NPP have been identified with the Hot Spot Analysis tool (Getis-Ord Gi*) embedded In ArcGIS 10.3. Figure 26 presents the detailed spatial distribution of hotspots and cold spots based on the MODIS annual total GPP and NPP datasets. For the years 2000, 2006 and 2012, hotspot areas are located in the middle-western to the middle-bottom of Schleswig-Holstein, forming an adjacent significant hotspot area with high annual total GPP areas which are not significant rounded to the hotspots areas. Cold spots areas mainly locate on the edge of the western and the eastern parts of the state. Most of the hotspot areas and most of the cold spots are located in Geest and Hügelland, respectively. The areas of hotspots and the cold spots fluctuate during the three years (Table 40). Approximately 36.12%, 32.69% and 32.38% of the states' areas are distributed in the identified hotspot areas for the years 2000, 2006 and 2012. Meanwhile, the percentage of the cold spots areas accounts to 33.72%, 33.84% and 30.73% for the areas of the state in the three years. The percentage of not significant areas increases from 30.16% in 2000 to 33.47% in 2006, and then reaches 36.89% in 2012. The areas of hotspots decrease and the areas of not significant results extend, providing a fluctuation for the cold spots areas during the study periods. The distributions of the hotspots and the cold spots areas of the annual total NPP are similar to the distributions of the annual total GPP. The hotspot areas are located in the middle-western to the middle-bottom of the state in 2000, 2006 and 2012. Furthermore, the distributions of hotspot areas in 2012 are much more fragmented than the distributions in 2000 and in 2006. The areas occupied by hotspots declined during the study period. Contrarily, the growth of the not significant areas proceeds rapidly, accounting for 28.93% of the total areas in 2000 to 44.94% of the total areas in 2012. The percentage of the cold spots areas (around 31.10%) is similar in the years 2000 and 2006, and then it descends to 24.73% in 2012. The decrease of the hotspot and cold spots areas is more obvious for the annual total NPP than the decrease of the areas for the annual total GPP for the three years.

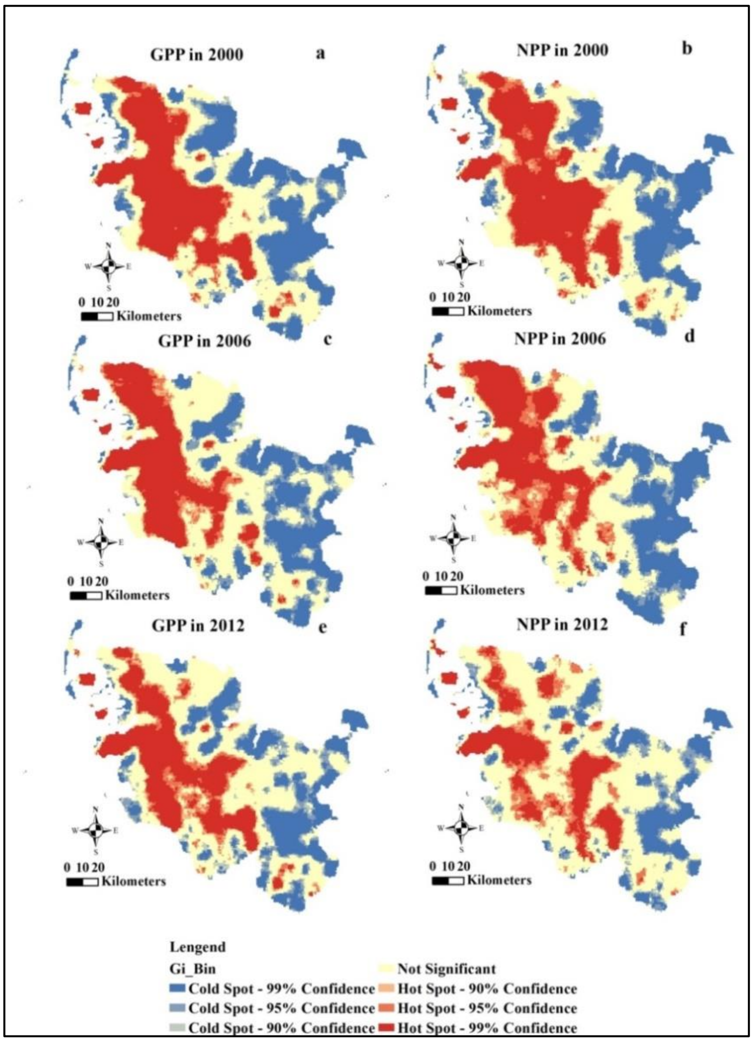

Figure 26. Spatial distributions of hotspots and cold spots for annual total GPP (a, c and e) and NPP (b, d and f) in Schleswig-Holstein for the years 2000, 2006 and 2012.

Hotspots and cold spots for annual total GPP and NPP reflect the spatial and temporal distributions of the annual total GPP and NPP in Schleswig-Holstein for the years 2000, 2006 and 2012. The assessments supply evidences that most of the hotspots areas of the annual total GPP and NPP concentrate in Geest, and most the cold spots are in Hügelland.

Table 40. Summary of the analysis for hotspot and cold spot areas of annual total GPP and NPP.

	Year	Areas of hotspot and cold spot (ha)						
		Cold Spot-99% Confidence	Cold Spot-95% Confidence	Cold Spot-90% Confidence	Not Significant	Hotspot-90% Confidence	Hotspot-95% Confidence	Hotspot-99% Confidence
GPP	**2000**	382049	94615	51525	472347	35770	66739	463200
	2006	359810	113410	56736	524258	43768	73461	394801
	2012	307043	112834	61456	577752	56269	91513	359379
NPP	**2000**	353639	90586	42932	453082	41829	91933	492245
	2006	352170	95339	40060	482294	59269	141421	395691
	2012	223674	106650	57035	703831	72384	136637	266034

3.1.3.5 Carbon storage in vegetation and in soil

Carbon enters the vegetation carbon pool as GPP and transfers to the atmosphere as plant respiration, stocking NPP as the net amount of carbon which is captured by vegetation through photosynthesis. Another transformation of carbon is from NPP to the soil carbon pool as litter production (Melillo *et al.*, 1993). Carbon storage (CS) in vegetation and in soil, including the carbon storage of above-ground, below-ground, SOC and litter, is a principle parameter which can present mid-term carbon storage. These quantitative parameters have been defined as indicators of global climate regulation, and can be used for assessing this ecosystem service (Burkhard *et al.*, 2014). The annual total GPP and NPP data are derived from the MOD17 products using the CORINE land cover maps as classification layers. The SOC density of the land cover classes are calculated from the data source of SOC storage in Europe. Furthermore the carbon density in aboveground, belowground and litter biomass of each land cover has been derived from researches that have been done in study areas with similar environmental conditions as in Schleswig-Holstein.

Table 41 indicates the carbon stocks and the carbon storage with the quantitative parameters (the annual total GPP, the annual total NPP, SOC and CS) and with the qualitative parameter of global climate regulation (GCR). The land cover classes which have the highest amounts of the annual total GPP are “coniferous forest” and “pastures”, followed by “mixed forest”, “broad-leaved forest” and “peat bogs”. The highest annual total NPP is found the land cover classes of “transitional woodland-shrub”, “complex cultivation patterns”, “peat bogs”, “pastures” and “fruit trees and berry plantations”. There are several variations of the amounts of SOC, resulting from land cover differences. The land cover classes of “peat bogs”, “intertidal flats”, “salt marshes”, “inland marshes” and “natural grasslands” occupy the highest amounts of SOC. “Broad-leaved forest”, “coniferous forest”, “mixed forest”, “peat bogs” and “intertidal flats” are the land cover classes which have the highest CS. Similarly to CS, “broad-leaved forest”, “coniferous forest”, “mixed forest”, “peat bogs” and “natural grassland” are estimated to have higher abilities on global climate regulation evaluated with the qualitative indicator GCR. The amounts of CS in vegetation and in soil are evaluated differently with distinct parameters. However, the land cover classes which have high abilities of storing carbon are estimated similarly with the annual total GPP, CS and GCR.

Table 41. Quantitative and qualitative indicators of global climate regulation based on land cover classes in 2006.

CORINE Land Cover Code	CORINE Land Cover Class	Annual total GPP (Mg C ha^{-1})	Annual total NPP (Mg C ha^{-1})	SOC Medium (Mg C ha^{-1})	CS (Mg C ha^{-1})	GCR
311	**Broad-leaved forest**	11.03	5.53	79.48	232.58	5
313	**Mixed forest**	11.07	5.67	76.12	209.60	5
312	**Coniferous forest**	11.38	5.75	85.05	198.91	5
412	**Peat bogs**	11.03	5.82	134.27	136.02	5
423	**Intertidal flats**	5.22	3.34	113.53	113.53	1
222	**Fruit trees and berry plantations**	10.75	5.81	89.91	110.99	2
421	**Salt marshes**	10.43	5.68	107.58	109.58	1
231	**Pastures**	11.38	5.95	97.75	104.45	2
411	**Inland marshes**	10.59	5.53	99.47	100.97	2
321	**Natural grasslands**	10.66	5.68	97.97	99.47	5
242	**Complex cultivation patterns**	10.87	5.90	93.22	96.87	1
324	**Transitional woodland-shrub**	10.93	5.89	81.00	95.55	2
211	**Non-irrigated arable land**	10.21	5.51	92.62	94.82	1
322	**Moors and heathland**	8.99	4.94	90.03	92.03	3
333	**Sparsely vegetated areas**	7.82	4.15	89.39	90.19	0
243	**Land principally occupied by agriculture, with significant**	10.53	5.67	86.89	90.09	2
331	**Beaches, dunes, sands**	5.30	2.69	9.34	10.84	0
132	**Dump sites**	No data	No data	No data	No data	0
111	**Continuous urban fabric**	No data	No data	No data	No data	0
112	**Discontinuous urban fabric**	No data	No data	No data	No data	0
121	**Industrial or commercial units**	No data	No data	No data	No data	0
122	**Road and rail networks and associated land**	No data	No data	No data	No data	0
123	**Port areas**	No data	No data	No data	No data	0
124	**Airports**	No data	No data	No data	No data	0
131	**Mineral extraction sites**	No data	No data	No data	No data	0
133	**Construction sites**	No data	No data	No data	No data	0
141	**Green urban areas**	No data	No data	No data	No data	2
142	**Sport and leisure facilities**	No data	No data	No data	No data	1
511	**Water courses**	No data	No data	No data	No data	0
512	**Water bodies**	No data	No data	No data	No data	1
521	**Coastal lagoons**	No data	No data	No data	No data	1
522	**Estuaries**	No data	No data	No data	No data	1

3.1.3.6 Integrative model output (InVEST)

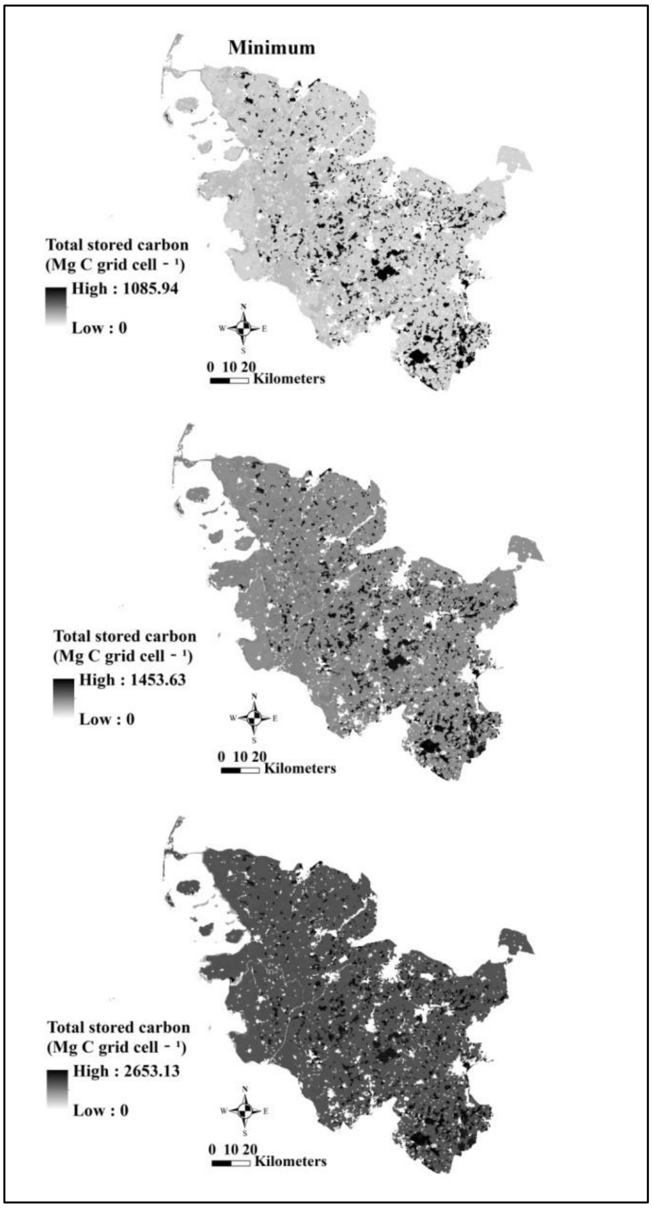

Figure 27. InVEST results for maximum, medium, and minimum carbon storage of Schleswig-Holstein based on CORINE land cover in 2006.

CS can show mid-term carbon storage, being a critical factor in reflecting carbon and energy stored in the processes of the carbon cycle. The carbon storage and sequestration model is one of the Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) models which estimate ecosystem services. This model assesses the amount of CS in a certain area (Sharp *et al.*, 2015a), which makes an possible evaluation of CS of the whole state Schleswig-Holstein within 17 land cover classes. The maximum, the medium and the minimum SOC data are derived from the map of SOC storage of agricultural soils from EEA for enhancing the reliability of the evaluation.

The InVEST model generates total carbon of the whole Schleswig-Holstein, and carbon storage of different layers which are mapped separately by four carbon pools (above-ground, below-ground, SOC and litter). The total carbon stored in the whole state is ranging from 56.47 Tg to 425.83 Tg due to the minimum SOC and maximum SOC values. The medium total carbon storage in Schleswig-Holstein is 154.63 Tg.

Furthermore, the amounts of carbon stored in Mg per grid cell (6.25 ha) on each land cover class for 2006 with the maximum, the medium and the minimum SOC are depicted in Figure 27. The simulated results of CS per grid cell show the land cover classes which influence the various amount of carbon storage. The minimum carbon storage is from 0 to 1085.94 Mg per grid cell, the maximum carbon storage is from 0 to 2653.13 Mg per grid cell, and the medium carbon storage is from 0 to 1453.63 Mg per grid cell. The variations of CS in Schleswig-Holstein depend on the input data, like different numbers of SOC, and on the land cover classes.

3.1.3.7 Comparison of the different country-wide results

(1) Correlation analysis among indicators of annual total GPP, annual total NPP, SOC, CS and GCR

The results of sub-section 3.1.3.5 show some distinctions exist in the assessments of CS in vegetation and in soil with different parameters. The correlations among the indicators and histograms of the indicators are presented in Figure 28. The numbers show the significance of two indicators based on the linear regression analysis shown in the left part of Figure 28. The strongest correlation is between the annual total GPP and the annual total NPP, which correlate to each other closely due to the process of calculation. GCR has the closest correlation with CS and the weakest correlation with the annual total SOC. The correlation between the quantitative and the qualitative indicators is diverse when being evaluated with the different quantitative indicators.

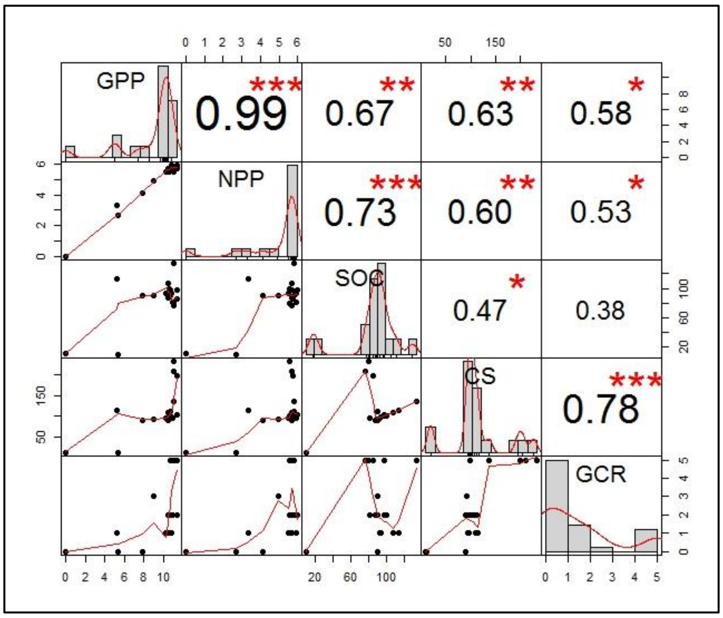

Figure 28. Correlation analysis among qualitative and quantitative indicators of global climate regulation.

(2) Mapping global climate regulation with indicators of annual total GPP, annual total NPP, SOC, CS and GCR

An important aim of this study is to map global climate regulation with the quantitative and qualitative indicators and to compare the differences of the mapping results. The quantitative (annual total GPP, annual total NPP, SOC and CS) and qualitative characteristics (GCR) are simple and useful indicators to estimate global climate regulation (Burkhard *et al.*, 2014). The correlation analysis among the indicators shows that there are significant relationships between the quantitative and the qualitative indicators. Therefore, the quantitative indicators are classified into classes 0-5 in order to compare their distributions with the qualitative indicator (Table 42).

In addition to analyze the global climate regulation based on the land cover classes, spatial variation may provide significant contributions for understanding differences because of various indicators on mapping global climate regulation. Therefore, the spatial distribution characteristics are presented in Figure 29 and Table 42. Class 5, being one of reclassified classes of the annual total GPP, includes the land cover classes of "fruit trees and berry plantations", "pastures", "complex cultivation patterns", "land principally occupied by agriculture", "broad-leaved forest", "coniferous forest", "mixed forest", "natural grasslands", "transitional woodland-shrub", "inland marshes", "peat bogs" and "salt marshes". The land cover classes in the class 5 occupy the largest parts of total areas of Schleswig-Holstein (730500 ha, 46.68% of the Schleswig-Holstein). Class 4 which is one of the 5 reclassified classes of the annual total GPP, consisting of "non-irrigated arable land", taking 666185 ha and accounting for 42.57% of the total areas of Schleswig-Holstein. Similarly to the reclassification of the annual total GPP, class 5 of the annual total NPP contains "non-irrigated arable land", "pastures", "complex cultivation patterns", "land principally occupied by agriculture", "broad-leaved forest", "coniferous forest", "mixed forest", "natural grasslands", "transitional woodland-shrub", "inland marshes", "peat bogs" and "salt marshes". The land cover classes in class 5 cover 1396686 ha, which account for 89.25% of the total areas. The class 3 and the class 4 of SOC which cover 837726 ha and 553810 ha, are the largest classes. The class 3 includes "non-irrigated arable land", "fruit trees and berry plantations", "land principally occupied by agriculture", "broad-leaved forest", "coniferous forest", "mixed forest", "moors and heathland", "transitional woodland-shrub" and "sparsely vegetated areas". The class 4 includes the land cover classes of "pastures", "complex cultivation patterns", "natural grasslands", "inland marshes" and "salt marshes". The class 2 is the class which affected the largest areas of the Schleswig-Holstein under estimation of CS. "non-irrigated arable land", "fruit trees and berry plantations", "pastures", "complex cultivation patterns", "land principally occupied by agriculture", "natural grasslands", "moors and heathland", "transitional woodland-shrub", "sparsely vegetated areas", "inland marshes", "salt marshes" and "inertial flats" are the land cover classes constitute class 2, accounted for 80.68% of the total areas. The areas of land cover classes of class 0 class 1 on GCR affect 95.04% of the total areas. Class 0 occupies 781,673 ha (49.95% of the total areas), including the land cover classes of "airports", "beaches, dunes, sands", "continuous urban fabric", "discontinuous urban fabric", "dump sites", "industrial or commercial units", "mineral extraction sites", "port areas", "road and rail networks", "sparsely vegetated areas" and "water courses". Class 1 is composed of "sport and leisure facilities", "non-irrigated arable land", "complex cultivation patterns", "salt marshes", "intertidal flats", "water bodies", "coastal lagoons and estuaries" and "estuaries", accounting for 56.66% (886671 ha) of the total areas.

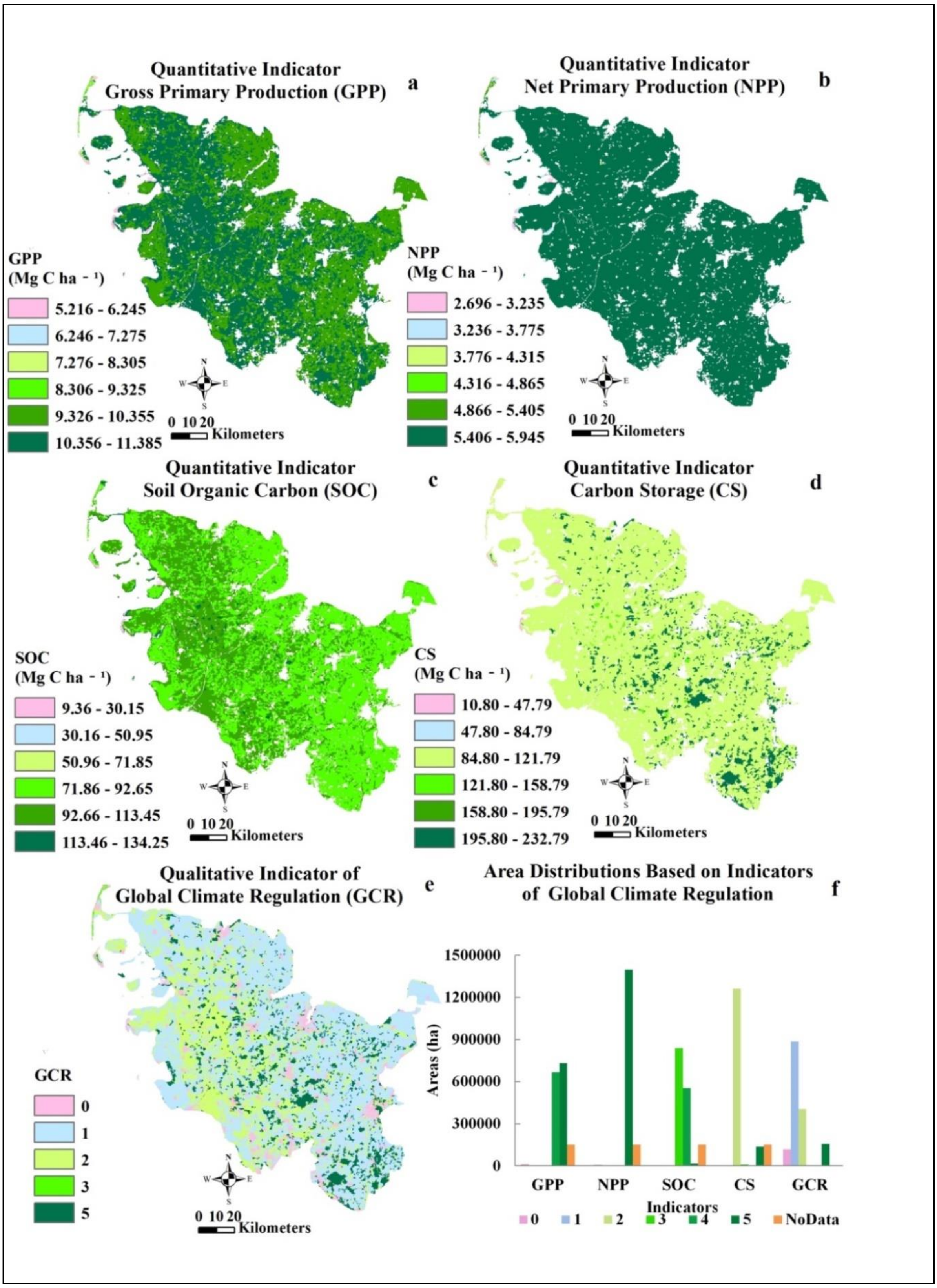

Figure 29. Global climate regulation assessed with qualitative and quantitative indicators (annual total GPP (a), annual total NPP (b), SOC (c), CS (d), GCR (e), and their area distributions (f)) of Schleswig-Holstein based on CORINE land cover in 2006.

Table 42. Reclassifications of quantitative and qualitative indicators of global climate regulation based on CORINE land cover classes in 2006.

CORINE Land Cover Code	CORINE Land Cover Class	Annual total GPP	Annual total NPP	SOC	CS	GCR
311	Broad-leaved forest	5	5	3	5	5
312	Coniferous forest	5	5	3	5	5
313	Mixed forest	5	5	3	5	5
412	Peat bogs	5	5	5	3	5
321	Natural grasslands	5	5	4	2	5
322	Moors and heathland	3	4	3	2	3
222	Fruit trees and berry plantations	5	5	3	2	2
231	Pastures	5	5	4	2	2
243	Land principally occupied by agriculture, with significant areas	5	5	3	2	2
324	Transitional woodland-shrub	5	5	3	2	2
411	Inland marshes	5	5	4	2	2
211	Non-irrigated arable land	4	5	3	2	1
242	Complex cultivation patterns	5	5	4	2	1
421	Salt marshes	5	5	4	2	1
423	Intertidal flats	0	1	5	2	1
333	Sparsely vegetated areas	2	2	3	2	0
331	Beaches, dunes, sands	0	0	0	0	0
141	Green urban areas	No data	No data	No data	No data	2
142	Sport and leisure facilities	No data	No data	No data	No data	1
512	Water bodies	No data	No data	No data	No data	1
521	Coastal lagoons	No data	No data	No data	No data	1
522	Estuaries	No data	No data	No data	No data	1
111	Continuous urban fabric	No data	No data	No data	No data	0
112	Discontinuous urban fabric	No data	No data	No data	No data	0
121	Industrial or commercial units	No data	No data	No data	No data	0
122	Road and rail networks and associated land	No data	No data	No data	No data	0
123	Port areas	No data	No data	No data	No data	0
124	Airports	No data	No data	No data	No data	0
131	Mineral extraction sites	No data	No data	No data	No data	0
132	Dump sites	No data	No data	No data	No data	0
133	Construction sites	No data	No data	No data	No data	0
511	Water courses	No data	No data	No data	No data	0

(3) Pair-wise map comparisons between annual total GPP, annual total NPP, SOC, CS and GCR

Differences of the ecosystem service assessments derived from the various indicators are worthy studying because it is helpful to evaluate the quantitative and the qualitative indicators on assessing ecosystem services. Table 43 shows the correlations between the maps mapped with different indicators. The differences between the annual total GPP and GCR, between the annual total NPP and GCR, between SOC and GCR and between

CS and GCR are with the MCS (Map Comparison Statistic) values of 0.432, 0.391 0.433 and 0.255. The CS map shows relatively small differences with GCR map, compared to the differences of GCR which are made by the annual total GPP, the annual total NPP and SOC. The map of the SOC, compared to other quantitative maps, has the least correlation with the GCR map. It is presented that the MCS values between SOC and GCR is close to two random maps MCS value (0.5). Two quantitative indicators maps are compared. Here, the MCS values range between 0.085 and 0.433. The maps of the annual total GPP and NPP present small differences due to the lowest MCS values. The map denoted with the qualitative indicator has the closest relationship with the quantitative indicator of CS map, followed by the maps indicated by the annual total NPP, the annual total GPP and SOC.

Table 43. Map comparison statistics of global climate change with quantitative and qualitative indicators of Schleswig-Holstein in 2006. The statistics indicate the average difference between two indicators of global climate regulation.

Map comparison	Qua (GCR)	Annual total GPP	Annual total NPP	SOC	CS
Qua (GCR)	0	0.432	0.391	0.433	0.255
Annual total GPP		0	0.085	0.293	0.414
Annual total NPP			0	0.305	0.400
SOC				0	0.394
CS					0

(4) Correlation of GPP, NPP and harvest

Harvest represents the materials and energy which can be used by human beings to support their lives (Donald & Hamblin, 1976). GPP and NPP strongly influence the amount of harvest because they are the beginning of the cycles of material and energy. Therefore, GPP, NPP and the harvest can be used as indicators for global climate regulation. Figure 30 presents the annual total GPP, the annual total NPP and the harvest of grain, green corn, root crops and winter rape based on the districts in 2006. Dithmarschen has a very high average harvest of grain, green corn, root crops and winter rape due to a large proportion of the root crops within the average harvest. Flensburg is the city which averagely harvested lest among the 15 districts, but having the highest harvest of grain, winter rape and green corn related to the area size. The harvests of grain and green corn are less in Hzgt. Lauenburg than in other districts. Flensburg and Neumünster are the districts with relatively weak abilities on root crops harvesting and winter rape harvesting.

The correlations among the annual total GPP, the annual total NPP, the monthly GPP, GPPAgri, NPPAgri and the harvest of grain, green corn, root crops and winter rape are presented in Table 44. The correlations between average harvest and the annual total GPP, the annual total NPP, GPPAgri, NPPAgri are significant. They illustrate that the harvest based on districts of Schleswig-Holstein is positively related to the annual total

GPP, the monthly GPP and the annual total NPP. The average harvest significantly is related to the grain, the root crop, winter rapes and green maize. The harvest of grain has significant positive relationships with the monthly GPP in September and October. This results from the characters of grain which stores energy abundantly before being harvested (in August and September). Species of plantations on the arable land and the areas of the plantations in each district are the primary factors affecting the correlations of harvest, monthly GPP, the annual total GPP and NPP.

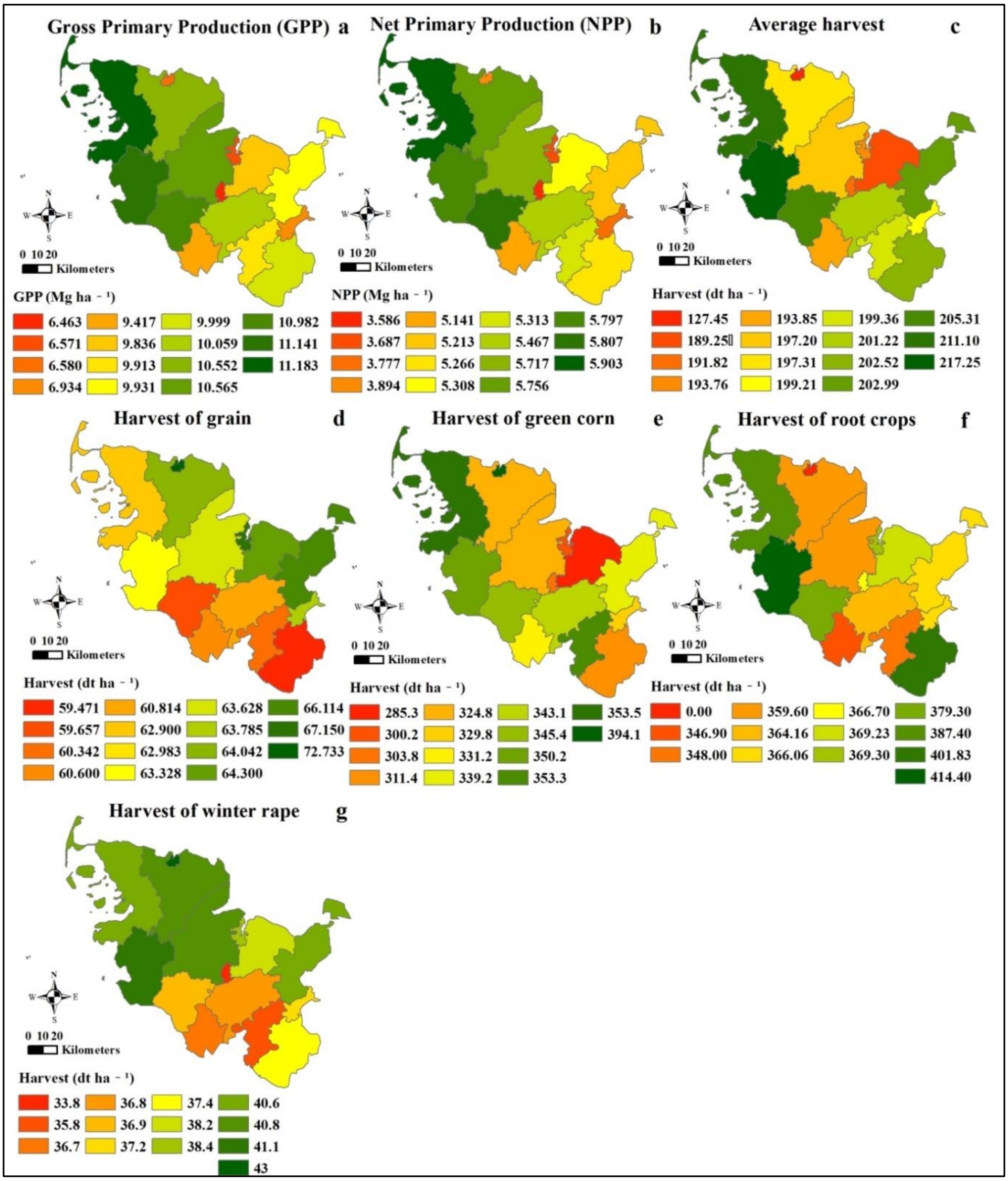

Figure 30. Annual GPP (a), annual NPP (b), average harvests (c), harvest of grain (d), harvest of green corn (e), harvest of root crops (f) and harvest of winter rape (g) based on districts of Schleswig-Holstein in 2006.

Table 44. Correlations among annual total GPP, annual total NPP, monthly GPP and statistical harvest of Schleswig-Holstein in 2006.

Ever is average harvest of grain, root crops, winter rape and green maize. GPPAgri and NPPAgri are short names of the annual total GPP and the annual total NPP distributions on the agricultural areas based on the CORINE land cover classification. GPPJan, GPPFeb, GPPMar, GPPApr, GPPMay, GPPJune, GPPJuly, GPPAug, GPPSep, GPPOct, GPPNov and GPPDec are monthly GPP.

	Grain	Root Crop	Winter rape	Green maize	Aver	GPP	NPP	GPP Agri	NPP Agri	GPP Jan.	GPP Feb.	GPP Mar.	GPP Apr.	GPP May	GPP June	GPP July	GPP Aug.	GPP Sep.	GPP Oct.	GPP Nov.	GPP Dec.
Grain	1	.044	.610*	.179	.496	.382	.371	.311	.407	.329	.346	.136	.271	.221	.182	.307	.511	.521*	.743**	.454	.470
Root Crop		1	.319	.004	.449	.313	.225	.209	.200	.278	.249	.278	.057	.363	.311	.181	.068	.161	.337	.325	.370
Winter rape			1	.201	.066	.351	.297	.231	.174	.272	.358	.408	.084	.254	.351	.302	.186	.175	.002	.171	.091
Green maize				1	.463	.402	.434	.213	.241	.334	.441	.288	.297	.270	.377	.370	.327	.395	.302	.350	.340
Aver					1	.782**	.668**	.579*	.596*	.632*	.746**	.643**	.582*	.679**	.729**	.561*	.596*	.675**	.743**	.819**	.795**
GPP						1	.961**	.889**	.900**	.921**	.957**	.804**	.650**	.704**	.882**	.900**	.900**	.936**	.875**	.754**	.706**
NPP							1	.907**	.932**	.943**	.914**	.779**	.671**	.654**	.843**	.943**	.893**	.943**	.839**	.663**	.618*
GPPAgri								1	.982**	.939**	.893**	.764**	.586*	.636*	.864**	.964**	.879**	.900**	.743**	.538*	.511
NPPAgri									1	.939**	.889**	.721**	.546*	.579*	.804**	.971**	.896**	.936**	.793**	.542*	.506
GPPJan.										1	.907**	.761**	.618*	.671**	.886**	.950**	.850**	.882**	.786**	.622*	.595*
GPPFeb.											1	.857**	.654**	.696**	.879**	.914**	.882**	.921**	.807**	.747**	.676**
GPPMar.												1	.861**	.886**	.868**	.750**	.646**	.711**	.621*	.824**	.758**
GPPApr.													1	.879**	.757**	.550*	.496	.550*	.579*	.822**	.801**
GPPMay														1	.868**	.596*	.500	.543*	.614*	.887**	.910**
GPPJune															1	.839**	.743**	.768**	.689**	.744**	.752**
GPPJuly																1	.896**	.929**	.750**	.542*	.506
GPPAug.																	1	.971**	.871**	.559*	.497
GPPSep.																		1	.886**	.613*	.552*
GPPOct.																			1	.756**	.738**
GPPNov.																				1	.969**
GPPDec.																					1

3.2 Regional assessments

According the CORINE land cover classification, the Bornhöved Lakes District is composed of “water bodies”, “discontinuous urban fabric”, “industry of commercial units”, “mineral extraction sites”, “non-irrigated arable land”, “pasture”, “complex cultivation patterns”, and “land principally occupies by agriculture”, “with significant areas of natural vegetation”, “broad-leaved forest”, “coniferous forest” and “mixed forest”. The local assessments cannot cover all the land cover classes of the Bornhöved Lakes District. Therefore, some investigations and regional assessments on carbon storage and ecosystem services of the district are summarized in this section.

The studies about this district primarily have focused on presenting land cover distribution and land cover changes using data sets from CORINE, ATKIS, InVeKoS and Landsat with various temporal resolutions (Kandziora et al., 2014, 2013b). As the CORINE land cover data have the lowest spatial resolutions, they are less concise for the scale of the Bornöved Lake District than the ATKIS, InVeKoS and Landsat data set. Furthermore, the CORINE land cover data set holds a lower number of land cover information for this study area, compared with the other data sets (Kandziora et al., 2014, 2013b). Spatial data on land cover are also widely used for mapping ecosystem services based on land cover and land cover changes on the potentials of multiple ecosystem services (Kandziora *et al.*, 2013b). According to Kandziora et al. (2014, 2013b), the CORINE data set overestimates the supply of the provisioning services by crops and fodder compared to the other types of the CORINE data set. This is due to rough information on the specific crops which causes uncertainties to quantifying yields by joining them with statistical information provided for crop specific yields. The area loss of grassland is associated with changes in provisioning ecosystem services, for instance the decrease of livestock and the increase of fodder and crops due to the loss of area. Moreover, a continuous enhancement of the maize cultivation area, using as biomass for biogas production, contributes to the addition of the ecosystem service of “biomass for energy” (Kandziora *et al.*, 2013b).

Kruse et al. (2013) assess the regulating services with various data sources and the applications in an agricultural landscape in the Bornhöved Lakes District. To evaluate the carbon sequestration in the Bornhöved Lakes District, they used the model InVEST for the years 1987 and 2011, and published carbon storage values ranging from 0 to 84.5 Mg C per grid cell. A loss of carbon storage for large areas of the case study area is modelled due to the detected land cover changes. Additionally, the erosion tool of the GISCAME platform based on a water flow regulation and nutrient regulation model has calculated a soil loss in 1987 (2009.32 t) and in 2011 (5363.32 t). The decrease in area of grassland and the increase in area of cropland accounts for an increase of the soil erosion risk potential.

The researches mentioned are case studies either on land cover and land cover changes or on ecosystem service mapping, which are necessary for decision making and management. They illustrate that the potentials of several ecosystem services can be influenced by regulating ecosystem services. The understanding of regulating services in the agricultural landscape is important for the evaluation of management strategies on agricultural areas. These studies on evaluating and mapping the potentials of ecosystem services in (e.g. crops, fodder, biomass for energy and livestock) in the Bornhöved Lakes District were a part of my case study area with reclassified data for matching the matrix method.

3.3 Local assessments

Carbon storage reflects the amount of energy captured and stocked, and the utilization of solar energy by ecosystems (Eggleston *et al.*, 2006). Rubin (2006) distinguishes carbon stocks into the following pools: atmosphere, terrestrial vegetation and soil, oceans and sediments and rocks within the biotic and abiotic form. Carbon in aboveground biomass and SOC are two important carbon pools reflecting carbon sequestration in ecosystems. Carbon density in the aboveground biomass indicates the carbon storage ability of the vegetation and can be mapped as a function of land cover. Furthermore, nitrogen density, water capacity, cation exchange capacity potential (CECpot), cation exchange capacity efficiency (CECeff) and concentration of hydrogen cation (H^+) influence the carbon density through interactions of carbon storage and the nitrogen cycle, the water flow, or other elemental cycles. Data used for the analysis in this sub-section have been derived from the 'Long-Tern Research in the Bornhöved Lakes District' program (Blume *et al.*, 2007). The respective results can be used to check the regional assessment outcomes for the whole state of Schleswig-Holstein and to find additional interactions within the ecosystem physiology with reference to the global climate change regulation ecosystem service.

In order to compare the differences between carbon pools, it is necessary to account for carbon density in aboveground biomass and SOC around the Lake Belau in the Bornhöved Lakes District. “Beech forest”, “spruce forest”, “mixed forest’, “grassland” and “arable land” have been identified as dominating land cover classes. Figure 31 shows the carbon density in aboveground biomass and SOC of these five land cover classes. The beech forest has the highest carbon density in the aboveground biomass, followed by “spruce forest”, “mixed forest”, “arable land” and “grassland”. However, SOC in “mixed forest” is much higher than in the other land cover classes. SOC in “grassland” and “beech forest” takes the second and third place, respectively. The “spruce forest” stores the lowest amount of SOC. The different land cover classes mirror a distinct tendency on carbon density of in the aboveground biomass and SOC.

The nitrogen density is an important factor supporting the growth of vegetation together with carbon density. The land cover classes affect the soil carbon density and nitrogen density (Figure 32), which have been considered as the primary elements influencing vegetative development in ecosystems. The nitrogen density in “grassland” is the highest compared to the contents on the other land cover classes. The nitrogen densities in “mixed forest”, “arable land”, “beech forest” and “spruce forest” are smaller. “Mixed forest” and “grassland” have higher carbon density and nitrogen density than “beech forest”, “spruce forest” and “arable land”. SOC and nitrogen density in the land cover classes are different from one land cover to the other, but they have the same trend along the various land cover classes.

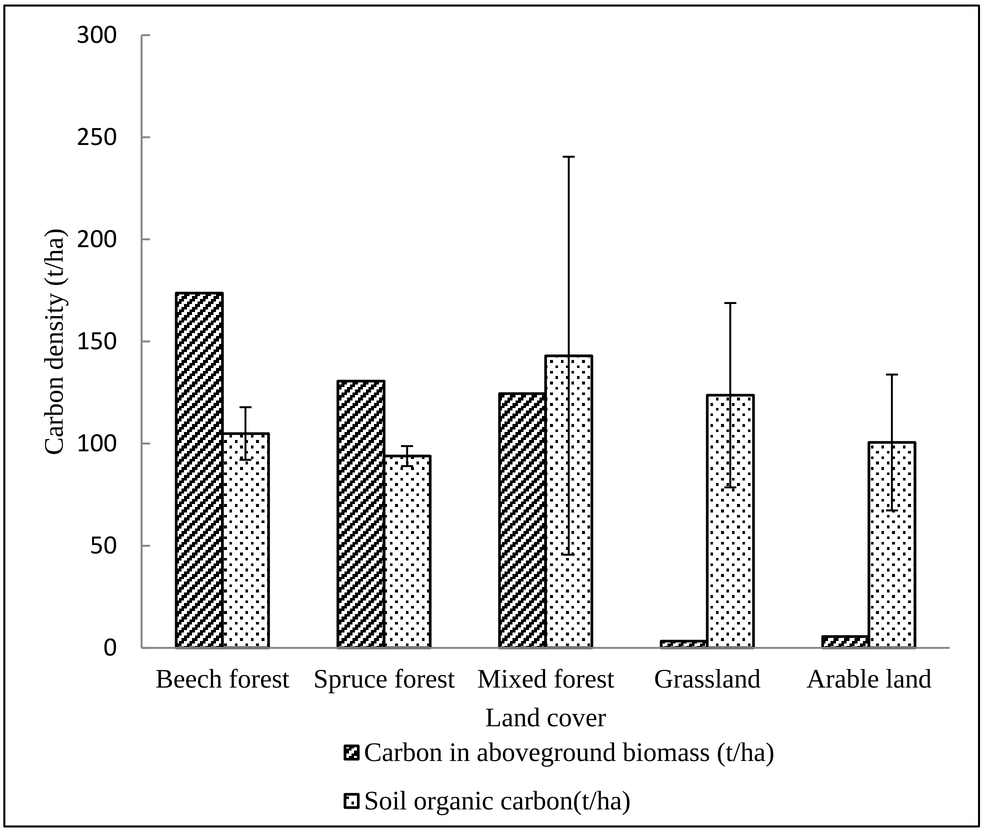

Figure 31. Carbon density in aboveground biomass and soil organic carbon of different investigated ecosystems of the Bornhöved Lakes District.

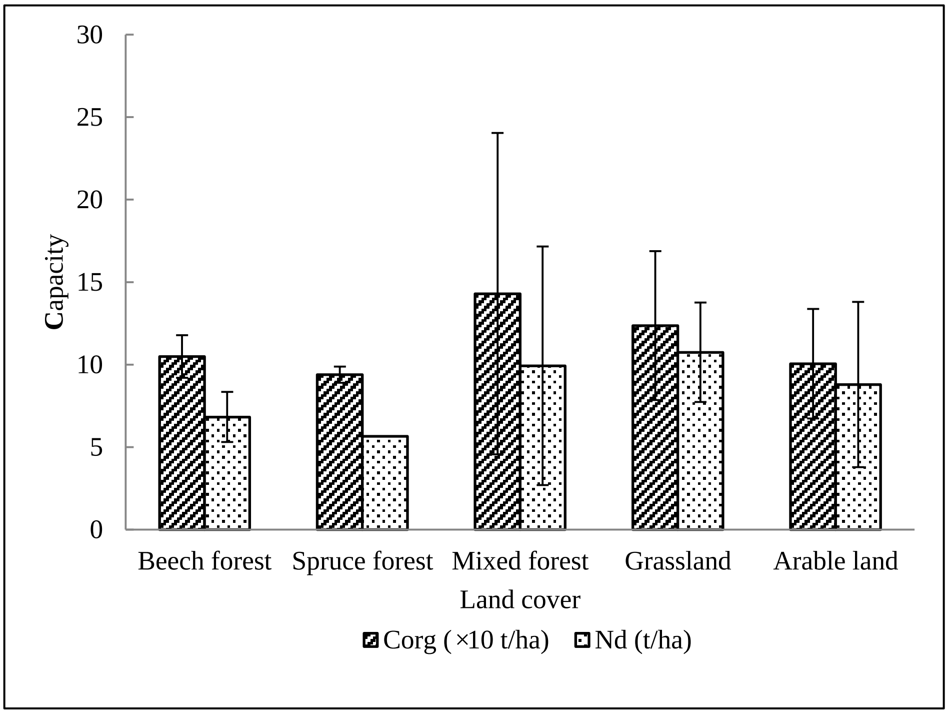

Figure 32. Soil organic carbon and nitrogen density of different investigated ecosystems of the Bornhöved Lakes District.

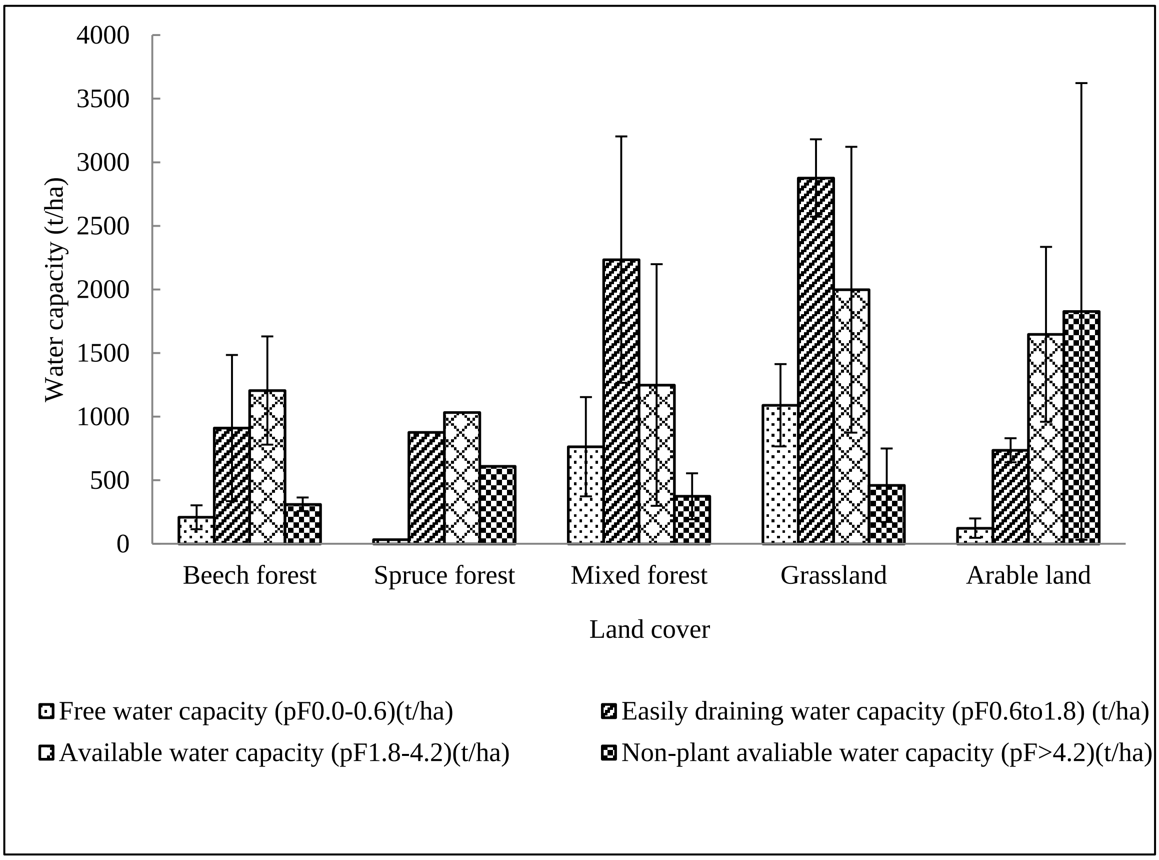

Figure 33. Water capacities of different investigated ecosystems of the Bornhöved Lakes District.

Nutrients, including carbon and nitrogen, are closely related to the water availability in ecosystems. The water capacity in soil is an important indicator because water is needed for hydration and the availability of nutrients for plant growth and the water availability for soil biological activity. The water capacity data of the different land cover classes are presented in Figure 33. The available water capacity and easily draining water capacity are higher than the free water capacity and non-plant available water capacity. “Grassland” is the land cover which has the highest water capacity compared to the other land cover classes, while the “spruce forest” has the lowest water capacity among these five types of land cover classes. “Arable land” and “mixed forest” are the land cover classes having a lower available water capacity than “grassland” but higher available water capacity than “beech forest” and “spruce forest”. Besides the available water capacity, “grassland” is the land cover class with the highest easily draining water capacity, followed by the ecosystems “mixed forest”, “beech forest”, “spruce forest” and “arable land”. Non-plant available water capacity in arable land accounts for the water capacity with the largest capacity. In contrast, available water capacity of the “beech forest” and “spruce forest” take the first place of the four water capacities even though the water capacity in these forests is lower than the capacity of other land cover classes. Free water capacity, easily draining water capacity, available water capacity and non-plant available water capacity have distinct trends in the different types of land cover.

The carbon storage in aboveground biomass and in SOC and the nitrogen content in soil and water capacity have been evaluated. It is necessary to analyze the correlation for appreciating interaction among them. Table 45 illustrates the correlation of the soil conditions (SOC, nitrogen density, cation exchange capacity potential (CECpot), cation exchange capacity efficiency (CECeff), water capacity and concentration of hydrogen cation (H^+)) on the five land cover classes. Interactions among soil nitrogen distribution, CECpot, CECeff, H^+ in soil and SOC are positively significant in the area of the Lake Belau in the Bornhöved Lake District. However, free water capacity negatively relates to the not-plant water capacity. The parameters with significant correlations denote that they are influencing each other. The nitrogen density, CECpot and CECeff are the parameters which critically impact carbon storage

Table 45. Correlation analysis of soil conditions of different investigated ecosystems of the Bornhöved Lakes District.

Correlations									
	Corg	**Nd**	**CECpot**	**CECeff**	**Free water pF0-0.6**	**Easily draining water pF0.6-1.8**	**Available water pF1.8-4.2**	**Not-plant water pF4.2**	**H^+**
Corg	1.000	0.667**	0.505**	0.486**	0.348	0.205	0.333	-0.209	0.664**
Nd		1.000	0. 788**	0.697**	0.091	0.212	-0.061	-0.182	0.646**
CECpot			1.000	0.905**	-0.077	0.154	-0.055	0.011	0. 605**
CECeff				1.000	-0.128	0.103	-0.055	0.055	0. 586**
Free water pF0-0.6					1.000	0.410	-0.282	-0.615**	0.078
Easily draining water pF0.6-1.8						1.000	-0.462*	-0.436*	0.468*
Available water pF1.8-4.2							1.000	0.143	-0.134
Not-plant water pF4.2								1.000	-0.246
H^+									1.000

Note: ** means significance > 0.01 and * means significance >0.05

Chapter 4. Discussion

This study aims at providing quantitative assessment of the land cover distributions, land cover changes and their impacts on ecosystem services, annual total Gross Primary Production (GPP) and annual total Net Primary Production (NPP) distributions, the monthly GPP distributions, calculated respiration, ratio between the annual total NPP and GPP, Soil Organic Carbon (SOC) density and Carbon Storage (CS) in each land cover. The annual total GPP and NPP, SOC and CS are classified as quantitative indicators of global climate regulation, used for comparison with the qualitative indicators from the matrix method (GCR). In order to achieve these purposes, I use the quantitative and qualitative indicators mentioned above to analyze the distributions of the indicators based on land cover, and to compare the classified quantitative and qualitative indicators of global climate regulation. The results have been produced by statistical analyse and mapping with empirical data of the study area. These findings proved the quantitative distributions of land cover and land cover changes, the annual total GPP and NPP, SOC and CS. The comparison of the indicators (the annual total GPP and NPP, SOC, CS and GCR) of global climate regulation is also disclosed by statistics. The main purpose of this chapter is to discuss the implications of the key results to determine the extent to which the distributions of land cover, landscape regions or districts are associated with the annual total GPP and NPP, SOC and CS.

4.1 Comparison of results among CORINE land cover classes

In order to define possible affections made by land cover to ecosystem services and their associated indicators, the distributions of land cover and land cover changes, the annual total GPP and NPP in each land cover, carbon storage in vegetation and in soils, the integrative model carbon output, the comparison of global climate regulation with qualitative and quantitative indicators, temporal dynamics and spatial patterns of the ecosystem service based on CORINE land cover are discussed in this section.

4.1.1 Land cover distribution and land cover changes

To investigate the land cover distributions and land cover changes in Schleswig-Holstein, the CORINE land cover maps are used as the primary data sources of the assessment. The CORINE land cover database is accessed friendly and widely used in studies relating to ecology for the whole of Europe. The database has been used for assessing ecological items and stability at the European , national, regional and local scales (Ludwig *et al.*, 2003; Cebecauer & Hofierka, 2008; Romanowicz & Osuch, 2011; Munafò *et al.*, 2013), or for evaluating ecosystem services (Kandziora *et al.*, 2013b; Kruse *et al.*, 2013). The CORINE land cover information has been used in assessing ecosystem service supply and demand at regional scale in the eastern part of Germany (Kroll *et al.*, 2012b). Land cover distributions and land cover changes in the Bornhöved Lakes area based on CORINE for the years 1990, 2000 and 2006 show that the less detailed CORINE map cannot show the land cover and land cover changes as clearly as the detailed combined ATKIS (Amtliches Topographisch-Kartographisches Informations system; Official Topographic-Cartographic Information System)/InVeKoS (Integriertes Verwaltungs- und Kontrollsystem; Integrated Administration and Control System)/Landsat system (Kandziora *et al.*, 2013b) at local scale. However, the CORINE land cover maps of

Germany have been mapped with a specific national approach using ATKIS as one basic data source (Keil *et al.*, 2014), which supports the CORINE land cover map in calculating land cover and land cover changes at regional and country-wide scales. Therefore, CORINE is well adapted for studies at broader extents and resolutions.

The findings in my study show that “non-irrigated arable land” and “pastures” are the land cover classes occupying the largest amount of areas of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012 (see Table 10). This distribution results from a significant dominance of agricultural areas in Schleswig-Holstein. The wide distributions of “non-irrigated arable land” and “pastures” have been strengthened by the European Commission Policies, for instance by the Common Agricultural Policy (CAP) (Cruickshank *et al.*, 2000; Muñoz-Rojas *et al.*, 2011). This is in agreement with Rounsevell et al. (2000), who have presented that over 50% of the surface area of the European Union is covered by agriculture.

The land cover distributions of Schleswig-Holstein based on MODIS and CORINE land cover (level 1) classifications are not completely consistent. However, “croplands”, “cropland/Natural vegetation mosaic”, “mixed forest” and “urban and built-up” compose the prime land cover classes in MODIS classification, which are similar to the major land cover classes in CORINE classification (“agricultural areas” and “forest and semi natural areas” and “artificial areas”). At the same time, the areas of CORINE land cover among 1990, 2000, 2006 and 2012 are relatively stable (Figure 15). This indicates that the GPP and NPP datasets from 2000 until 2015 based on the MODIS land cover map of Schleswig-Holstein in 2004 are reliable (Running & Zhao, 2015). The MODIS products about GPP and NPP are used for analyzing the annual total GPP and NPP distributions, and monthly distributions based on the CORINE land cover level 3 classes, being discussed in chapter 4.1.2.

Assessing the land cover changes is a vital factor, most areas of the land cover changes in Schleswig-Holstein are among “non-irrigated arable land”, “pastures” and “complex cultivation patterns”. This result is supported by the comparison of land cover distribution maps of the Bornhöved Lakes Area for the years 1990, 2000, and 2006 based on CORINE data (Kandziora et al., 2013b, P49). Feranec et al. (2010) also confirmed that the most extensive land cover changes area induced by “intensification of agriculture” in Europe between 1990 and 2000 based on CORINE land cover. The study on CORINE land cover changes and vegetation carbon stocks in Spain shows that a large area relates to “arable land” or has transformed to “pastures” (Muñoz-Rojas *et al.*, 2011). Furthermore, a study on CORINE land cover changes between 2000 and 2006 in Germany presents that land cover changes from “coniferous forest” to “transitional woodland-shrub”, from “pastures” to “non-irrigated arable land”, from “non-irrigated arable land” to “discontinuous urban fabric” and from “transitional woodland-shrub” to “mixed forest” are the dominating changes (Keil *et al.*, 2014). The transformations agree with that there are a large number of areas changed from other land cover classes into “non-irrigated arable land” and simultaneously a great many of areas transformed from “non-irrigated arable land” to the other land cover classes during the periods 1990-2000, 2000-2006 and 2006-2012 in my study (see Table 8-10 in the Appendix A). The imparities between the study of the whole country of Germany and my research in Schleswig-Holstein may result from the fact that

Schleswig-Holstein has been taken as an important agricultural state where much attention is paid on developing agriculture. Consequently, the land cover changes in Schleswig-Holstein focus on the changes among agricultural land cover classes, such as “non-irrigated arable land”, “pastures” and “complex cultivation patterns”. The reduction of “pastures” and increase of “non-irrigated arable land” during the four periods have been resulted from the political planning of rising the amounts of biogas plants and decreasing food plants in order to carry out the ecosystem service target changing from food to energy production.

Land cover changes are droved by complex environmental, social and economic conditions, they are focal items for making sustainable land cover plans (Feranec *et al.*, 2010; Hewitt & Escobar, 2011). The transformations frequently happen due to human activities which have been influenced increasingly by political plans during these centuries, for instance urbanization, or intensively using agricultural land (Feranec *et al.*, 2007) . Land cover changes in Schleswig-Holstein have been often initiated by the cultivation of silage maize for biogas plants, which has been discussed widely as a German political issue. May be today this is an important parameter which provides the highest overall impacts land cover (Landwirtschaftskammer Schleswig-Holstein, 2011). The possible target parameter is the renewable energy sources (RES) system in Germany. The vision about RES has been established since 1980, developing during the 1990s and 2000s, and has become as a consensual aim in 2010 because of a continuously growing number of beneficiaries (Strunz, 2014). Biogas, energy has become an important political target due to the decision of the German government to close down the nuclear power plants. Following the energy transitional regime, the number of biogas plants in Germany significantly grows by 57.6 times from 1992 until 2013 (Baumann, 2014). As the critical biogas plants, pastures and maize have been cultivated increasingly during the recent decades. Schleswig-Holstein is one of the important agricultural states in Germany, and regenerating the land cover classes of “pasture”, “non-irrigated arable land” or “complex cultivation patterns” is a prime step for developing RES. However, the land cover changes from 2006 to 2012 account for 31.10% of the land cover areas during this period, being prominently higher than the other two periods. Consequently, the heterogeneity of land cover changes is manly results from the developing stages of RES. Parts of these changes are appearing because that a specific national approach has been used in the updated 2012 CORINE land cover maps, which are the official topographical cartographic information system ATKIS as the land survey authorities, being different approach used for the years 1990, 2000 and 2006 (Environmental Protection Agency, 2015). Thus, several modifications between the years 2006 and 2012 are based on that change of satellite image interpretation techniques. In the preceding chapters such potential factors are for example appearing with replace to land cover classes, such as “continuous urban fabric”, “discontinuous urban fabric”, “industrial or commercial units”, “port areas”, “green urban areas”, “sport and leisure facilities”, “complex cultivation patterns”, “land principally occupied by agriculture”, “beaches, dunes, sands”, “sparsely vegetated areas”, “salt marshes” and “coastal lagoons”. Besides the land cover change assessments, the Shannon Index and the land cover diversity index also indicate the temporal-spatial land cover distribution of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012 (Table 17 and Figure 7). 2012 and 2006 have the lowest and highest land cover diversities, respectably. Schleswig-Holstein has the low and high fragmented land cover in 2012 and 2006 implicates that land cover in 2012 is of benefit to enhance stability of economic and biodiversity due to the integrity resulting from the land cover.

4.1.2 Relationship between GPP or NPP and land cover

The land cover classes in Schleswig-Holstein which have the largest annual total GPP and NPP (see Figure 17 a and 22 a) are “coniferous forest” (1246.58 g C m^{-2} yr^{-1} GPP in 2000, 1138.21 g C m^{-2} yr^{-1} GPP in 2006, 1175.68 g C m^{-2} yr^{-1} GPP in 2012, 690.82 g C m^{-2} yr^{-1} NPP in 2000, 574.86 g C m^{-2} yr^{-1} NPP in 2006, and 646.47 g C m^{-2} yr^{-1} NPP in 2012), “mixed forest” (1208.77 g C m^{-2} yr^{-1} GPP in 2000, 1106.96 g C m^{-2} yr^{-1} GPP in 2006, 1148.82 g C m^{-2} yr^{-1} GPP in 2012, 675.58 g C m^{-2} yr^{-1} NPP in 2000, 567.13 g C m^{-2} yr^{-1} NPP in 2006, and 642.21 g C m^{-2} yr^{-1} NPP in 2012), “broad-leaved forest” (1220.96 g C m^{-2} yr^{-1} GPP in 2000, 1103.31 g C m^{-2} yr^{-1} GPP in 2006, 1126.88 g C m^{-2} yr^{-1} GPP in 2012, 675.58 g C m^{-2} yr^{-1} NPP in 2000, 567.13 g C m^{-2} yr^{-1} NPP in 2006, and 642.21 g C m^{-2} yr^{-1} NPP in 2012), and “pastures” (1234.57 g C m^{-2} yr^{-1} GPP in 2000, 1138.41 g C m^{-2} yr^{-1} GPP in 2006, 1141.68 g C m^{-2} yr^{-1} GPP in 2012, 677.84 g C m^{-2} yr^{-1} NPP in 2000, 594.54 g C m^{-2} yr^{-1} NPP in 2006, and 640.84 g C m^{-2} yr^{-1} NPP in 2012). The annual total NPP of my study have similar results as a previous study about NPP (456.8 g C m^{-2} yr^{-1} NPP in needle forest, 613.1 g C m^{-2} yr^{-1} NPP in broad-leaf forest, 559.5 g C m^{-2} yr^{-1} g C m^{-2} yr^{-1} NPP in mixed forest and 122.6 in grass g C m^{-2} yr^{-1} NPP in grass land) of Chinese terrestrial ecosystems (Feng *et al.*, 2007). The reasons account for the annual total NPP in the three types of forests and grass land of China is lower than the annual total NPP of Schleswig-Holstein are that the Chinese geophysical and geochemical conditions are much more heterogeneous than the conditions in Schleswig-Holsten. The heterogeneous conditions may lead to the negative influences on GPP and NPP through affecting vegetation growth. El-Masri et al.'s (2013) research presents that forests (2.6-2.9 Kg C m^{-2} yr^{-1} for the annual total GPP and 1.0-1.1 Kg C m^{-2} yr^{-1} for the annual total NPP) and pastures (2.1 Kg C m^{-2} yr^{-1} for the annual total GPP and 1.1 Kg C m^{-2} yr^{-1} for the annual total NPP), depicting “pastures” and forests have similar abilities to fixing energy and materials through storing GPP and NPP (Sjöström *et al.*, 2013). Nutrient availability, such as phosphorus, calcium and potassium which are imported during the process of fertilization, seems to support that “pastures” are in performing so well parallel with forests. However, the annual total GPP and the annual total NPP in other land cover classes are different from the annual total GPP and NPP in “pastures” and forests. Reasons resulting in the differences of the annual total GPP and the annual total NPP based on 17 land cover classes are that the land cover changes may have impacts on albedo, evapotranspiration, sources and sinks of gases which are ingredients of biological sequestration (Pachauri & Meyer, 2014).

The annual stored GPP and the annual stored NPP (see Figure 17 b and 22 b) in “non-irrigated arable land” and “pastures” are much more than the other land cover classes even if the annual total GPP and the annual total NPP in “non-irrigated arable land” and “pastures” are similar to the other land cover classes illustrate that the affection from the annual total GPP and the annual total NPP are not as obvious as that from the land cover areas (see Table 26 and Table 33). Meanwhile, the annual total GPP and the annual total NPP are affected by the land cover classes. These results support that the land cover changes have significant effects on biological sequestration (Wang *et al.*, 2011; Chen *et al.*, 2015), such as GPP and NPP which further affect carbon storage and sequestration.

Studies have demonstrated that models can estimate monthly GPP of various ecosystems based on the use of remotely sensed data besides the established method of eddy covariance (Chiesi *et al.*, 2007; Shim *et al.*, 2014). The model C-Fix has been applied in Italian forest areas, where it is capable of accurately reproducing monthly GPP proved with the method of eddy covariance (Maselli *et al.*, 2006). The outcome of monthly GPP estimated with model C-Fix ranges from 10 g C m^{-2} $month^{-1}$ to 280 g C m^{-2} $month^{-1}$, which is similar to the result shown in this study, ranging from 0 g C m^{-2} $month^{-1}$ to 384.6 g C m^{-2} $month^{-1}$ (see Figure 20). At the same time, the MODIS data sets of GPP and NPP have been widely used for global or regional ecological studies on energy fixation and drought-induced reduction (Turner *et al.*, 2003; Zhao & Running, 2010). The study on comparison of the monthly variability of GPP at the Gwangneung Deciduous site (GDK) flux tower with the MODIS GPP presents that the MODIS GPP reaches a maximum in June and May, which also is in agreement with monthly GPP of Schleswig-Holstein. The reason of the fluctuation is that GPP is mostly related to the photosynthesis rates of biomass. GPP of the growing months is much higher than GPP of the other months due to the strong photosynthesis. Moreover, the maximum of monthly GPP appears in June or May (maximum solar radiation due to clearer sky condition) rather than in July and August (maximum temperature) which illustrates that monthly GPP is influenced more strongly by solar radiation and temperature (Shim *et al.*, 2014). Furthermore, the species composition of vegetation is the other prime factor that influences the photosynthesis of biomass, being associated with monthly GPP. Grain, corn, root crops and winter rape are the dominating types of plated species in Schleswig-Holstein, which have significant relationships with the annual total GPP and the annual total NPP due to being much more sensitive to solar radiation than to temperature (Muchow *et al.*, 1990).

The annual plant respiration is calculated as the difference between GPP and NPP (Zhang *et al.*, 2009), being presented in Figure 24. The calculated respiration and GPP at different ages of forests range from 230 g C m^{-2} yr^{-1} to 340 g C m^{-2} yr^{-1} in Goulden's et al. study (2011). However, respiration and GPP on the land cover classes of Schleswig-Holstein range from around 182.33 g C m^{-2} yr^{-1} to 556.73 g C m^{-2} yr^{-1} in 2000, from 188.34g C m^{-2} yr^{-1} to 563.34 g C m^{-2} yr^{-1} in 2006, and from 101.56g C m^{-2} yr^{-1} to 529.20 g C m^{-2} yr^{-1} in 2012. This study contains 17 land cover classes, attributing to the large differences of the calculated respirations, leads to the heterogeneity of the land cover classes.

The ratios of NPP/GPP are between 0.5011 and 0.6774 in Schleswig-Holstein, which relates to geographical, topographic and climatic factors, need to be discussed in order to understanding the carbon storage of ecosystems and their responses to climate change (Cheng *et al.*, 2000; De Lucia *et al.*, 2007). The NPP/GPP ratio is affected by latitude, altitude and precipitation evidently (Zhang *et al.*, 2009). The study on global NPP/GPP rations claim that the ratio fluctuates with an average of 0.5 from 2000 until 2003, and the ratio is stabilized around 0.61 between 30° and 60° of Northern Hemisphere. The NPP/GPP ratios of Schleswig-Holstein for the years 2000, 2006 and 2012 match to the results of Zhang's study. Additionally, "sparse herbaceous or shrub vegetation", "pastures", "mixed forest", "coniferous forest" and "broad-leaved forest" are the land cover classes that have the highest NPP/GPP ratio.

4.1.3 Carbon storage in vegetation and in soils, and integrative model outputs for Schleswig-Holstein

Land cover is critical for carbon dynamics because of the verying amount of biomass and soil carbon stored in various land cover classes and due to the losses in carbon storage during the processes of land cover changes. In my study, “mixed forest” (209.60 Mg C ha^{-1}), “broad-leaved forest” (232.58 Mg C ha^{-1}), “coniferous forest” (198.91Mg C ha^{-1}) are the land cover classes which have the greatest carbon storage (Table 41). The land cover classes of “patures” (104.45 Mg C ha^{-1}), “complex cultivated patterns” (96.87 Mg C ha^{-1}) and “non-irrigated arable land” (94.82 Mg C ha^{-1}) have lower carbon storage than the forests but higher carbon storage than other land cover classes. The land cover classes in Schleswig-Holstein having high abilities to stock carbon are the ones that are primarily oppupied by vegetation. Vegetation with large biomass per area, such as “mixed forest”, “broad-leaved forest”, “coniferous forest”, account for a high ability of carbon storage. This consituation exists because the increasing intensity of urban development is considered as the reason of decreasing of the carbon sensity in terrestrial land cover (Tao *et al.*, 2015). The land cover classes with higher vegetation covers, for example forest, grassland or agricultural areas converted from other land cover classes lead to higher carbon storage in the area (Churkina *et al.*, 2010).

The carbon strorage abilities are different from one carbon pool to another. The SOC is the greatest of the four carbon pools of aboveground, belowground, litter and SOC in my study. As the most important carbon pool, SOC of Schleswig-Holstein has been characterised by the maximum, medium and minimun values for each land cover classes due to the down-scaling demand of the data source (see Table 6). The ranges of SOC and the carbon storage modeled by InVEST can be estimated due to the maximum, medium and minimun SOC values. Furthermore, the evaluation of carbon storage through the InVEST model with the maximum, the medium, and the minimum SOC reduce the uncertainties account for the down-scaling use of the SOC data source. Moreover, SOC and carbon stored in vegetation and litter are long-term and relative stable carbon pools. They are closely correlated to the land cover classes and land cover changes. “Peat bogs” have the greatest SOC in all the land cover classes, which is agree with Kruse’s study about quantifying regulationg services with the indicator of carbon storage (2013). SOC in “natural grasslands”, “pastures”, “complex cultuvation patterns”, “non-irrigated arable land” of Schleswig-Holstein with the amounts of 97.97 Mg C ha^{-1}, 97.75 Mg C ha^{-1}, 93.22 Mg C ha^{-1} and 92.62 Mg C ha^{-1} are higher than SOC in “coniferous forest”, “broad-leaved forest”, and “mixed forest” with medium values of 85.05 Mg C ha^{-1}, 79.48 Mg C ha^{-1} and 76.12 Mg C ha^{-1}. The study on physical, chemical and biological characteristics of soils shows similar trends that SOC in arable land is higher than SOC in forests (Ordoñez *et al.*, 2015). Fertilization and pesticide account for the increase of SOC due to significant correlations between SOC and nitrogen density, cation exchange capacity potential (CECpot) and cation exchange capacity efficiency (CECeff) in soil (Table 45). Carbon density in soil and biomass in five land cover classes around the Bornhöved Lakes District also illustrate that SOC in grassland and arable land are higher than in beech forest and spruce forest (see Figure 31).

Besides SOC, the aboved-ground carbon pool is the second largest one, followed by the carbon pool of belowground (see Table 6). The results are in agreement with the findings of He et al.’s 2016 and Sallustio et al.'s (2015) studis about the carbon density of the above-ground, below-ground, soil and litter carbon pools. The above-ground carbon density in cropland, woodland, and grassland of Beijing are 7.4 Mg C hm^{-2} , 43.2

Mg C hm^{-2} and 0.7 Mg C hm^{-2}, while the below-ground carbon density are 0.7 Mg C hm^{-2} , 10.8Mg C hm^{-2} and 2.8 Mg C hm^{-2} in cropland, woodland, grassland and unused land (He *et al.*, 2016). However, the above-ground carbon density in “non-irrigated arable land”, forest, “natural grassland” of Schleswig-Holstein are 1.71 Mg C ha^{-1}, 100 Mg C ha^{-1} and 1.34 Mg C ha^{-1}, and the below-ground carbon density are 0.49 Mg C ha^{-1}, 21.8 Mg C ha^{-1} and 0.16 Mg C ha^{-1}. The carbon density differences may be because the study area of He et al. locates in urban areas of China where is in different climatic zones and different soil conditions compared to the climatic and soil conditions of Schleswig-Holstein. Furthermore, forest ages, strongly affecting carbon density, in Schleswig-Holstein are much older than the forest ages in Beijing. It results in the either the above-ground carbon density or the below-ground carbon density in Schlewswig-Holstein is higher than the carbon density in Beijing. Despite that the distictions of carbon density between Beijing and Schleswig-Holstein are relatively high, the above-ground and below-ground carbon density in forest and arable land in Italy are similar to the carbon density in Schleswig-Holstein (Sallustio *et al.*, 2015), resulting from closely resembled grographic and climate development.

The InVEST model is a widely used model to assess carbon stroage at multiple scales. The result of carbon storage in the different land cover classes of Schleswig-Holstien calculated by the InVEST model are presented with the three versions of maximum, the medium, and the minimum carbon storage to the different SOC assigements (see Figure 27.) is in agreement with the result of the case studies that woodland or forests are the land cover classes which have higher carbon stroage, flowed by grassland and arable land. Case studies on evaluation of the carbon storage based on the InVEST model have been done either in the urban area of Beijing which presents the carbon storage loss are 0.10 Tg, 0.42 Tg, 1.54 Tg, 3.22 Tg, and 1,53 Tg in the diferent annular areas formed by the ring road, or in the northern German agricultural landscape including carbon storage in maize, rapeseed, cereals, grassland, broad-leaved forest, coniferous forest, bog, sealed area, water bodies and mineral extrction (Kruse *et al.*, 2013; He *et al.*, 2016). Kruse’s study present broad-leaved forest, coniferous forest and grassland are the land cover classes storing much carbon than the other land cover, which is agree with the results of my study.

4.1.4 Comparison of global climate regulation with the different indicators based on CORINE land cover

The annual total GPP, the annual total NPP, SOC and CS have been used as quantitative indicators as well as the secondary indicators of the global climate regulation due to the difficulty of getting primary data about the service. The annual total GPP and the annual total NPP distribution and reclassification of the annual total GPP and the annual total NPP based on land cover into the classes 0-5 (Figure29 and Table 42) show that different indicators account for distinct mapping results of global climate regulation service. Maps evaluated with qualitative and quantitative indicators of the ecosystem service of global climate regulation present similar results as the correlation analysis. The differences of the mapping results are from the distinctions of the land cover distributions and the reclassified classes for the land cover classes. The maps in Figure 29 illustrate that the land cover classes covering large areas of Schleswig-Holstein, such as “non-irrigated arable land”, “complex cultivation patterns” and “pastures” are classified into class3 and 4, class 5, class 3 and 4, class 2, and class 1 and 2 for the indicators of the annual total GPP, the annual total NPP, and SOC, CS and GCR.

The annual total GPP and the annual total NPP, SOC and CS are closely correlated because the calculation of the annual total NPP and CS is based on the annual total GPP and SOC, respectively (see Figure 28). GCR has significant correlations with the quantitative indicators and the close correlation with CS illustrates that the qualitative and quantitative indicators of global climate regulation can be used to indicate the service. CS is the quantitative indicator which emerges similar result as the qualitative indicator. Hence, the uncertainties resulted from the background and acknowledgements of experts might be reduced when assessing ecosystem services with quantitative indicators. In spite of that the inaccuracy could be decreased if the quantitative indicators used the uncertainties form the various quantitative indicators need to be considered as well. Heterogeneity of the maps (see Table 43) with the indicators of the annual total GPP, the annual total NPP, SOC, CS and GCR are 0.432, 0.391, 0.433 and 0.255, being higher than the diversity of the maps (MCS ranges from 0.15 to 0.27) on climate regulation based on a national scale in Europe, assessed with various sources of indicators, such as Net Ecosystem Productivity (NEP) based on RS image (Schulp *et al.*, 2014). The different chosen indicators, various data sources and the distinct research scales compose the differences of the research results between the study based on the national classes of the whole Europe and my study which is on land cover classes of country-wide Schleswig-Holstein. Therefore, finding out the most suitable quantitative indicator for ecosystem service assessments is critical for evaluation.

4.1.5 Temporal dynamics and spatial patterns of the investigated ecosystem services

The spatial dynamics of the ecosystem services of crops, domestic livestock and landscape aesthetics and inspiration assessed with qualitative indicators are discussed in this sub-section. The results in chapter 3.1.2.1 to chapter 3.1.2.3 present that “broad-leaved forest”, “coniferous forest” and “mixed forest” are the land cover classes having very high potentials of the regulation service (global climate regulation) and the cultural service (landscape aesthetics and inspiration), but no potential in the provisioning services of crops and livestock. Another result shows that “non-irrigated arable land” has a high potential for the provisioning service crops and no potential of provisioning service livestock. Meanwhile, “pastures” provide high potentials of the provisioning service livestock and no potential of provisioning service crops. The results are similar to outcomes of the study of Cabral et al.'s (2016), which show that climate regulation decreases more in the urban areas and areas with a few trees and the ecosystem service recreation is also affected by the urbanization and forest stuck. Moreover, the results of my study illustrate that the same land cover may lead to distinct distributions of different ecosystem services, and even in the same ecosystem service category, e.g. provisioning services, different land cover classes may account for different service potentials (see Table 19-20). The results have agreements with the study on the provision services of crops and fodder in Bornhöved Lake Area (Kandziora *et al.*, 2013b). This study supply the different capacities for the provisioning services crops and fodders in “non-irrigated arable land”, “pastures” and “complex cultivation patterns”. Hence, it is necessary for the managers or the policy makers to consider the achievements relying on the distributions of the land cover classes in order to gain the comprehensively high benefits.

Land cover changes are another important factor besides the land cover distributions, which influences ecosystem services. Mapping the ecosystem services of crops, domestic livestock, and landscape aesthetics and inspiration for the years 1990, 2000, 2006 and 2012 presents the temporal-spatial dynamic of the ecosystem services evaluated with the qualitative indicators (chapter 3.1.2.4). The land cover changes results show that the primary land cover changes are among “non-irrigated arable land”, “pastures” and “complex cultivation patterns” during the periods of 1990-2000, 2000-2006 and 2006-2012 (see Table 2 and Table 8-10 in the appendix). The areas of “non-irrigated arable land” increase by 75176 ha from 1990 to 2012, meanwhile the areas of “complex cultivation patterns” and “pastures” decrease by 95,235 ha and 12653 ha during the same period. “Non-irrigated arable land” and “pastures” belong to class 1 and class 2 of the global climate regulation potential. The area increase of “non-irrigated arable land” (class 1) and the decrease of “pastures” (class 2) account for the evaluation that the decline is much higher than the increase of the global regulation potential change during 1990-2012. For the provisioning service crops, the declining areas of “complex cultivation patterns” (class 4 of the crops potential classification) is larger than the increasing areas of “non-irrigated arable land” (class 5 of the crops potential classification). The circumstances contribute to the fact that the decrease of provisioning service crops is much more significant than the increase. Similarly to the provisioning service crops, the provisioning service (livestock) decrease much more than they increase from 1990 to 2012. However, the reason is different from the one contributing to provisioning service crops. The area decrease of “pastures” (class 5) and “complex cultivation patterns” (class 1), and the area increase of “non-irrigated arable land” (class 0) are responsible for the decrease of the provisioning service (livestock) is much than the increase. The reasons why the decrease of culture service (landscape aesthetics and inspiration) is much than the increase is that the decrease area is related to “pastures” (class 2) and “complex cultivation patterns” (class 2), which the increase area is assigned to “non-irrigated arable land” (class 1). The land cover area changes account for the carbon storage decrease 17.24 Tg in Andalusia between 1956 and 2007 as well (Muñoz-Rojas *et al.*, 2011). The ecosystem service global climate regulation which takes carbon storage as an important indicator decline due to the obvious land cover changes from agricultural areas (5089 km^2) to other land cover areas. Therefore, the land cover dynamics are the primary factors influencing ecosystem services.

4.2 Comparison of results among landscape regions

Within the study on land cover distributions, the annual total GPP and the annual total NPP distributions based on landscape regions have been quantified and analyzed as one section of my research. In this sub-section, the relationships between the annual total GPP or the annual total NPP and landscape regions are discussed to show the influence of the landscape regions on the distributions of the annual total GPP and NPP.

4.2.1 Land cover distribution

The analysis of potential interactions between the land cover classes and regional classes (Table 11-13) demonstrate that “pastures” and “non-irrigated arable land” are the land cover classes suitable and needed by human beings in Geest, Marsch and Hügelland for the years 1990, 2000, 2006 and 2012. This is also due to the political issue of cultivating of silage maize for biogas plants (Landwirtschaftskammer Schleswig-Holstein, 2011; Kandziora *et al.*, 2013b). 60% of “non-irrigated arable land” (406052 ha in 1990, 402026 ha in 2000, 391748 ha in 2006 and 396942 ha in 2012) locates in Hügelland, and "pasture" is much more present in Geest (289630 ha in 1990, 288057 ha in 2000, 218510 ha in 2006 and 249821 ha in 2012) in comparison with Marsch and Hügelland. Furthermore, statistical reports on land cover and harvest of Schleswig-Holstein give more insights into the influence of landscape regions on land cover distributions. The statistic results show that the areas of permanent pastures in Geest are averagely 52720 ha from 2000 to 2005 and averagely 28899 ha from 2006 to 2011, which are larger than the areas in Marsch (averagely 8726 ha during 2000-2005 and averagely 4123 ha during 2006-2011) and Hügelland (averagely 21186 ha during 2000-2005 and averagely 15655 ha during 2006-2011). And the same periods, the areas of grain, root crop, winter rape and green maize in Hügelland are more than the areas in Geest and Marsch (Statistisches Amt für Hamburg und Schleswig-Holstein, 2007, 2013). The results of my study together with the statistic reports illustrate that Geest is the landscape region being mainly suitable to develop pastures and Hügelland is adaptable to extend arable land in Schleswig-Holstein. In spite of that the land cover classes occupying the large areas have been clearly identified, the land cover classes with the small areas need to be recognized much carefully. "Moors and heathland" can be found in Hügelland based on the study of mapping provisioning ecosystem services within the ATKIS land cover maps (Kandziora *et al.*, 2013b), but ignored by the CORINE land cover maps. The missing land cover class ("moors and heathland") may result from the small areas being less than the minimum clarified areas (25 ha) have been ignored in the CORINE land cover classification (Kosztra *et al.*, 2014).

4.2.2 Relationship between GPP, NPP and landscape regions

Marsch Hügelland have the highest and lowest annual total GPP and the annual total NPP due to the distinct vegetation in the various land cover classes, soil conditions and environmental stresses. The results of the annual total GPP and NPP based on land cover of landscape regions (Table 28 and Table 35) show that the annual total GPP and NPP of one land cover fluctuate among the different landscape regions (Geest, Marsch and Hügelland). This corresponds to carbon dynamics studies linking the differences of GPP and NPP to water and nutrient stresses (Sakai *et al.*, 2004; El-Masri *et al.*, 2013). El-Masri et al.'s (2013) study illustrates that different soil types of the landscape regions, such as regions covered by clay have relative higher GPP and NPP than the regions covered by silt and sand and regions locating on sand have the lowest GPP and NPP. The distribution trends of GPP and NPP are agree with the results of the annual total GPP and the annual total NPP in the three regions of Schleswig-Holstein.

The annual total stored GPP and the annual total stored NPP in Geest is higher than in Marsch and Hügelland, and Marsch has the lowest annual total stored GPP and the annual total stored NPP of the years 2000, 2006 and 2012. It is because the differences of the annual total stored GPP and the annual total NPP based on the landscape regions are primarily from the land cover distributions (see Table 29 and Table 36). "Pastures" and "non-irrigated arable land", which has the higher annual total stored GPP and the higher annual total stored NPP compared with the other land cover classes, occupy the most of Geest's areas for the years 2000, 2006 and 2012. "Pastures", "non-irrigated arable land" and "complex cultivation patterns" are the main land cover classes which primarily compose Marsch. They contribute to the annual total stored GPP and the annual total stored NPP to be the region having the largest annual total stored GPP and the annual total stored NPP in Marsch. “Pastures” “non-irrigated arable land” and “broad-leaved forest” are the widely covering land cover classes in Hügelland, which leads to the high annual total stored GPP and the high annual total stored NPP in the three land cover classes for the years 2000, 2006 and 2012.

The maps of hotspots and cold spots for the annual total GPP and the annual total NPP indicate that the total GPP and the annual total NPP for the years 2000, 2006 and 2012 are not scattered randomly across Schleswig-Holstein, but rather occur in particular patterns (Figure 26). The distribution of the annual total GPP and the annual total NPP of Schleswig-Holstein for the years 2000, 2006 and 2012 are much clearer through the analysis. The hotspots depict areas with high levels of the annual total GPP and the annual total NPP, and the cold spots presents areas with low level of the annual total GPP and the annual total NPP. My study shows that the areas of hotspots of the annual total GPP and NPP concentrate in Geest. Meanwhile, the areas of cold spots of the annual total GPP and NPP are mainly located in the western and eastern Schleswig-Holstein for the years 2000, 2006 and 2012. However, the distributions of hotspots and cold spots are relative values within one map, illustrating areas with high or low levels in one temporal- spatial item, respectively (Plieninger *et al.*, 2013). The areas of “pastures” in Geest, Marsch and Hügelland decrease from 2000 to 2006, and the locations of the changed “pastures” match to the hotspots loss of the annual total GPP and NPP form 2000 to 2006. Similarly to situation that “pastures” leads the hotspots loss from 2000 to 2006. “Complex cultivation patterns” result in the hotspots loss of the annual total GPP and NPP from 2006 to 2012 due to the sharp area decline of “complex cultivation patterns” in Geest, Marsch and Hügelland since 2006 until 2012. Enhancing the annual total GPP and the annual total NPP in the western and eastern Schleswig-Holstein may increase the annual total stored GPP and the annual total stored NPP. Expending the land cover areas of “pastures” and “complex cultivation patterns” in Geest, Marsch and Hügelland is critical to increase the annual total stored GPP and the annual total stored NPP which are representative of the ability of fixing solar energy and material.

Monthly GPP in Marsch and Hügelland are excessing of monthly GPP in Geest during the periods of March to July and November to December (see Figure 19). “Broad-leaved forest”, “coniferous forest” and “mixed forest” which having the higher annual GPP are primarily distributing in Marsch and Hügelland. Wang et al.’s (2003) research on the spatial and temporal variability of GPP presents that GPP in forests has a high amount from March to July and reaches a peak in April. The results explain why monthly GPP in Marsch and Hügelland mainly dominated by arable lands and forests are higher than monthly GPP in Geest from March to July. From August to October, GPP in Geest is higher than GPP in Marsch and Hügelland. The reason is that “pastures”, occupying the largest areas of Geest, have high monthly GPP rates during the period from August to October in Schleswig-Holstein. The monthly GPP of Geest fluctuates from 149.26 g C m^{-2} yr^{-1} to 73.69 g C m^{-2} yr^{-1}. The result is in agreement with the study of the U.S. national grasslands which presents that the monthly GPP of grasslands are from153.42 g C m^{-2} yr^{-1} to 70.15 g C m^{-2} yr^{-1} during August to October (Sun *et al.*, 2015). Monthly GPP in Marsch and Hügelland is higher than monthly GPP in Geest from November to December. It is because root crops and winter rape contributing to monthly GPP during the months, and they are classified as “non-irrigated arable land” which are coring areas in Marsch and Hügelland.

4.3 Comparison of results among districts

Assessing the land cover distributions, the annual total GPP and the annual total NPP distributions based on districts is useful for understanding the consequences of the land cover distributions of districts affected by complex socio-economic and biophysical conditions (Upadhyay *et al.*, 2006). In this sub-section, the annual total GPP and NPP and comparison of the correlation of GPP, NPP and harvest are combined to land cover classes of each district.

4.3.1 Land cover distribution

The land cover distributions and ecosystem services affected by the districts are interpreted, besides the land cover distributions based on the landscape regions and the potential interactions between the land cover classes and landscape regional classes mentioned above. “Non-irrigated arable land” and “pastures” which are the two main land cover classes in Schleswig-Holstein are not distributed homogeneously among different districts for the years 1990, 2000, 2006 and 2012. This situation is caused by the soil conditions, landscape regions, economics and political plans. Vice versa, the results about the correlations between the 32 land cover distributions in 15 different districts and the soil conditions, landscape regions are typical factors which may influence land cover management of Schleswig-Holstein for land cover planners. The study about the land cover changes and soil erosion in Slovakia interpret that the transformation of political system followed by the transformation of society and economics may induce significant land cover changes with consequences on soil patterns (Cebecauer & Hofierka, 2008).

Besides “non-irrigated arable land” and “pastures”, the areas of artificial surfaces (CORINE land cover level 1), including “continuous urban fabric”, “discontinuous urban fabric”, “industrial or commercial units”, “road and rail networks and associated land”, “port areas”, “airports”, “green urban areas”, and “sport and leisure facilities” (CORINE land cover level 3) fluctuate sharply from 2006 to 2012 indicate that the land cover distributions in 2012 produced with new technologies need to be calibrate further at the district scales.

Even though the further calibration are necessary, the distributions of the artificial land cover classes have similar areas in Dithmarschen, Hzgt. Lauenburg, Nordfriesland, Ostholstein, Pinneberg, Plön, Rendsburg-Eckernförde, Schleswig Flensburg, Segeberg, Steinburg and Stormarn for the years 1990, 2000 and 2006 (see Appendix A Table 5). The fluctuations of the land cover areas (CORINE land cover level 3) in Kiel (“continuous urban fabric” areas are from 204 ha in 2006 to 112 ha in 2012), Lübeck (“continuous urban fabric” areas are from 459 ha in 2006 to 125 ha in 2012), Flensburg (“continuous urban fabric” areas are from 81 ha in 2006 to 39 ha in 2012) and Neumünster (“continuous urban fabric” areas are from 0 ha in 2006 to 41 ha in 2012) are much sharper than the fluctuations in the other districts of Schleswig-Holstein, resulting from the fact that Kiel, Lübeck, Flensburg and Neumünster contain less total areas but much more artificial areas than the other districts. It indicates that Kiel, Lübeck, Flensburg and Neumünster are fragmental areas, which enhances the possibilities of inaccuracy in calculating the land cover distributions.

Even though, the areas of land cover classified with the CORINE land cover level 1 are similar among the years 1990, 2000, 2006 and 2012, interpreting the stability of the land cover distractions and low land cover changes based on level 1 (see Figure 15). However, the land cover distributions on CORINE land cover level 3 sharply fluctuate, such as “discontinuous urban fabric” areas in Kiel increase form 4025 ha (2006) to 4207 ha (2012), the areas in Lübeck rise from 4297 ha (2006) to 4612 ha (2012), the areas in Flensburg increase 71 ha from 2006 to 2012, the areas in Neumünster rises 77 ha during the same period. The changed areas of “discontinuous urban fabric” in that Kiel, Lübeck, Flensburg and Neumünster approximately equal to the changed areas of “continuous urban fabric”. The disparity of the significant changes among the land cover classes of artificial surfaces is carried out by the CORINE land cover technical improvement and the connection to the concept of Eionet Action Group on Land Monitoring in Europe (EAGLE) (Kosztra *et al.*, 2014). The other possible reasons accounting for the changes are the shortcomings of the CLC nomenclature, such as no equal representation of land cover, the selected temporal transitional phenomena or status, missing thematic content, and inflexible classification systems. The uncertainties of CORINE land cover distributions in districts of Schleswig-Holstein need to be calibrated.

4.3.2 Relationship between GPP, NPP and districts

The differences of the land cover distributions in the districts is the primary reason accounting for the distinctions of GPP and NPP among the districts. The districts, for example Steinburg, Dithmarschen, Nordfriesland, Rendsburg-Eckernförde and Schleswig-Flensburg, whose areas are primarily occupied by “pastures”, “complex cultivation patterns” and “non-irrigated arable land” have higher annual total GPP and the higher annual total NPP than the other districts (see Figure 18a and Figure 23a). Nordfriesland (around 2635 Mg C yr^{-1} for the annual total GPP and around 1447 Mg C yr^{-1} for the annual total NPP), Rendsburg-Eckernförde (around 2345 Mg C yr^{-1} for the annual total GPP and around 1316 Mg C yr^{-1} for the annual total NPP) and Schleswig-Flensburg (around 2211 Mg C yr^{-1} for the annual total GPP and around 1243 Mg C yr^{-1} for the annual total NPP) and Dithmarschen (around 1613 Mg C yr^{-1} for the annual total GPP and around 877 Mg C yr^{-1} for the annual total NPP) are the districts which have large amounts of the annual total stored GPP and the annual total stored NPP (see Figure 18b and Figure 23b). However, Kiel (around 75 Mg C yr^{-1} for the annual total GPP and around 30 Mg C yr^{-1} for the annual total NPP), Lübeck (around 155 Mg C yr^{-1} for the annual total GPP and around 90 Mg C yr^{-1} for the annual total NPP), Flensburg (around 39 Mg C yr^{-1} for the annual total GPP and around 23 Mg C yr^{-1} for the annual total NPP) and Neumünster (around 50 Mg C yr^{-1} for the annual total GPP and around 28 Mg C yr^{-1} for the annual total NPP) have a lower annual total stored GPP and annual total stored NPP than the other districts due to smaller areas. “Broad-leaved forest”, “coniferous forest” and “mixed forest” are highly suitable to store the annual total GPP and the annual total NPP. Hence, an increase of the areas of “broad-leaved forest”, “coniferous forest” and “mixed forest” are positive to enhance the annual total GPP and the annual total NPP. Even though, forests cannot increase in all the districts of Schleswig-Holstein because of the biogeochemical and biogeophysical conditions. Taking Steinburg, Dithmarschen, and Nordfriesland for example, the three districts locate on Marsch which is not suitable for forestry. Meanwhile, Rendsburg-Eckernförde is partially covered by Geest, being primarily comprising of “non-irrigated arable land”, “pastures” and “complex cultivated patterns” which also have a high annual total GPP and NPP. Therefore, the landscape conditions need to be considered during the process of managing land cover for the managers of the districts. It is helpful for enhancing the amounts of the annual total stored GPP and the annual total stored NPP. Kiel, Lübeck, Flensburg and Neumünster have been defined as metropolises, accounting for the low annual total GPP and the low annual total NPP owing to large artificial areas and small areas of “broad-leaved forest”, “coniferous forest”, “mixed forest”, “non-irrigated arable land”, “pastures” and “complex cultivated patterns”. The annual total GPP and the annual total NPP in these four districts may be increased through expending the land cover which is covered by as much vegetation as possible because land cover changes influence the annual total GPP and the annual total NPP based on the districts through redistributing areas of land cover (Muñoz-Rojas *et al.*, 2011).

4.3.3 Comparison of the correlation of GPP, NPP and harvest based on districts

A comparison of the annual total GPP, the annual total NPP, the monthly GPP, the average harvests, the harvest of grain, the harvest of root crop, the harvest of winter rape and the harvest of green maize based on districts of Schleswig-Holstein show that the correlations between the average of harvest and the annual total GPP, the annual total NPP, GPPAgri, NPPAgri are significant. The significant correlations illustrate that the MODIS products of GPP and NPP are reliable in Schleswig-Holstein. The correlation analysis among various indicators is also a verification and validation for the reduction of uncertainties due to modelling methods which are usually as consequences of model-drawback or transform-using to other research areas (Hou *et al.*, 2013).

The affections on GPP, NPP, the average harvests, the harvest of grain, the harvest of root crops, the harvest of winter rape and the harvest of green maize made by the land cover distributions based on landscape regions and districts are complicated. The districts, such as Flensburg, Nordfriesland, Stormarn, Dithmarschen, Steinburg and Segeberg have high harvests of green maize, mainly locating in the landscape regions of Geest and Marsch which are rich of the land cover classes of “pastures” and “complex cultivation patterns” (see Figure 28.). The land cover distributions of districts account for a higher monthly GPP in August, September and October due to the growing season of green maize during these months. Meanwhile, Dithmarschen, Hzgt. Lauenburg, Nordfriesland, Steinburg, Kiel, Plön, Neumünster and Lübeck are the districts where the harvest of root crops is higher than in the other districts of Schleswig-Holstein. They occupy the landscape regions Marsch and Hügelland which are primarily covered by the land cover class of “non-irrigated arable land”. April, May, June and July are the growing months of green maize and root crop which are assigned to “non-irrigated arable land”. As a result, monthly GPP in Marsch and Hügelland is higher than in Geest during April, May, June and July. Furthermore, the harvest of green maize and root crops is much higher than the harvest of grain and winter rape. This fact indicates that the growing season of green maize and root crops can affect the monthly GPP much more than grain and winter rape. Vegetation above the different land cover classes is a vital factor which can influence monthly GPP.

4.4 Uncertainties in this study

The uncertainty of an environmental aspect is considered as the integration of errors, inexactness, unreliability and ignorance (Funtowicz & Ravetz, 1990), and is described as the inadequacy of people’s knowledge of understanding the system under investigation (WU & LI, 2006). Carbon storage, as an ecosystem service provides uncertainty due to the high complexity and the integrative position between humans and ecosystems

(Scolozzi *et al.*, 2012). The reasons that cause the uncertainty of carbon storage and sequestration are variable. Moreover, the land cover data, missing data and scale issues are considered as the most prominent uncertainty sources in spatial ecosystem service assessments (Hou *et al.*, 2013). Carbon storage which is one of the most important indicators of ecosystem services is influenced by the factors, such as land cover distributions, land cover changes, vegetation species. We discuss the respective uncertainties and their possible reasons in this chapter.

4.4.1 Uncertainties of the land cover distribution and land cover changes

A thematic accuracy assessment of CORINE land cover confirms that the total reliability of CORINE land cover 2000 is around 87.0% (Büttner & Maucha, 2006). Rivers, lakes, industrial and commercial units and discontinuous urban fabric have the highest reliability (>95%), the reliabilities of arable land, coniferous forest are located between 90% and 95%, and mineral extraction sites occupy the position of the lowest class-level reliability which is below 70% (Büttner & Maucha, 2006; Feranec *et al.*, 2010). Reasons for these uncertainties are inaccuracy in identification, classification and delimitation of CORINE land cover classes and overestimations or underestimations caused by missing areas due to minimum mapping units, or by confusion or erroneous determination of classes which are similar to each other (Feranec *et al.*, 2007). Moreover, technical changes, for instance different satellites used for extracting the images of land cover and distinct land cover inventories, during the process of producing the CORINE land cover productions contributes to the inaccuracy of the data of land cover and land cover changes, especially for the year 2012 (Büttner *et al.*, 2014). The possible reasons of the inaccuracy of the CORINE land cover database may strongly affect the results of land cover distribution and land cover changes. The areas of “complex cultivation patterns” sharply decrease from 2006 to 2012 (see Table 10), which results either from the land cover changes or from the technical changes on measuring the land cover areas. However, most of the changes of “complex cultivation patterns” from 2006 to 2012 are derived from new satellite used for the classification and delimitation of CORINE land cover classes instead from the real land cover changes due to stable agricultural development-policies in Schleswig-Holstein (Landwirtschaftskammer Schleswig-Holstein, 2011). Furthermore, the comparison of CORINE land cover distributions and MODIS land cover distributions confirms that the CORINE land cover distributions in the classification level 1 are stable. Therefore, the differences of the land cover areas from 2006 to 2012 mainly result from the delimitation of the land cover classes in CORINE classification level 3. The land cover distributions in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012 (see Table 5 in the Appendix A) also reflect the uncertainties leaded by the delimitation among the similar land cover classes in level 3, such as the changed areas of “continuous urban fabric” in Kiel, Lübeck, Flensburg and Neumünster from 2006 to 2012 approximately equal to the changed areas of “discontinuous urban fabric”. Therefore, analysis and assessments of the land cover distributions and land cover changes with higher reliability are needed in future studies.

4.4.2 Uncertainties of temporal dynamics and spatial patterns of the investigated ecosystem services assessed with qualitative indicators

The data source of the qualitative indicator of the global climate regulation is the ecosystem services matrix which is based on the evaluation of experts (see chapter 2.2.3). It may be affected by the knowledge and experience of the experts. Mapping ecosystem services with qualitative evaluated matrix data is uncertain due to the limitations of the expert evaluations. Therefore, comparison of quantitative and qualitative assessments of global climate regulation has been done. The quantitative indicators, for instance the annual total GPP, the annual total NPP, SOC and CS, have been normalized into the classes 0-5 which are comparable with the qualitative indicator, GCR (see Figure 29). However, mapping ecosystem services and map comparisons of global climate regulation with normalized quantitative indicators and qualitative indicators increase the uncertainties due to the information missing in progress of normalization. Taking “broad-leaved forest”, “coniferous forest” and “mixed forest” for example, the annual total GPP, the annual total NPP, SOC, CS are different in the three types of forest, but the three land cover classes have the same normalized classes (see Table 42). The ingeneration of the differences may deduce the inaccuracy when comparing carbon storage among the different forests.

Mapping the qualitative assessments with indicators of the matrix method being based on the evaluations of experts (see Appendix B) decline limitation made from data availability and allow questions to be addressed (Busch *et al.*, 2011). The qualitative approaches attribute to assess ecosystem services which are hard to be measured with quantitative indicators, especially to the cultural services recreation and tourism, landscape aesthetics and inspiration and natural heritage and natural diversity in this study. It is because that there are few quantitative indicators could directly indicate the cultural services. At the same time, the uncertainties need to be considered when the qualitative assessments are used due to the limitation deriving from background and acknowledgement of experts (Schulp *et al.*, 2014). The uncertainties results from the data flexibility of qualitative assessments enhance the uncertainties of the assessments of ecosystem services even though they enable large scale assessments of many ecosystem services (Hou *et al.*, 2013). In my study, eight regulating services, nine provisioning services, and three cultural services have been mapped based on 32 CORINE land cover classes. It is rare possible to derive the quantitative indicators of all the ecosystem services mentioned above for quantitative estimations. In spite that the land cover classes are the only factor being considered in evaluating the qualitative ecosystem changes, the changes can be clearly identified during the periods of 1990-2000, 2000-2006, 2006-2012. Considering the amount of limitation leading by the qualitative assessments, such as exclusion of real data on nature preservation areas when estimating natural hazard, being lack of available quantitative data when evaluating erosion regulation, nutrient regulation, air quality regulation, water flow regulation and water purification, and shortage of coastal and marine ecosystems, and local statistical information on tourism when assessing the recreation and tourism, landscape aesthetic and cultural heritage, all ecosystem service assessments should be accomplished by quantitative indicators having been recommended in Figure 1-3 of appendix B.

4.4.3 Uncertainties of GPP and NPP

The results in chapter 3.1.3 show the distributions based on land cover classes, landscapes and districts, the differences between the annual total GPP and the annual total NPP, the hotspots and cold spots for the annual total GPP and the annual total NPP, and the ecosystem service of global climate regulation which takes the annual total GPP and the annual total NPP as indicators through analysing the MODIS global terrestrial primary production, including monthly GPP, the annual total GPP and the annually total NPP in near-real time at a 1-km resolution. The MODIS products of GPP and NPP are the down-stream MODIS land products (Zhao *et al.*, 2005). Uncertainties from upstream inputs, such as land cover, Fraction of absorbed Photosynthetic Active Radiation (FPAR) or Leaf Area Index (LAI), the meteorological data, and algorithm itself can influence the accuracy of the products (Zhao *et al.*, 2006). However, the MODIS GPP fits well with flux tower GPP data derived in North America (Phillips *et al.*, 2008). Simultaneously, the MODIS products of NPP and the Ecosystem Model-Data Intercomparison (EMDI) NPP data set are comparable (Zhao *et al.*, 2005; Wang *et al.*, 2011). Furthermore, the MODIS products of the annual total GPP and the annual total NPP relate to the atmospheric CO_2 growth rates inversely (IPCC, 2005). What has been mentioned above indicates that the MODIS products of GPP and NPP are reliable datasets despite that several potential uncertainties exist.

As a comparison of the quantitative and qualitative indicators of global climate regulation, the annual total GPP, the annual total NPP, SOC, the carbon storage (CS) and qualitative indicators (GCR) have significant correlations (see Figure 28) though there are the various data sets and calculation methods. The annual total GPP and the annual total NPP distribution based on the CORINE land cover classes were derived from the global estimate system of the annual total GPP and the annual total NPP. SOC based on CORINE land cover classes of Schleswig-Holstein was taken from the European soil inventory. It is possible that the accuracy of the annual total GPP, the annual total NPP or SOC on some land cover classes deduces with the down scaling calculation from the global or European scale into the country-wide scale. The reasons have been illustrated in the study about uncertainties in landscape analysis and ecosystem service assessment (Hou *et al.*, 2013).

4.4.4 Uncertainties of carbon storage in vegetation and in soils, and integrative model output

In this study, input data for the InVEST model have been derived from German local studies, European and Irish inventories and reports. These data referred from the other studies leads uncertainty of the results due to the value-transfers from the literatures. The critical reason is that a lack of the empirical data for all the land cover classes and for the carbon pools of above-ground, the below-ground, the soil organic carbon (SOC) and the litter leads to value-transfers from the literatures in lots of case studies (see Table 6). The value-transfers may increase the uncertainty either on the local assessment of carbon in biomass on the five types of land cover classes of the Bornhöved Lakes District or on the country-wide assessment of carbon storage in vegetation and the InVEST model output of the studies. It means that the carbon storage in “broad-leave forest”, “coniferous forest”, “mixed forest”, “non-irrigated arable land”, “pastures”, “complex cultivation patterns”, “Land principally occupied by agriculture”, “moors and heathland”, “inland marshes”, “peat bogs” and “intertidal flats” which calculated based on the carbon storage of the Bornhöved Lakes District might have been overestimated or underestimated.

Furthermore, general published reports (e.g., IPCC) are available for the above-ground, below-ground biomass, soil organic carbon and litter of several species, such as “broad-leave forest”, “coniferous forest”, (Verchot *et al.*, 2006)“mixed forest”, “crops”, “maize” and “grassland” (IPCC, 2005). They are the popular source of deriving input data for the InVEST model as well as an adequate estimate of the carbon pools (Garrastazù *et al.*, 2015). Even though the data transformation from general published reports to case studies induce the uncertainty of the assessment on the carbon storage and sequestration within the InVEST model due to the data heterogeneity coming from differences between the study sites and general published reports, studies’ results and reports from sites with similar biophysical conditions as the conditions of the case study have been derived for my study (Harmáčková & Vačkář, 2015). The carbon density in litter of “pastures” and “natural grassland” of my study have been derived from the IPCC report (Verchot *et al.*, 2006). Considering that data which are collected from field estimations of local plot studies can deduce the uncertainty of modelling results on carbon storage and sequestration (Cruickshank *et al.*, 2000; Delphin *et al.*, 2013), the data on carbon pools of all the land cover classes of Schleswig-Holstein requires the further investigations for gaining comparable data for the results.

Besides the uncertainties from the input data, inaccuracy derived from models are also needs to be considered. As one of the simple models, the InVEST model is prone to oversimplify the carbon storage and sequestration over time (e.g., fixing the average of measured storage levels as the storage level of the land cover classes) (Kruse *et al.*, 2013). The results of the InVEST model are only reliable on the classification of the land cover (Conte *et al.*, 2011; Kruse *et al.*, 2013; Sharp *et al.*, 2015a). Future more, biological process (e.g., moves of carbon from one pool to another) resulting from disease of vegetation, cutting or fire, is taken into consideration incompletely. The limitations from the InVEST model enhance the uncertainties of the results of this study on carbon storage and sequestration (Conte *et al.*, 2011; Kruse *et al.*, 2013; Sharp *et al.*, 2015a).

4.4.5 Uncertainties and reducing strategies in ecosystem service assessments

By analyzing the possible uncertainties, several methods which seem to be promising to assess uncertainties in ecosystem services have been found. Approaches used to improve ecosystem service assessments with respect to uncertainties have been listed in Figure 34. The uncertainty origins and the potential measures to cope with the respective uncertainties are classified at the left side and the right side, respectively. The four steps of uncertainty assessment can be considered as guidelines to qualify the uncertainties of ecosystem services based on land cover.

From the descriptions about the uncertainties in the regional assessments of ecosystem services in northern Germany, approaches to deal with uncertainties in the assessments have been derived. Apply different land cover data sources is a prerequisite for decreasing uncertainties in land cover dynamics which can affect ecosystem services further. As an important methods used for assessing ecosystem services at regional and global scales, outcomes of models need to be calibrated for declining inaccuracy resulted from models. Besides the uncertainties from algorithms of models, high quality data and complete input data are also attributing to reduce uncertainties either in modelling or in spatial evaluation of ecosystem services. Furthermore, improving methodology and indicators which are suitable to estimate ecosystem services are critical methods for uncertainty deduction.

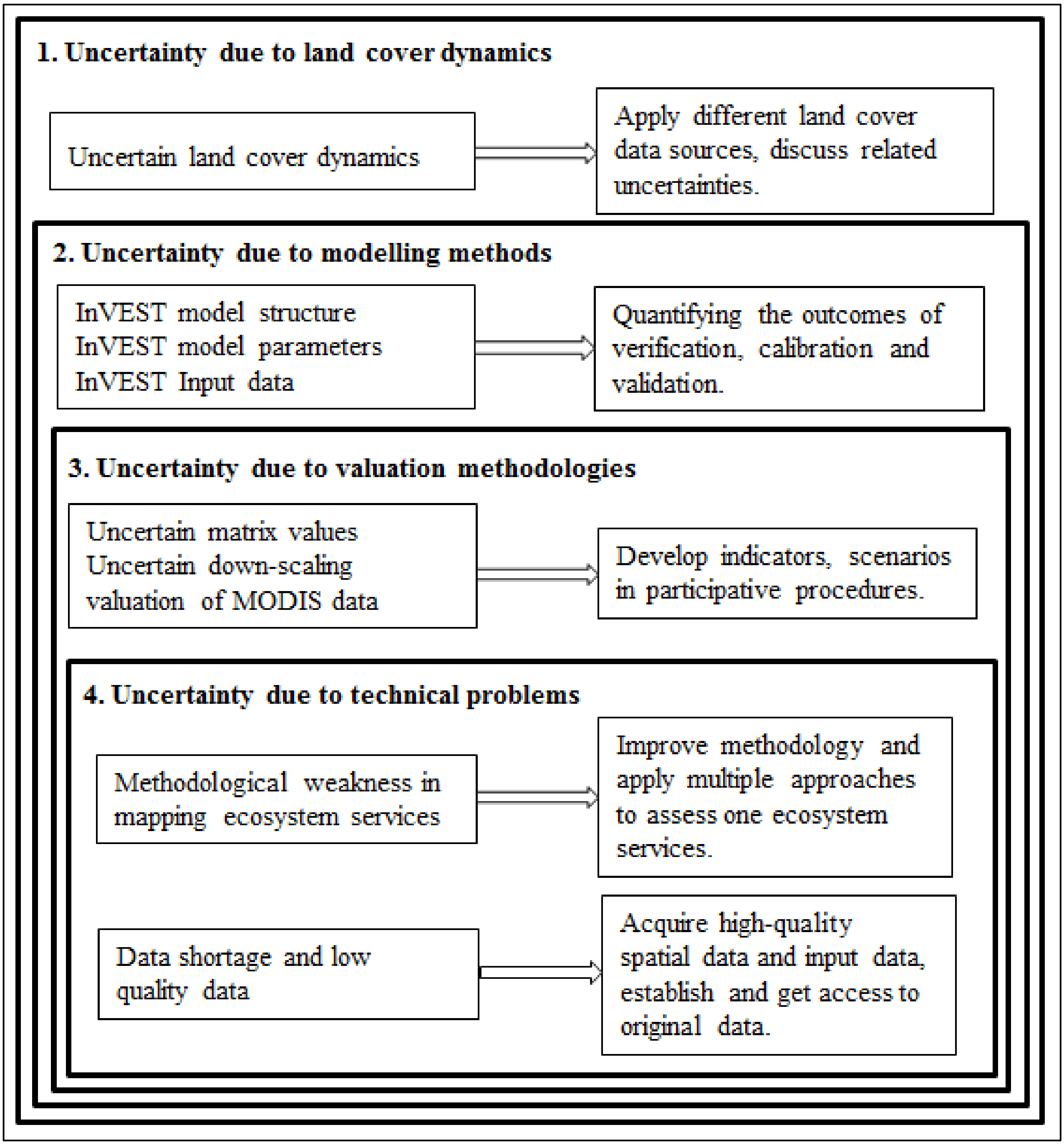

Figure 34. Special sources of uncertainty in ecosystem service assessments and potential actions for uncertainty reduction.

4.5 Comparison of the concepts used

The ecosystem service potential is defined as the hypothetical maximum yield of selected ecosystem services, being comparable to natural capital stocks and yield from a future flow of ecosystem service (Kroll *et al.*, 2012a; Burkhard *et al.*, 2014). It is one of the critical components of ecosystem capacity, being known as a potential of ecosystem to deliver services based on biophysical properties, social conditions, and ecological functions (Daily *et al.*, 2009; van Oudenhoven *et al.*, 2012; Villamagna *et al.*, 2013). The ecosystem service potential is the basic of the ecosystem service delivery process, consisting of ecosystem service potential, ecosystem service flow, and human benefits. Consequently, ecosystem services of Schleswig-Holstein based on land cover classes, landscape regions and districts assesse with qualitative indicators, and the ecosystem service of global climate regulation estimates with several quantitative indicators in this study. It is helpful to understand the ecosystem service potential on each land cover, landscape region or district. Theoretical supply is provided to the politicians and managers when they make politics and management.

Ecosystem services are estimated by indicators which are distinguished as primary indicators and secondary indicators (Kienast & Helfenstein, 2016). The primary indicators present a proxy measure of the service, most of which exist for regulating and provisioning services. Moreover, the secondary indicators provide information which composes the primary indicators, being frequently used for the evaluation of cultural and provisioning services (Egoh *et al.*, 2012). The annual total GPP, the annual total NPP, SOC and CS have been taken as the quantitative indicators as well as the secondary indicators of the global climate regulation due to the difficulty of getting primary indicators of the service.

Chapter 5. Conclusions

The targets of this study are to assess ecosystem services, particularly the global climate regulation service with qualitative and quantitative indicators based on CORINE land cover data. Carbon storage (CS) is related to global climate regulation service at regional (Kandziora *et al.*, 2013b; Kruse *et al.*, 2013), local and country-wide scales has been studied. The outcomes at the country-wide scale are fruitful because of the relatively abundant and easily accessible data sources. A comprehensive approach for land cover distribution, land cover density, land cover change, the annual total GPP and NPP, and annual total stored GPP and NPP based on temporal-spatial database from the CORINE dataset and MOD17 products have been used in this study. this research provides the first evaluations of land cover distributions, land cover changes, distributions of ecosystem services with qualitative indicators based on land cover, changes of ecosystem service potentials induced by land cover changes, the annual total GPP and NPP, and the annual total stored GPP and NPP of Schleswig-Holstein. This study also analyzes the annual total GPP and NPP, and the annual total stored GPP and NPP distribution trends associated with land cover classes, landscape regions and districts in Schleswig-Holstein. The relationships among land cover areas, the annual total GPP and NPP, and the annual total stored GPP and NPP are firstly estimated as well. Furthermore, the calculated respiration, the ratio between the annual total NPP and GPP based on the land cover classes, and hotspots and cold spots of the annual total GPP and NPP of Schleswig-Holstein are estimated. At the same time, the monthly GPP of the state in 2006 is evaluated in order to understand GPP absorption during each month.

Various qualitative and quantitative indicators can be used to assess ecosystem services. Given that the annual total GPP and NPP can be used as indicators of the global climate regulation service (Burkhard *et al.*, 2014; Müller *et al.*, 2016), quantitative indicators, such as the annual total GPP and NPP, soil organic carbon (SOC), and CS, have been employed to indicate global climate regulation. in addition, maps have been presented of the global climate regulation potential using quantitative indicators of the annual total NPP and GPP, SOC, CS, and the qualitative indicator GCR.

InVEST models have been chosen to estimate the CS of Schleswig-Holstein based on the CORINE land cover classification which significantly affects carbon storage. The total CS of Schleswig-Holstein is determined by the above-ground, below-ground, SOC and litter carbon pools of the land cover classes.

In addition to studies of CS and ecosystem services at countrywide scales, assessments at local and regional scales were conducted to achieve one of the goals of this study, calculating CS in biomass and SOC and analyzing their correlations with soil conditions in the land cover classes in the Bornhöved Lakes District. Consequently, beech forest, spruce forest, mixed forest, grassland and arable land around Lake Belau in the Bornhöved Lakes District are chosen as an experimental field of this study. Carbon in biomass, SOC, nitrogen distribution in soil, water capacity, cation exchange capacity potential (CECpot), cation exchange capacity efficiency (CECeff) and concentration of hydrogen cations (H+) in soil are presented in chapter 3.3. Previous studies on carbon storage and correlated ecosystem services of the whole Bornhöved Lakes District have been summarized as well.

5.1 Conceptual outcomes

The study of the land cover distribution at the countrywide scale shows that "non-irrigated arable land", "pastures" and "complex cultivation patterns" are the dominating land cover classes for the years 1990, 2000 and 2006. "Non-irrigated arable land", "pastures" and "discontinuous urban fabric" occupy much more areas compared to other land cover classes in 2012. The land cover distribution in the landscape regions has similar trends as the distribution in the whole state for the years 1990, 2000, 2006 and 2012. It means that "pastures" and "non-irrigated arable land" are the most widely distributed land cover classes estimated at the scale of landscape regions in Schleswig-Holstein. Simultaneously, the most important land cover classes estimated based on areas differs from one district to another.

Most land cover changes occur among "non-irrigated arable land", "pastures" and "complex cultivation patterns" in Schleswig-Holstein for the years 1990, 2000, 2006 and 2012. The cultivation of silage maize for biogas plants as the focal political driver results in most areas of land cover changes in Schleswig-Holstein. Moreover, land cover changes also are affected by environmental, social and economic conditions that must be considered during the progress of making political plans (Kandziora *et al.*, 2013b). Furthermore, the land cover changes influence the land cover distributions. This effect is shown in the fluctuations of the Shannon Diversity Index based on land cover classes and the land cover diversity index during 1990, 2000, 2006 and 2012. Considering the interactions between the land cover distributions and land cover modifications, the land managers and land politicians can make political plans or recommend land cover changes, such as afforestation, intensification of agriculture etc., to the landlords, e.g. based on the land cover constitutions analysis in this study in order to enhance the efficiency of land cover utilization.

The results of mapping the ecosystem services imply that their distributions are determined both by the areas of the land cover and by the classes (0-5) of the potentials. Furthermore, the dynamics in the ecosystem services of global climate regulation, crops, livestock and landscape aesthetics and inspiration for the years 1990, 2000, 2006 and 2012 result from the land cover changes. These dynamics are due to the fact that the same qualitative data of the ecosystem service potentials from the matrix approach have been supplied for the four periods. During the process of this analysis, ecosystem service changes (global climate regulation, crops, livestock and landscape aesthetics and inspiration) are presented during the periods of 1990-2000, 2000-2006, 2006-2012 and 1990-2012. The areas with decreased ecosystem service potentials are larger than the areas with increased ecosystem potentials during the four periods, indicating a general loss of the overall capacities in the state.

Quantitative as well as qualitative assessments are two primary methods used to assess ecosystem services. The annual total GPP and NPP, SOC, and CS are the potential indicators of the ecosystem services of global climate regulation. The annual total GPP is greatest in 2000t, and lowest in 2006. "Coniferous forest", "pastures", "mixed forest" and "broad-leaved forest" are the land cover classes with the largest annual total GPP. Meanwhile, "non-irrigated arable land" and "pastures" have the largest amount of the annual total stored GPP for the years 2000, 2006 and 2012. Similarly to the annual total GPP, the largest and least annual total NPP occur in 2000 and in 2006, respectively. The land cover classes which have larger annual total NPP values are different during 2000, 2006 and 2012. “Pasture” and “coniferous forest” have larger annual total NPP than the other land cover classes for the three periods. However, “non-irrigated arable land” and “pastures” have the largest amount of the annual total stored NPP for the years 2000, 2006 and 2012.

In addition to land cover, the physical and socio-economic structures of the landscape regions and districts are the focal factors impacting the annual total GPP and NPP and the annual total stored GPP and NPP besides land cover. The landscape type with the highest annual total GPP and NPP is Marsch, while, Geest has the highest annual total stored GPP and NPP compared to the landscapes of Marsch and Hügelland. The annual total GPP and NPP of each land cover among the three landscape regions are similar. Even if the land cover differences account for the variations in the annual total GPP and NPP, the areas of land cover determine the annual total stored GPP and NPP. Thus, it is clear that the land cover areas influence the annual total stored GPP and NPP.

Dithmarschen and Rendsburg-Eckernförde are the districts which have the largest annual total GPP and NPP, and the largest annual total stored GPP and NPP among the districts in Schleswig-Holstein. “Pastures”, “broad-leaved forest”, “coniferous forest”, “mixed forest”, “non-irrigated arable land” and “complex cultivation patterns” are the land cover classes containing more annual total GPP than the other land cover classes in each district for the years 2000, 2006 and 2012. “Natural grasslands”, “broad-leaved forest”, “coniferous forest”, “mixed forest”, “pastures”, “complex cultivation patterns” and “non-irrigated arable land” have greater abilities to produce the annual total NPP in each district for the same periods as GPP. Expanding the areas of “pastures”, “broad-leaved forest”, “coniferous forest”, “mixed forest”, “non-irrigated arable land”, “complex cultivation patterns” and “natural grasslands” is beneficial to enhance the annual total GPP and NPP for each district of Schleswig-Holstein.

The annual total GPP and NPP and the annual total stored GPP and NPP indicate the ability of carbon storage. Statistically hotspots and cold spots of the annual total GPP and NPP are forming an adjacent significant hotspot area with the high annual total GPP and NPP, located in the middle-western to the middle-bottom of Schleswig-Holstein. Cold spots areas with the low annual total GPP and NPP are located primarily at the western edge and in the eastern part of the state. Most of the hotspot and cold spots are in Geest and Hügelland, respectively. The relationships between calculated respiration and the annual NPP/GPP have been analysed because they also are factors that influence GPP and NPP. The calculated respiration in 2000 is higher than that in 2006 and 2012, and 2006 has the lowest respiration among the three years. Average ratios of the annual NPP/GPP are 0.5647, 0.5350 and 0.5573 in 2000, 2006 and 2012.

Greater annual total stored GPP and NPP values imply more carbon fixation, and lower CO_2 emission. Hence, the land cover managers of Schleswig-Holstein can decrease greenhouse gas emission (e.g. CO_2) through afforestation and a sustainable intensification of agriculture which can increase areas of “broad-leaved forest”, “coniferous forest”, “mixed forest”, “pastures” and “non-irrigated arable land”. Additionally, the land cover distributions and land cover changes are affected by the landscape regions due to geophysical and geochemical differences. “Broad-leaved forest”, “coniferous forest” and “mixed forest” are not adaptable to the soil types, nutrient contents and the agro-economy in Marsch, in addition, the peat bogs are rarely distributed in Hügelland. Therefore, the politicians need to consider the landscape region conditions during the processes of afforestation and intensification of agriculture. As a critical policy of Schleswig-Holstein, the cultivation of silage maize for biogas plants have been widely developed in “non-irrigated arable land” and “complex cultivation patterns” which are primary distributed in Hügelland. Hence, the possibility of further enlarging silage maize for biogas in Hügelland is limited. However, the further cultivation of silage maize for biogas has been progressed in Geest where is also suitable for developing agricultural areas based on former livestock growth.

In the administration of the districts in Schleswig-Holstein, it is necessary to follow the state’s general design of the land cover distributions and changes. Thereafter, the land cover managers in the districts could consider the possibilities of intensifying the areas of “broad-leaved forest”, “coniferous forest” and “mixed forest”, “pastures” and “non-irrigated arable land” with high abilities of storing carbon which indicates a high global climate regulation service based on the districts’ locations in the landscape regions. Such as the district of Nordfriesland which is located largely only in Marsch, it is difficult to develop afforestation and intensify agriculture. Moreover, Kiel, Lübeck, Neumünster and Flensburg have been designed as the metropolises of Schleswig-Holstein, which means forest and arable land could not be the dominating areas. It implies that enhancing the carbon storage through enlarging areas covered with vegetation in urban areas is mainly suitable for high of urbanized districts. Schleswig-Flensburg and Rendsburg-Eckernförde are the districts with the largest areas located both in Geest and in Hügelland. The areas of the two districts located in Hügelland have been dominated by “non-irrigated arable land” which is the main land cover for cultivation of silage maize for biogas plants, and the areas of Geest have been primary covered with “pastures” which is critical for fodders and livestock. Considering the purpose of intensifying silage maize for biogas plants, Schleswig-Flensburg and Rendsburg-Eckernförde could reduce the areas of the “pastures” in order to increase the areas of “non-irrigated arable land”. However, the annual total GPP and NPP of “non-irrigated arable land” is lower than those of “pastures”. Declining the areas of “non-irrigated arable land” indicates losing CS. Thereby clarifying the developing purpose of one district is important for the managers of each district. Simultaneously, the interactions between the districts and landscape regions support experiences to the general design of Schleswig-Holstein as well. The land cover managers of Schleswig-Holstein also should consider the responses of the interactions deriving from the districts and landscape regions when they make decisions about land cover distributions and land cover changes. Finally it must be clear that besides the climate regulation potential, all the other services also must be considered, leading to a multidimensional optimization strategy.

Other objectives of this study are to estimate the CS potential of Schleswig-Holstein based on the CORINE land cover classes, analyze the correlation among the annual total GPP and NPP, SOC, CS and GCR, and make comparison of the results of ecosystem service mapping with the five indicators related to global climate regulation.The InVEST model has been used to estimate the countrywide carbon storage and sequestration. The medium total CS has been assessed to be 154.63 Tg in Schleswig-Holstein, and the CS per grid cell is different because of the various CS capacities of the carbon pools (above-ground, below-ground, SOC and litter) in the different land cover areas. The four carbon pools constitute CS, and play a significant role in assessing the ecosystem service of global climate regulation. “Broad-leaved forest”, “coniferous forest” and “mixed forest” are the land cover classes which have high contents of CS, the annual total GPP and the annual total NPP, which demonstrates that land cover classes with abundant vegetation especially with woody plants have higher capabilities to stock carbon. Similar trends are also shown in GCR from the ecosystem service matrix on evaluating the global climate regulation potential. The correlations among the annual total GPP and NPP, SOC, CS and GCR are significant, illustrating that the annual total GPP and NPP, SOC and CS can be selected as quantitative indicators for assessing the ecosystem service of global climate regulation. The differences of the pair-wise map comparisons between the annual total GPP and GCR, between the annual total NPP and GCR, between SOC and GCR, and between CS and GCR indicate correlations between the indicators of global climate regulation as well. The results obtained from mapping global climate regulation with indicators of the annual total GPP and NPP, SOC, CS and GCR illustrate that these indicators have obvious influence on the estimation of global climate regulation. The maps of global climate regulation assessment differ in their indicator contents and normalized classes for the same land cover.

The local assessments demonstrate that different land cover classes have distinct abilities to store carbon because of their different nitrogen content and water capacity, and that the correlations among the factors of the soil are not homogenous. The beech forest and the mixed forest have the highest carbon storage in biomass and in soil, meanwhile, the nitrogen content and water capacity in the grassland is the highest in the land cover classes of beech forest, spruce forest, mixed forest, grassland and arable land around the Lake Belau in the Bornhöved Lakes District. Soil nitrogen distribution, CECpot, CECeff and H+ have positive significant relationships to CS in soil. Whilst, the free water capacity and the not-plant water capacity show negative correlations.

5.2 Methodological outcomes

This study conducted a comprehensive critical analysis of methods for the estimation of CS and sequestration based on land cover at multiple scales has been described in this study. The role of CS and sequestration for climate change (e.g. deducting the efficiency of the anthropogenic carbon perturbation, increasing species extinction and decreasing biodiversity as well as wild life populations), and the interrelated processes of the carbon cycle in the four carbon pools have been illustrated. All of the descriptions and illustrations should be pivotal to understand the significance of carbon storage and sequestration.

The ecosystem assessments with quantitative indicators enhance the independence, declining uncertainties leaded by knowledge of experts. Quantitative indicator should be recommended for estimating ecosystem services if the data sources are available. Meanwhile, the qualitative indicators, for example, the indicators from the matrix method, are more adaptable when quantitative data are rare or difficult to access. The results above strongly encourage using the indicators of assessing the global climate regulation based on land cover classes to understand better the functions of global climate regulation in the different land cover classes in northern Germany. Land cover managers can consider the results of this study into consideration in their management plans in order to enhance the ecosystem service of global climate change regulation.

At the same time, methods that can be used on ecosystem assessments at different scales are distinct.

Studies based on sample experiments can be adaptable for use at the local scale because many details of the study areas need to be known. Therefore, the methods are widely used at local scales. The SOC, the soil nitrogen contents, the water capacity, and the hydrogen cation concentration (H^+) of beech forest, spruce forest, mixed forest, grassland and arable land around Lake Belau in the Bornhöved Lakes District have been tested from the field samples. Modelling and mapping methods are available to assess ecosystem services at regional or global scales, considering the difficulties of deriving data from sample experiments at such large scales. Even so, using models to evaluate the ecosystem services increases the uncertainties attributable to inaccuracies that result either from limitations of the formulas in the models, or from the transformation of habitats that have been used to calibrate the models to other habitats (Busch *et al.*, 2011; Sharp *et al.*, 2015b). Nevertheless, modelling is still one of the most suitable and adaptable methods on estimating the ecosystem services at large scales. Mapping distributions and changes of the ecosystem services has the potential to aggregate complex information, especially to aggregate the modelling results due to the spatial peculiarity (Kroll *et al.*, 2012a). The mapped results account for the implementation of the ecosystem services concept into environmental institutions and decision making (Daily & Matson, 2008). Mapping the ecosystem services with the qualitative indicators, mapping the ecosystem services of global climate regulation with various quantitative indicators, and mapping the land cover distributions and land cover changes are accomplished in this study. These maps show the temporal-spatial distributions of each ecosystem service based on the land cover classes in Schleswig-Holstein and can be used to compare the ecosystem services estimated with matrix and quantitative methods.

5.3 Answers to the questions from the introduction

The initial questions in the dissertation focus on factors which may influence global climate regulation of Schleswig-Holstein. It intends to test the land cover dynamics, the distributions of the annual total GPP and NPP, the SOC and CS, the suitably quantifiable indicators on assessing the ecosystem service of global climate regulation based on the CORINE land cover classification, and the relationships among the quantitative indicators and the qualitative indicator have been proposed as research targets. With these goals, three research questions have been asked at the beginning of the dissertation, being answered based on the results of this study now:

1. How are different land cover classes distributed spatially, and how does the land cover pattern change based on the datasets of CORINE land cover in Schleswig-Holstein?

The area distributions based on the CORINE land cover classification, on the landscape regions and on the districts have been analyzed and presented. The land cover changes among the years 1990, 2000, 2006 and 2012 of Schleswig-Holstein have also been estimated.

2. How much carbon has been stocked, evaluated with parameters of the annual total GPP, the annual total NPP, SOC and CS based on CORINE land cover?

Given that the land cover dynamics which are important drivers of changing CS have been found. CS implied with the annual total GPP, the annual total NPP, SOC and CS have been calculated based on the

CORINE land cover classification.

3. What are the relationships among the quantitative indicators (the annual total GPP, the annual total NPP, SOC and CS) and the qualitative indicator, GCR of global climate regulation in Schleswig-Holstein?

The potential of ecosystem services can be altered by global climate change and land cover changes. CS related measurements are providing parameters which can indicate the global climate regulation service. The assessments of global climate regulation with quantitative (the annual total GPP, the annual total NPP, SOC and CS) and qualitative indicators (GCR) are shown, and the quantitative linkages between the indicators of estimating the global climate regulation potential are presented based on the CORINE land cover approach.

The encouraging findings of this study show that the land cover distributions and land cover changes are important drivers which make changes of CS through natural environmental change effects, population change effects and political influences. These drivers may alter geological, biogeochemical and biological factors that have critical influences on changing the potentials of CS. These findings are informative for regional environmental management, especially for the climate policy making. The outcomes about the annual total GPP, the annual total NPP, SOC and CS based on the CORINE land cover classification, on regions and districts in this study can be referred to and used when climate related decisions have to be made.

5.4 Demands for future investigations

Despite some notable limitations, the study in this dissertation derives new results to reveal the land cover dynamics and qualitative and quantitative assessments of ecosystem services in spite of the noticeable limitations. My research has used a comprehensive and continental data source adapted to the European CORINE nomenclature for estimating the land cover distributions and the land cover changes. It may result in a rough classification of land cover for Schleswig-Holstein due to using downscaling data from the continental scale to a reginal scale. In future studies, the data set should contain either all of the land cover classes in Schleswig-Holstein, or more detailed information of the land cover classes to analyze the land cover distributions, and to compare the results within the study.

Temporal and spatial dynamics are closely associated with each other, and are interdisciplinary research issues in the fields of climate change, sustainable development policies, influences on soils and water use, and vegetation CS (Cruickshank *et al.*, 2000; Muñoz-Rojas *et al.*, 2011; Delphin *et al.*, 2013; Chaudhuri & Ale, 2014; Bae & Ryu, 2015; Beuchle *et al.*, 2015; Corbelle-Rico *et al.*, 2015; Disperati & Virdis, 2015; Garrastazù *et al.*, 2015; Harmáčková & Vačkář, 2015). However, there are uncertainties with respect to only considering the land cover differences among different years even though land cover change is the issue that connects both temporal and spatial aspects. However, considering climatically ecological and biophysical issues about the temporal dynamics and spatial patterns that affect SOC (e.g., temperature, humidity, fertilization, pesticides, nutrient eutrophication, and importation of food for livestock), global climate regulation, and correlated policies are necessary in future studies.

Furthermore, the attempt to qualify the ecosystem services can be regarded as promising. However, there is a limitation on the assessment of the ecosystem services with the qualitative methods because of the inaccuracy of expert evaluation on investigating and evaluating the 20 basic ecosystem services. This study compared the qualitative and quantitative indicators of global climate regulation of 17 land cover classes of Schleswig-Holstein are compared in my study. Moreover, quantitative assessments for each ecosystem service should be necessary or at least supplementary estimations should be done in long-term future studies because the quantitative data collections are consuming a lot of time.

As one of the primary indicators of global climate regulation, CS in different carbon pools of various land cover classes in Schleswig-Holstein considers both the carbon in vegetation and the carbon in SOC. However, there are limitations during the process of the study because the amount of CS is considered to be keeping stable unless there is a land cover change from one type to another (Sharp *et al.*, 2015b). Actually, considering flows of carbon among different carbon pools, and the differences of carbon in different months, seasons or years may decrease the CS estimation related uncertainties due to over-simplifying the carbon cycling. The items about CS should be focal elements of long-term further studies basing upon the carbon cycling processes.

Considering the inaccuracy of data sets resulting from data collection and data transfer from one study to other similar studies, either calibrating with approved methods and instruments, or collecting data from the case study area is beneficial in order to reducing the uncertainties of the studies. In further researches that could explore exact data sets such as GPP and NPP from eddy covariance of the land cover classes of Schleswig-Holstein would be extremely preferable. Additional estimations of CS could be elaborated by assessing the carbon pools of sites in various land cover classes, which can be estimated in long-term investigations.

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Appendix A. Land cover and land cover changes in Schleswig-Holstein

Table 1. Land cover areas and the percentage of land cover classes in Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover Classes	1990		2000		2006		2012	
	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)	Area (ha)	Percentage (%)
Continuous urban fabric	997	0.06	997	0.06	1030	0.07	527	0.03
Discontinuous urban fabric	80675	5.16	84572	5.40	88601	5.66	100177	6.40
Industrial or commercial units	5950	0.38	7487	0.48	9076	0.58	14877	0.95
Road and rail networks and associated land	303	0.02	338	0.02	486	0.03	472	0.03
Port areas	918	0.06	926	0.06	965	0.06	489	0.03
Airports	2422	0.15	2446	0.16	2438	0.16	2465	0.16
Mineral extraction sites	1953	0.12	2814	0.18	3504	0.22	2987	0.19
Dump sites	620	0.04	719	0.05	807	0.05	380	0.02
Construction sites	91	0.01	493	0.03	308	0.02	56	0.00
Green urban areas	1119	0.07	1148	0.07	1148	0.07	2063	0.13
Sport and leisure facilities	4752	0.30	5827	0.37	7100	0.45	9708	0.62
Non-irrigated arable land	670840	42.87	666449	42.59	666186	42.57	746015	47.67
Fruit trees and berry plantations	326	0.02	259	0.02	293	0.02	244	0.02
Pastures	454041	29.01	452238	28.90	367189	23.46	441388	28.21
Complex cultivation patterns	95978	6.13	93850	6.00	164279	10.50	743	0.05
Land principally occupied by agriculture	24332	1.55	24262	1.55	27661	1.77	6488	0.41
Broad-leaved forest	60408	3.86	60288	3.85	62450	3.99	81247	5.19
Coniferous forest	52252	3.34	51808	3.31	51759	3.31	53196	3.40
Mixed forest	22184	1.42	22005	1.41	22863	1.46	14302	0.91
Natural grasslands	9299	0.59	9400	0.60	9129	0.58	9519	0.61
Moors and heathland	3008	0.19	3056	0.20	3015	0.19	4477	0.29
Transitional woodland-shrub	1133	0.07	2132	0.14	2206	0.14	3934	0.25
Beaches, dunes, sands	4300	0.27	4653	0.30	4433	0.28	2032	0.13
Sparsely vegetated areas	1699	0.11	1321	0.08	1321	0.08	29	0.00
Inland marshes	4352	0.28	4307	0.28	4480	0.29	4729	0.30
Peat bogs	8802	0.56	8946	0.57	9484	0.61	6623	0.42
Salt marshes	8235	0.53	8476	0.54	8735	0.56	11755	0.75
Intertidal flats	8285	0.53	7977	0.51	8130	0.52	7485	0.48
Water courses	3244	0.21	3241	0.21	3606	0.23	4308	0.28
Water bodies	27867	1.78	27950	1.79	29781	1.90	25556	1.63
Coastal lagoons	2819	0.18	2817	0.18	1117	0.07	5340	0.34
Estuaries	1717	0.11	1716	0.11	1344	0.09	1313	0.08

Table 2. Land cover areas (ha) in the landscape regions in Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover Classes	1990			2000			2006			2012		
	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land
Continuous urban fabric	140	0	857	140	0	857	173	0	857	137	0	390
Discontinuous urban fabric	40948	5841	33886	42338	6221	36013	44174	6725	37620	50911	7360	41906
Industrial or commercial units	3184	592	2174	4004	673	2810	5173	760	3143	8509	1028	5339
Road and rail networks and associated land	80	0	224	80	0	258	80	83	406	118	0	354
Port areas	44	45	830	44	53	829	44	91	829	71	27	390
Airports	2089	37	296	2114	37	295	2105	37	295	2124	45	296
Mineral extraction sites	1142	9	802	1656	39	1119	2168	9	1328	1895	2	1090
Dump sites	361	41	217	421	41	257	490	41	275	158	53	170
Construction sites	0	40	51	52	0	441	81	32	195	56	0	0
Green urban areas	400	0	719	424	0	724	424	0	724	802	0	1261
Sport and leisure facilities	1476	142	3134	2120	201	3506	2832	286	3982	3996	300	5413
Non-irrigated arable land	165783	99005	406052	164794	99629	402026	172535	101903	391748	240141	108932	396942
Fruit trees and berry plantations	25	192	109	25	191	43	26	191	76	31	143	70
Pastures	289630	86855	77557	288057	86241	77939	218510	76682	71997	249821	84782	106785
Complex cultivation patterns	52326	9262	34390	50692	8947	34211	105576	15252	43451	362	205	176
Land principally occupied by agriculture	12162	426	11745	12152	426	11684	13388	439	13835	3108	45	3334
Broad-leaved forest	16477	627	43303	16459	585	43244	16699	612	45139	22942	983	57322
Coniferous forest	37645	61	14546	37186	61	14561	37267	61	14431	38945	179	14072
Mixed forest	9966	181	12037	9950	4	12051	10709	4	12150	8756	53	5493
Natural grasslands	2207	5337	1755	2338	5293	1769	2018	5197	1914	4245	1940	3333
Moors and heathland	2977	31	0	3026	31	0	2984	31	0	4405	73	0
Transitional woodland-shrub	736	97	300	1339	315	477	1324	300	582	2020	259	1655
Beaches, dunes, sands	1904	2289	107	1940	2606	106	1940	2386	106	1055	799	178
Sparsely vegetated areas	1054	185	460	1050	140	130	1050	140	130	29	0	0
Inland marshes	716	1268	2367	712	1240	2356	763	1286	2430	414	3310	1005
Peat bogs	7633	101	1068	7777	101	1067	8299	104	1081	5081	370	1172
Salt marshes	633	7603	0	726	7750	0	720	8014	0	1491	10263	0
Intertidal flats	2038	6248	0	2115	5862	0	2111	6019	0	1886	5599	0
Water courses	1628	680	935	1627	680	935	1997	674	935	1806	715	1787
Water bodies	939	2303	24625	1005	2239	24706	1150	2248	26383	1362	2250	21943
Coastal lagoons	88	6	2731	88	6	2730	4	0	1113	4	0	5336
Estuaries	418	1294	0	418	1293	0	52	1293	0	61	1252	0

Table 3. Percentage (%) of land covers areas in landscape regions in Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover Classes	1990			2000			2006			2012		
	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land
Continuous urban fabric	0.02	0.00	0.13	0.02	0.00	0.13	0.03	0.00	0.13	0.02	0.00	0.06
Discontinuous urban fabric	6.23	2.53	5.00	6.45	2.69	5.32	6.72	2.91	5.56	7.75	3.19	6.19
Industrial or commercial units	0.48	0.26	0.32	0.61	0.29	0.42	0.79	0.33	0.46	1.30	0.45	0.79
Road and rail networks and associated land	0.01	0.00	0.03	0.01	0.00	0.04	0.01	0.04	0.06	0.02	0.00	0.05
Port areas	0.01	0.02	0.12	0.01	0.02	0.12	0.01	0.04	0.12	0.01	0.01	0.06
Airports	0.32	0.02	0.04	0.32	0.02	0.04	0.32	0.02	0.04	0.32	0.02	0.04
Mineral extraction sites	0.17	0.00	0.12	0.25	0.02	0.17	0.33	0.00	0.20	0.29	0.00	0.16
Dump sites	0.05	0.02	0.03	0.06	0.02	0.04	0.07	0.02	0.04	0.02	0.02	0.03
Construction sites	0.00	0.02	0.01	0.01	0.00	0.07	0.01	0.01	0.03	0.01	0.00	0.00
Green urban areas	0.06	0.00	0.11	0.06	0.00	0.11	0.06	0.00	0.11	0.12	0.00	0.19
Sport and leisure facilities	0.22	0.06	0.46	0.32	0.09	0.52	0.43	0.12	0.59	0.61	0.13	0.80
Non-irrigated arable land	25.24	42.90	59.95	25.09	43.15	59.37	26.27	44.13	57.85	36.57	47.16	58.61
Fruit trees and berry plantations	0.00	0.08	0.02	0.00	0.08	0.01	0.00	0.08	0.01	0.00	0.06	0.01
Pastures	44.09	37.63	11.45	43.85	37.35	11.51	33.27	33.21	10.63	38.04	36.71	15.77
Complex cultivation patterns	7.97	4.01	5.08	7.72	3.87	5.05	16.07	6.61	6.42	0.06	0.09	0.03
Land principally occupied by agriculture	1.85	0.18	1.73	1.85	0.18	1.73	2.04	0.19	2.04	0.47	0.02	0.49
Broad-leaved forest	2.51	0.27	6.39	2.51	0.25	6.39	2.54	0.26	6.67	3.49	0.43	8.46
Coniferous forest	5.73	0.03	2.15	5.66	0.03	2.15	5.67	0.03	2.13	5.93	0.08	2.08
Mixed forest	1.52	0.08	1.78	1.51	0.00	1.78	1.63	0.00	1.79	1.33	0.02	0.81
Natural grasslands	0.34	2.31	0.26	0.36	2.29	0.26	0.31	2.25	0.28	0.65	0.84	0.49
Moors and heathland	0.45	0.01	0.00	0.46	0.01	0.00	0.45	0.01	0.00	0.67	0.03	0.00
Transitional woodland-shrub	0.11	0.04	0.04	0.20	0.14	0.07	0.20	0.13	0.09	0.31	0.11	0.24
Beaches, dunes, sands	0.29	0.99	0.02	0.30	1.13	0.02	0.30	1.03	0.02	0.16	0.35	0.03
Sparsely vegetated areas	0.16	0.08	0.07	0.16	0.06	0.02	0.16	0.06	0.02	0.00	0.00	0.00
Inland marshes	0.11	0.55	0.35	0.11	0.54	0.35	0.12	0.56	0.36	0.06	1.43	0.15
Peat bogs	1.16	0.04	0.16	1.18	0.04	0.16	1.26	0.05	0.16	0.77	0.16	0.17
Salt marshes	0.10	3.29	0.00	0.11	3.36	0.00	0.11	3.47	0.00	0.23	4.44	0.00
Intertidal flats	0.31	2.71	0.00	0.32	2.54	0.00	0.32	2.61	0.00	0.29	2.42	0.00
Water courses	0.25	0.29	0.14	0.25	0.29	0.14	0.30	0.29	0.14	0.27	0.31	0.26
Water bodies	0.14	1.00	3.64	0.15	0.97	3.65	0.18	0.97	3.90	0.21	0.97	3.24
Coastal lagoons	0.01	0.00	0.40	0.01	0.00	0.40	0.00	0.00	0.16	0.00	0.00	0.79
Estuaries	0.06	0.56	0.00	0.06	0.56	0.00	0.01	0.56	0.00	0.01	0.54	0.00

Table 4. Percentages (%) of landscape regions areas in land cover classes of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover Classes	1990			2000			2006			2012		
	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land	Geest	Marsch	Hügel-land
Continuous urban fabric	14.01	0.00	85.99	14.01	0.00	85.99	16.79	0.00	83.21	25.93	0.00	74.07
Discontinuous urban fabric	50.76	7.24	42.00	50.06	7.36	42.58	49.90	7.60	42.50	50.82	7.35	41.83
Industrial or commercial units	53.51	9.95	36.53	53.48	8.99	37.53	57.00	8.37	34.63	57.20	6.91	35.89
Road and rail networks and associated land	26.25	0.00	73.75	23.58	0.00	76.42	14.01	14.54	71.46	25.04	0.00	74.96
Port areas	4.78	4.88	90.33	4.74	5.74	89.52	4.55	9.48	85.97	14.59	5.54	79.87
Airports	86.26	1.54	12.20	86.40	1.52	12.08	86.35	1.53	12.12	86.17	1.83	11.99
Mineral extraction sites	58.46	0.45	41.09	58.86	1.38	39.77	61.86	0.25	37.89	63.44	0.08	36.48
Dump sites	58.27	6.69	35.05	58.54	5.76	35.70	60.74	5.13	34.13	41.50	13.87	44.63
Construction sites	0.00	43.88	56.12	10.45	0.00	89.55	26.26	10.43	63.31	100.00	0.00	0.00
Green urban areas	35.73	0.00	64.27	36.93	0.00	63.07	36.93	0.00	63.07	38.89	0.00	61.11
Sport and leisure facilities	31.06	2.99	65.95	36.38	3.45	60.17	39.88	4.02	56.09	41.46	3.09	55.75
Non-irrigated arable land	24.71	14.76	60.53	24.73	14.95	60.32	25.90	15.30	58.80	32.19	14.60	53.21
Fruit trees and berry plantations	7.77	58.84	33.40	9.74	73.76	16.50	8.87	65.29	25.84	12.84	58.68	28.48
Pastures	63.79	19.13	17.08	63.70	19.07	17.23	59.51	20.88	19.61	56.60	19.21	24.19
Complex cultivation patterns	54.52	9.65	35.83	54.01	9.53	36.45	64.27	9.28	26.45	48.73	27.56	23.71
Land principally occupied by agriculture	49.98	1.75	48.27	50.09	1.75	48.16	48.40	1.59	50.01	47.91	0.69	51.39
Broad-leaved forest	27.28	1.04	71.69	27.30	0.97	71.73	26.74	0.98	72.28	28.24	1.21	70.55
Coniferous forest	72.05	0.12	27.84	71.78	0.12	28.11	72.00	0.12	27.88	73.21	0.34	26.45
Mixed forest	44.93	0.81	54.26	45.22	0.02	54.77	46.84	0.02	53.14	61.22	0.37	38.41
Natural grasslands	23.73	57.40	18.87	24.87	56.31	18.82	22.11	56.92	20.97	44.60	20.38	35.02
Moors and heathland	98.98	1.02	0.00	99.00	1.00	0.00	98.99	1.01	0.00	98.38	1.62	0.00
Transitional woodland-shrub	64.98	8.55	26.47	62.83	14.78	22.39	60.01	13.59	26.40	51.33	6.60	42.07
Beaches, dunes, sands	44.28	53.24	2.48	41.70	56.01	2.29	43.77	53.83	2.40	51.93	39.31	8.76
Sparsely vegetated areas	62.03	10.87	27.10	79.53	10.60	9.87	79.53	10.60	9.87	100.00	0.00	0.00
Inland marshes	16.46	29.14	54.40	16.52	28.79	54.69	17.04	28.70	54.26	8.75	69.99	21.26
Peat bogs	86.72	1.15	12.13	86.94	1.13	11.93	87.50	1.10	11.40	76.72	5.58	17.69
Salt marshes	7.68	92.32	0.00	8.57	91.43	0.00	8.25	91.75	0.00	12.69	87.31	0.00
Intertidal flats	24.59	75.41	0.00	26.52	73.48	0.00	25.96	74.04	0.00	25.20	74.80	0.00
Water courses	50.20	20.97	28.83	50.20	20.97	28.83	55.38	18.70	25.92	41.92	16.60	41.49
Water bodies	3.37	8.26	88.37	3.60	8.01	88.39	3.86	7.55	88.59	5.33	8.81	85.86
Coastal lagoons	3.12	0.22	96.66	3.12	0.22	96.66	0.34	0.00	99.66	0.07	0.00	99.93
Estuaries	24.42	75.58	0.00	24.42	75.58	0.00	3.86	0.00	96.14	4.68	95.32	0.00

Table 5. Land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012, numbers in italic are calculated with new technology.

Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	**Hzgt. Lauenburg**	**Nordfries-land**	**Ostholstein**	**Pinneberg**	**Plön**	**Rendsburg**	**Schleswig**	**Segeberg**	**Steinburg**	**Stormarn**	**Kiel**	**Lübeck**	**Flensburg**	**Neu-münster**
Continuous urban fabric	**1990**	0	48	88	37	0	0	80	0	0	0	0	204	459	81	0
	2000	0	48	125	0	0	0	80	0	0	0	0	204	459	81	0
	2006	0	48	125	0	0	0	80	0	0	0	0	204	459	81	0
	2012	*37*	*27*	*0*	*0*	*0*	*32*	*54*	*0*	*32*	*0*	*26*	*112*	*125*	*39*	*41*
Discontinuous urban fabric	**1990**	5709	6258	7125	6584	7901	3652	7408	6289	6889	4764	5954	3999	4161	1798	2181
	2000	5966	6588	7879	6380	8116	4009	7883	6621	7514	4946	6332	4033	4215	1880	2210
	2006	6142	6654	8285	6695	8344	4202	8475	7176	7997	5187	6618	4025	4297	2166	2253
	2012	*6992*	*8227*	*8945*	*7490*	*9422*	*4719*	*10609*	*7800*	*9398*	*5517*	*7886*	*4207*	*4612*	*2237*	*2330*
Industrial or commercial units	**1990**	448	272	177	259	477	141	594	225	758	305	601	439	640	258	357
	2000	471	326	254	294	577	181	772	341	887	390	754	572	841	352	476
	2006	671	497	345	382	720	181	870	451	1117	464	984	623	873	402	497
	2012	*871*	*738*	*1370*	*686*	*1027*	*472*	*1137*	*1610*	*1577*	*873*	*1295*	*907*	*1170*	*490*	*654*
Road and rail networks and associated land	**1990**	0	0	0	0	0	0	0	0	0	0	0	127	33	66	45
	2000	0	0	34	0	0	0	0	0	0	0	0	161	33	66	44
	2006	0	0	34	0	0	0	0	0	0	83	80	171	90	66	44
	2012	*0*	*0*	*0*	*0*	*4*	*0*	*51*	*0*	*28*	*0*	*81*	*168*	*59*	*37*	*44*
Port areas	**1990**	45	25	0	48	19	3	12	45	0	0	0	192	437	93	0
	2000	53	25	0	48	19	3	12	63	0	0	0	192	437	93	0
	2006	91	25	0	48	19	3	12	45	0	0	0	192	437	93	0
	2012	*0*	*0*	*46*	*14*	*0*	*22*	*62*	*0*	*0*	*0*	*0*	*74*	*251*	*21*	*0*
Airports	**1990**	37	0	876	0	136	0	207	623	57	103	0	123	172	53	35
	2000	37	0	875	0	136	0	206	623	83	103	0	123	172	53	35
	2006	37	0	842	0	136	0	206	623	91	103	0	123	172	70	35
	2012	*45*	*0*	*895*	*0*	*0*	*0*	*297*	*614*	*71*	*137*	*0*	*127*	*151*	*85*	*39*

Table 5. Land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012, numbers in italic are calculated with new technology.

Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg-Eckernförde	Schleswig-Flensburg	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Mineral extraction sites	1990	51	106	74	183	72	0	182	211	483	325	207	0	58	0	0
	2000	90	102	81	200	87	30	427	322	810	373	225	0	58	0	0
	2006	60	84	172	205	115	28	527	582	984	386	217	0	143	0	0
	2012	*110*	*61*	*130*	*214*	*65*	*62*	*494*	*508*	*920*	*243*	*110*	*0*	*70*	*0*	*0*
Dump sites	1990	27	66	0	46	27	39	266	0	43	41	0	0	26	0	39
	2000	14	101	0	64	27	61	312	0	33	41	0	0	26	0	39
	2006	14	95	0	64	27	54	355	0	57	41	0	0	26	0	44
	2012	*0*	*28*	*0*	*0*	*31*	*42*	*60*	*0*	*43*	*53*	*0*	*0*	*67*	*0*	*55*
Construction sites	1990	40	0	0	0	0	0	14	0	0	0	0	37	0	0	0
	2000	0	0	0	33	0	26	45	0	0	0	169	0	135	85	0
	2006	32	0	23	28	0	0	0	0	38	0	52	0	135	0	0
	2012	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*29*	*0*	*27*	*0*	*0*	*0*	*0*
Green urban areas	1990	0	29	0	81	33	0	93	0	11	0	120	275	225	71	181
	2000	0	29	0	81	33	0	94	0	11	0	120	280	225	78	198
	2006	0	29	0	81	33	0	94	0	11	0	120	280	225	78	198
	2012	*0*	*41*	*0*	*64*	*203*	*60*	*189*	*30*	*220*	*77*	*191*	*391*	*238*	*218*	*139*
Sport and leisure facilities	1990	99	128	324	582	169	418	508	89	186	143	250	937	428	265	220
	2000	196	382	481	597	431	481	572	89	304	143	312	888	461	265	220
	2006	299	382	611	821	581	612	739	132	440	166	468	907	494	221	220
	2012	*296*	*753*	*787*	*1217*	*986*	*610*	*1341*	*217*	*865*	*128*	*717*	*794*	*716*	*86*	*196*
Non-irrigated arable land	1990	50604	69074	58634	96843	16468	58365	83664	80389	64467	32920	47543	2198	7576	1131	1717
	2000	50976	67972	58651	96000	16158	57913	82977	81202	63185	32610	46823	2135	7197	968	1618
	2006	53548	65993	77566	77569	15406	57319	85368	86430	60394	31762	43994	2117	6287	837	1547
	2012	*64026*	*61084*	*80864*	*91995*	*20893*	*62881*	*101976*	*114853*	*61959*	*36160*	*39874*	*1787*	*4532*	*873*	*1545*

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Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Fruit trees and berry plantations	1990	0	0	0	109	217	0	0	0	0	0	0	0	0	0	0
	2000	0	0	0	43	217	0	0	0	0	0	0	0	0	0	0
	2006	0	0	0	76	191	0	0	0	0	0	0	0	0	0	0
	2012	*0*	*0*	*0*	*70*	*118*	*0*	*0*	*0*	*0*	*57*	*0*	*0*	*0*	*0*	*0*
Pastures	1990	61299	7848	100073	8360	22416	11406	71118	76526	30895	49155	9626	1048	1834	1066	1371
	2000	60510	8261	99921	8458	22300	11324	70832	76075	30764	48977	9589	1038	1900	979	1309
	2006	52063	8600	72734	8798	20113	11000	56712	50240	27908	44459	9425	975	2467	536	1158
	2012	*55547*	*15552*	*87294*	*14911*	*25290*	*17983*	*64042*	*57051*	*33336*	*47281*	*15185*	*1501*	*3429*	*1126*	*1590*
Complex cultivation patterns	1990	8933	2580	13489	3780	9267	12781	14850	18536	6007	2594	1587	557	228	254	536
	2000	8799	2864	13004	3660	9057	12725	14590	17426	6111	2722	1512	510	103	238	529
	2006	14218	3532	35457	5299	10999	12945	24378	35982	9269	7438	2864	478	103	636	681
	2012	*99*	*0*	*32*	*50*	*129*	*58*	*56*	*76*	*114*	*129*	*0*	*0*	*0*	*0*	*0*
Land principally occupied by agriculture	1990	922	2792	779	2004	2297	1645	4426	2356	2374	2206	1750	255	526	0	0
	2000	922	2791	778	1989	2300	1610	4423	2354	2367	2204	1749	249	525	0	0
	2006	916	3066	847	2195	2771	1893	4947	2686	2724	2319	2536	292	470	0	0
	2012	*144*	*1045*	*236*	*519*	*490*	*546*	*971*	*622*	*586*	*556*	*343*	*56*	*212*	*0*	*162*
Broad-leaved forest	1990	1041	14974	1115	8916	1769	7478	9077	3684	3167	1817	5205	428	1583	154	0
	2000	1040	14947	1073	8896	1768	7474	9063	3681	3165	1815	5202	428	1582	154	0
	2006	1100	15039	1099	9409	1660	7596	9208	4219	3567	1931	5359	428	1627	207	0
	2012	*1755*	*17557*	*1929*	*11225*	*1932*	*9816*	*13731*	*6180*	*5249*	*2397*	*6400*	*588*	*2494*	*226*	*137*
Coniferous forest	1990	2174	12280	4401	961	1769	730	5735	3467	13096	4214	2237	0	1036	82	69
	2000	2128	12289	4371	961	1768	729	5730	3416	13010	3974	2235	0	1043	82	69
	2006	2060	12230	4332	961	1751	729	5780	3424	13131	3929	2244	0	1038	82	69
	2012	*2431*	*11630*	*4222*	*804*	*2039*	*820*	*6251*	*3745*	*14041*	*4260*	*2110*	*0*	*730*	*111*	*53*

Table 5. Land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012, numbers in italic are calculated with new technology.

Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Mixed forest	**1990**	869	4542	591	800	203	2004	6244	2332	1559	1635	814	0	283	91	214
	2000	869	4540	414	822	203	2003	6280	2331	1558	1592	813	0	283	84	213
	2006	869	4694	476	851	203	2014	6417	2224	1935	1736	825	0	344	59	213
	2012	*506*	*4058*	*361*	*549*	*322*	*359*	*2409*	*943*	*1278*	*1696*	*1515*	*25*	*198*	*0*	*107*
Natural grasslands	**1990**	3143	0	2308	1068	264	194	695	737	386	82	182	0	0	238	0
	2000	3111	0	2481	1010	264	194	716	736	385	82	182	0	0	238	0
	2006	3029	0	2411	1010	264	194	635	875	283	82	182	0	0	162	0
	2012	*1632*	*221*	*1862*	*989*	*181*	*150*	*1729*	*1135*	*567*	*618*	*99*	*0*	*327*	*0*	*0*
Moors and heathland	**1990**	0	0	2508	0	139	0	40	165	74	82	0	0	0	0	0
	2000	0	0	2557	0	139	0	40	165	74	82	0	0	0	0	0
	2006	0	0	2516	0	139	0	40	165	74	82	0	0	0	0	0
	2012	*0*	*15*	*4167*	*42*	*0*	*12*	*93*	*0*	*35*	*51*	*0*	*0*	*62*	*0*	*0*
Transitional woodland-shrub	**1990**	36	0	175	0	20	0	91	424	12	272	103	0	0	0	0
	2000	104	0	420	122	20	0	200	471	115	577	103	0	0	0	0
	2006	104	130	405	92	34	0	394	471	152	413	103	0	0	0	0
	2012	*200*	*152*	*321*	*240*	*187*	*65*	*1056*	*447*	*276*	*282*	*346*	*56*	*168*	*136*	*0*
Beaches, dunes, sands	**1990**	0	0	4193	92	0	0	0	0	0	0	0	0	0	0	0
	2000	0	0	4546	92	0	0	0	0	0	0	0	0	0	0	0
	2006	0	0	4326	73	0	0	0	0	0	0	0	0	0	0	0
	2012	*0*	*0*	*1854*	*153*	*0*	*7*	*0*	*0*	*0*	*0*	*0*	*7*	*11*	*0*	*0*
Sparsely vegetated areas	**1990**	0	330	1159	119	0	0	35	0	0	45	0	0	0	0	0
	2000	0	0	1202	73	0	0	35	0	0	0	0	0	0	0	0
	2006	0	0	1202	594	0	0	35	0	0	0	0	0	0	0	0
	2012	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*0*	*29*	*0*	*0*	*0*	*0*	*0*

Table 5. Land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012, numbers in italic are calculated with new technology.

Land Cover classes	**Year**	**Land Cover Areas of Districts (ha)**														
		Dithmar-schen	**Hzgt. Lauenburg**	**Nordfries-land**	**Ostholstein**	**Pinneberg**	**Plön**	**Rendsburg**	**Schleswig**	**Segeberg**	**Steinburg**	**Stormarn**	**Kiel**	**Lübeck**	**Flensburg**	**Neu-münster**
Inland marshes	**1990**	260	117	1478	983	0	470	429	142	0	161	46	109	151	0	0
	2000	259	117	1861	982	0	470	418	142	0	134	46	109	151	0	0
	2006	289	181	1878	594	0	470	418	138	0	163	51	109	151	0	0
	2012	*1158*	*0*	*2167*	*139*	*252*	*333*	*282*	*228*	*0*	*32*	*38*	*95*	*0*	*0*	*0*
Peat bogs	**1990**	1596	0	732	0	160	64	2729	1743	888	448	189	0	0	0	253
	2000	1679	0	865	0	160	64	2639	1742	888	468	188	0	0	0	253
	2006	1687	0	868	0	271	64	2653	1938	1056	486	208	0	0	0	253
	2012	*1176*	*73*	*452*	*280*	*237*	*87*	*1307*	*1736*	*598*	*473*	*94*	*0*	*0*	*0*	*110*
Salt marshes	**1990**	1995	0	6240	0	0	0	0	0	0	0	0	0	0	0	0
	2000	2037	0	6439	0	0	0	0	0	0	0	0	0	0	0	0
	2006	2005	0	6730	0	0	0	0	0	0	0	0	0	0	0	0
	2012	*2517*	*0*	*9166*	*0*	*0*	*0*	*0*	*0*	*0*	*71*	*0*	*0*	*0*	*0*	*0*
Intertidal flats	**1990**	959	0	7318	0	8	0	0	0	0	0	0	0	0	0	0
	2000	915	0	7054	0	8	0	0	0	0	0	0	0	0	0	0
	2006	915	0	7208	0	8	0	0	0	0	0	0	0	0	0	0
	2012	*821*	*0*	*6642*	*0*	*0*	*0*	*0*	*0*	*0*	*32*	*0*	*0*	*0*	*0*	*0*
Water courses	**1990**	837	21	169	0	0	0	1435	198	0	273	0	59	253	0	0
	2000	837	21	169	0	0	0	1434	198	0	273	0	58	252	0	0
	2006	1055	21	222	0	0	0	1434	289	0	275	0	58	252	0	0
	2012	*917*	*67*	*164*	*0*	*0*	*98*	*1344*	*251*	*0*	*333*	*0*	*79*	*1057*	*0*	*0*
Water bodies	**1990**	584	3598	2084	2509	0	9241	4351	3787	1247	57	231	27	29	0	122
	2000	584	3619	2178	2406	0	9269	4347	3821	1246	57	243	27	29	0	122
	2006	574	3724	2283	2406	0	9269	4347	3821	1253	57	243	27	1653	0	122
	2012	*573*	*3686*	*2178*	*2729*	*44*	*9349*	*3452*	*691*	*1289*	*67*	*262*	*26*	*1073*	*0*	*132*

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Land Cover classes	Year	Land Cover Areas of Districts (ha)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Coastal lagoons	1990	0	0	94	84	0	0	0	1029	0	0	0	0	1617	0	0
	2000	0	0	178	0	0	0	0	1029	0	0	0	0	1617	0	0
	2006	0	0	88	0	0	0	0	1029	0	0	0	0	0	0	0
	2012	*0*	*0*	*4*	*14*	*0*	*0*	*1102*	*4201*	*0*	*0*	*0*	*0*	*0*	*19*	*0*
Estuaries	1990	924	0	403	0	156	0	0	92	0	137	0	0	0	0	0
	2000	923	0	403	0	156	0	0	91	0	136	0	0	0	0	0
	2006	708	0	344	0	156	0	0	0	0	136	0	0	0	0	0
	2012	*690*	*0*	*309*	*0*	*168*	*0*	*0*	*0*	*0*	*147*	*0*	*0*	*0*	*0*	*0*

Table 6. Percentages of land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover classes	Year	Percentage of Land Cover Areas of Districts (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Continuous urban fabric	1990	0.00	0.04	0.04	0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.00	1.86	2.11	1.43	0.00
	2000	0.00	0.04	0.05	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	1.86	2.11	1.43	0.00
	2006	0.00	0.04	0.05	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	1.86	2.11	1.43	0.00
	2012	0.03	0.02	0.00	0.00	0.00	0.03	0.03	0.00	0.02	0.00	0.03	1.02	0.58	0.69	0.56
Discontinuous urban fabric	1990	4.00	5.00	3.29	4.90	12.35	3.36	3.46	3.10	5.20	4.68	7.77	36.29	19.12	31.54	29.71
	2000	4.19	5.27	3.37	5.42	12.69	3.69	3.68	3.26	5.67	4.86	8.27	36.62	19.38	32.99	30.12
	2006	4.31	5.32	3.55	5.69	13.05	3.87	3.96	3.54	6.03	5.10	8.64	36.55	19.76	38.02	30.71
	2012	4.90	6.53	4.05	5.95	14.73	4.32	4.95	3.83	7.06	5.39	10.29	38.27	21.21	39.21	31.76
Industrial or commercial units	1990	0.31	0.22	0.08	0.19	0.75	0.13	0.28	0.11	0.57	0.30	0.78	3.99	2.94	4.52	4.86
	2000	0.33	0.26	0.11	0.25	0.90	0.17	0.36	0.17	0.67	0.38	0.98	5.19	3.86	6.17	6.49
	2006	0.47	0.40	0.15	0.32	1.13	0.17	0.41	0.22	0.84	0.46	1.28	5.65	4.01	7.06	6.78
	2012	0.61	0.59	0.61	0.54	1.61	0.44	0.53	0.79	1.19	0.86	1.69	8.25	5.38	8.59	8.91
Road and rail networks and associated land	1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.15	0.15	1.15	0.61
	2000	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	1.46	0.15	1.15	0.61
	2006	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.11	1.55	0.42	1.15	0.61
	2012	0.00	0.00	0.00	0.00	0.01	0.00	0.02	0.00	0.02	0.00	0.11	1.52	0.27	0.66	0.60
Port areas	1990	0.03	0.02	0.00	0.04	0.03	0.00	0.01	0.02	0.00	0.00	0.00	1.74	2.01	1.63	0.00
	2000	0.04	0.02	0.00	0.04	0.03	0.00	0.01	0.03	0.00	0.00	0.00	1.74	2.01	1.63	0.00
	2006	0.06	0.02	0.00	0.04	0.03	0.00	0.01	0.02	0.00	0.00	0.00	1.74	2.01	1.63	0.00
	2012	0.00	0.00	0.03	0.00	0.00	0.02	0.03	0.00	0.00	0.00	0.00	0.67	1.15	0.37	0.00
Airports	1990	0.03	0.00	0.40	0.00	0.21	0.00	0.10	0.31	0.04	0.10	0.00	1.12	0.79	0.94	0.48
	2000	0.03	0.00	0.37	0.00	0.21	0.00	0.10	0.16	0.06	0.10	0.00	1.12	0.79	0.94	0.48
	2006	0.03	0.00	0.36	0.00	0.21	0.00	0.10	0.31	0.07	0.10	0.00	1.12	0.79	1.23	0.48
	2012	0.03	0.00	0.38	0.00	0.00	0.00	0.14	0.30	0.05	0.13	0.00	1.16	0.70	1.49	0.53

Table 6. Percentages of land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover classes	Year	Percentage of Land Cover Areas of Districts (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Mineral extraction sites	1990	0.04	0.08	0.03	0.14	0.11	0.00	0.08	0.10	0.36	0.32	0.27	0.00	0.26	0.00	0.00
	2000	0.06	0.08	0.03	0.17	0.14	0.03	0.20	0.16	0.61	0.37	0.29	0.00	0.26	0.00	0.00
	2006	0.04	0.07	0.07	0.17	0.18	0.03	0.25	0.29	0.74	0.38	0.28	0.00	0.66	0.00	0.00
	2012	0.08	0.05	0.06	0.18	0.10	0.06	0.23	0.25	0.69	0.24	0.14	0.00	0.32	0.00	0.00
Dump sites	1990	0.02	0.05	0.00	0.03	0.04	0.04	0.12	0.00	0.03	0.04	0.00	0.00	0.12	0.00	0.53
	2000	0.01	0.08	0.00	0.05	0.04	0.06	0.15	0.00	0.02	0.04	0.00	0.00	0.12	0.00	0.53
	2006	0.01	0.08	0.00	0.05	0.04	0.05	0.17	0.00	0.04	0.04	0.00	0.00	0.12	0.00	0.60
	2012	0.00	0.02	0.00	0.00	0.05	0.04	0.03	0.00	0.03	0.05	0.00	0.00	0.31	0.00	0.75
Construction sites	1990	0.03	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.00
	2000	0.00	0.00	0.00	0.03	0.00	0.02	0.02	0.00	0.00	0.00	0.22	0.00	0.62	1.50	0.00
	2006	0.02	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.03	0.00	0.07	0.00	0.62	0.00	0.00
	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.04	0.00	0.00	0.00	0.00
Green urban areas	1990	0.00	0.02	0.00	0.06	0.05	0.00	0.04	0.00	0.01	0.00	0.16	2.50	1.03	1.25	2.47
	2000	0.00	0.02	0.00	0.07	0.05	0.00	0.04	0.00	0.01	0.00	0.16	2.54	1.03	1.38	2.70
	2006	0.00	0.02	0.00	0.07	0.05	0.00	0.04	0.00	0.01	0.00	0.16	2.54	1.03	1.38	2.70
	2012	0.00	0.03	0.00	0.05	0.32	0.06	0.09	0.01	0.17	0.08	0.25	3.55	1.09	3.83	1.90
Sport and leisure facilities	1990	0.07	0.10	0.15	0.43	0.26	0.38	0.24	0.04	0.14	0.14	0.33	8.51	1.97	4.64	3.00
	2000	0.14	0.31	0.21	0.51	0.67	0.44	0.27	0.04	0.23	0.14	0.41	8.07	2.12	4.64	3.00
	2006	0.21	0.31	0.26	0.70	0.91	0.56	0.35	0.06	0.33	0.16	0.61	8.24	2.27	3.88	3.00
	2012	0.21	0.60	0.34	1.03	1.54	0.56	0.63	0.11	0.65	0.13	0.94	7.22	3.29	1.50	2.67
Non-irrigated arable land	1990	35.48	55.22	27.07	72.01	25.74	53.72	39.04	39.58	48.62	32.35	62.03	19.94	34.82	19.84	23.40
	2000	35.77	54.37	31.62	68.70	25.27	53.34	38.75	40.01	47.68	32.07	61.13	19.39	33.09	16.99	22.05
	2006	37.57	52.78	33.23	65.93	24.09	52.79	39.87	42.59	45.58	31.23	57.43	19.22	28.91	14.70	21.09
	2012	44.92	48.90	41.11	65.44	32.68	57.98	47.64	56.62	46.85	35.59	52.06	16.26	20.84	15.31	21.06

Table 6. Percentages of land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover classes	Year	Percentage of Land Cover Areas of Districts (%)														
		Dithmar-schen	**Hzgt. Lauenburg**	**Nordfries-land**	**Ostholstein**	**Pinneberg**	**Plön**	**Rendsburg**	**Schleswig**	**Segeberg**	**Steinburg**	**Stormarn**	**Kiel**	**Lübeck**	**Flensburg**	**Neu-münster**
Fruit trees and berry plantations	**1990**	0.00	0.00	0.00	0.08	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.00	0.04	0.34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	0.00	0.06	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	0.06	0.18	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
Pastures	**1990**	42.98	6.27	46.20	6.22	35.03	10.50	33.19	37.68	23.30	48.30	12.56	9.51	8.43	18.69	18.68
	2000	42.46	6.61	42.80	7.19	34.87	10.43	33.08	37.49	23.22	48.16	12.52	9.43	8.74	17.19	17.85
	2006	36.53	6.88	31.16	7.48	31.46	10.13	26.49	24.76	21.06	43.72	12.30	8.85	11.34	9.41	15.79
	2012	38.97	12.47	37.58	12.43	39.55	16.63	29.92	28.14	25.16	46.49	19.89	13.66	15.76	19.73	21.67
Complex cultivation patterns	**1990**	6.26	2.06	6.23	2.81	14.48	11.76	6.93	9.13	4.53	2.55	2.07	5.05	1.05	4.45	7.30
	2000	6.17	2.29	5.57	3.11	14.16	11.72	6.81	8.59	4.61	2.68	1.97	4.63	0.47	4.19	7.21
	2006	9.98	2.83	15.19	4.50	17.20	11.92	11.39	17.73	6.99	7.31	3.74	4.34	0.47	11.16	9.28
	2012	0.07	0.00	0.01	0.04	0.20	0.05	0.03	0.04	0.09	0.13	0.00	0.00	0.00	0.00	0.00
Land principally occupied by agriculture	**1990**	0.65	2.23	0.36	1.49	3.59	1.51	2.07	1.16	1.79	2.17	2.28	2.31	2.42	0.00	0.00
	2000	0.65	2.23	0.33	1.69	3.60	1.48	2.07	1.16	1.79	2.17	2.28	2.26	2.42	0.00	0.00
	2006	0.64	2.45	0.36	1.87	4.33	1.74	2.31	1.32	2.06	2.28	3.31	2.65	2.16	0.00	0.00
	2012	0.10	0.84	0.10	0.44	0.77	0.50	0.45	0.31	0.44	0.55	0.45	0.51	0.97	0.00	2.21
Broad-leaved forest	**1990**	0.73	11.97	0.51	6.63	2.76	6.88	4.24	1.81	2.39	1.79	6.79	3.88	7.27	2.71	0.00
	2000	0.73	11.96	0.46	7.56	2.76	6.88	4.23	1.81	2.39	1.79	6.79	3.88	7.27	2.71	0.00
	2006	0.77	12.03	0.47	8.00	2.60	7.00	4.30	2.08	2.69	1.90	7.00	3.88	7.48	3.63	0.00
	2012	1.23	14.02	0.82	9.51	3.02	8.96	6.40	3.01	3.92	2.36	8.29	5.35	11.48	3.96	1.86
Coniferous forest	**1990**	1.52	9.82	2.03	0.71	2.77	0.67	2.68	1.71	9.88	4.14	2.92	0.00	4.76	1.44	0.95
	2000	1.49	9.83	1.87	0.82	2.77	0.67	2.68	1.68	9.82	3.91	2.92	0.00	4.79	1.44	0.95
	2006	1.45	9.78	1.86	0.82	2.74	0.67	2.70	1.69	9.91	3.86	2.93	0.00	4.77	1.44	0.95
	2012	1.71	9.30	1.80	0.68	3.19	0.76	2.92	1.85	10.58	4.19	2.75	0.00	3.36	1.94	0.72

Table 6. Percentages of land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover classes	Year	Percentage of Land Cover Areas of Districts (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Mixed forest	1990	0.61	3.63	0.27	0.59	0.32	1.84	2.91	1.15	1.18	1.61	1.06	0.00	1.30	1.60	2.91
	2000	0.61	3.63	0.18	0.70	0.32	1.84	2.93	1.15	1.18	1.57	1.06	0.00	1.30	1.48	2.91
	2006	0.61	3.75	0.20	0.72	0.32	1.85	3.00	1.10	1.46	1.71	1.08	0.00	1.58	1.04	2.91
	2012	0.35	3.25	0.15	0.47	0.50	0.31	1.13	0.46	0.96	1.67	1.98	0.23	0.91	0.00	1.46
Natural grasslands	1990	2.20	0.00	1.07	0.79	0.41	0.18	0.32	0.36	0.29	0.08	0.24	0.00	0.00	4.17	0.00
	2000	2.18	0.00	1.06	0.86	0.41	0.18	0.33	0.36	0.29	0.08	0.24	0.00	0.00	4.17	0.00
	2006	2.13	0.00	1.03	0.86	0.41	0.18	0.30	0.43	0.21	0.08	0.24	0.00	0.00	2.85	0.00
	2012	1.15	0.18	0.99	0.46	0.28	0.14	0.81	0.56	0.43	0.61	0.13	0.00	1.51	0.00	0.00
Moors and heathland	1990	0.00	0.00	1.16	0.00	0.22	0.00	0.02	0.08	0.06	0.08	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	1.10	0.00	0.22	0.00	0.02	0.08	0.06	0.08	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	1.08	0.00	0.22	0.00	0.02	0.08	0.06	0.08	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.01	1.79	0.04	0.00	0.01	0.04	0.00	0.03	0.05	0.00	0.00	0.28	0.00	0.00
Transitional woodland-shrub	1990	0.02	0.00	0.08	0.00	0.03	0.00	0.04	0.21	0.01	0.27	0.13	0.00	0.00	0.00	0.00
	2000	0.07	0.00	0.18	0.10	0.03	0.00	0.09	0.23	0.09	0.57	0.13	0.00	0.00	0.00	0.00
	2006	0.07	0.10	0.17	0.08	0.05	0.00	0.18	0.23	0.11	0.41	0.13	0.00	0.00	0.00	0.00
	2012	0.14	0.12	0.14	0.20	0.29	0.06	0.49	0.22	0.21	0.28	0.45	0.51	0.77	2.39	0.00
Beaches, dunes, sands	1990	0.00	0.00	1.94	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	1.95	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	1.85	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.80	0.13	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.06	0.05	0.00	0.00
Sparsely vegetated areas	1990	0.00	0.26	0.54	0.09	0.00	0.00	0.02	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.80	0.06	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	0.51	0.50	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00

Table 6. Percentages of land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover classes	Year	Percentage of Land Cover Areas of Districts (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Inland marshes	1990	0.18	0.09	0.68	0.73	0.00	0.43	0.20	0.07	0.00	0.16	0.06	0.99	0.69	0.00	0.00
	2000	0.18	0.09	0.80	0.50	0.00	0.43	0.20	0.07	0.00	0.13	0.06	0.99	0.69	0.00	0.00
	2006	0.20	0.14	0.80	0.00	0.00	0.43	0.20	0.07	0.00	0.16	0.07	0.99	0.69	0.00	0.00
	2012	0.81	0.00	0.95	0.08	0.39	0.31	0.13	0.11	0.00	0.03	0.05	0.86	0.00	0.00	0.00
Peat bogs	1990	1.12	0.00	0.34	0.00	0.25	0.06	1.27	0.86	0.67	0.44	0.25	0.00	0.00	0.00	3.45
	2000	1.18	0.00	0.37	0.00	0.25	0.06	1.23	0.86	0.67	0.46	0.25	0.00	0.00	0.00	3.45
	2006	1.18	0.00	0.37	0.00	0.42	0.06	1.24	0.95	0.80	0.48	0.27	0.00	0.00	0.00	3.45
	2012	0.83	0.06	0.21	0.21	0.37	0.08	0.61	0.86	0.45	0.47	0.12	0.00	0.00	0.00	1.50
Salt marshes	1990	1.40	0.00	2.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	1.43	0.00	2.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	1.41	0.00	2.88	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	1.77	0.00	3.93	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00
Intertidal flats	1990	0.67	0.00	3.38	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	0.64	0.00	3.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.64	0.00	3.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.58	0.00	2.84	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Water courses	1990	0.59	0.02	0.08	0.00	0.00	0.00	0.67	0.10	0.00	0.27	0.00	0.53	1.16	0.00	0.00
	2000	0.59	0.02	0.07	0.00	0.00	0.00	0.67	0.10	0.00	0.27	0.00	0.53	1.16	0.00	0.00
	2006	0.74	0.02	0.09	0.00	0.00	0.00	0.67	0.14	0.00	0.27	0.00	0.53	1.16	0.00	0.00
	2012	0.64	0.05	0.07	0.00	0.00	0.09	0.63	0.12	0.00	0.33	0.00	0.72	4.86	0.00	0.00
Water bodies	1990	0.41	2.88	0.96	1.87	0.00	8.51	2.03	1.86	0.94	0.06	0.30	0.24	0.13	0.00	1.66
	2000	0.41	2.89	0.93	2.05	0.00	8.54	2.03	1.88	0.94	0.06	0.32	0.24	0.13	0.00	1.66
	2006	0.40	2.98	0.98	2.05	0.00	8.54	2.03	1.88	0.95	0.06	0.32	0.24	7.60	0.00	1.66
	2012	0.40	2.95	1.02	2.15	0.07	8.61	1.61	0.34	0.97	0.07	0.34	0.24	4.94	0.00	1.80

Table 6. Percentages of land cover areas in the districts of Schleswig-Holstein for the years 1990, 2000, 2006 and 2012.

Land Cover classes	Year	Percentage of Land Cover Areas of Districts (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Coastal lagoons	**1990**	0.00	0.00	0.04	0.06	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	7.43	0.00	0.00
	2000	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	7.43	0.00	0.00
	2006	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.51	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	0.01	0.00	0.00	0.51	2.07	0.00	0.00	0.00	0.00	0.00	0.33	0.00
Estuaries	**1990**	0.65	0.00	0.19	0.00	0.24	0.00	0.00	0.05	0.00	0.13	0.00	0.00	0.00	0.00	0.00
	2000	0.65	0.00	0.17	0.00	0.24	0.00	0.00	0.05	0.00	0.13	0.00	0.00	0.00	0.00	0.00
	2006	0.50	0.00	0.15	0.00	0.24	0.00	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00	0.00
	2012	0.48	0.01	0.13	0.00	0.26	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.00	0.00	0.00

Table 7. Percentages of areas of the districts in land cover classes of Schleswig-Holstein for the years 1990, 2006 and 2012.

Land Cover classes	Year	Percentage of Areas of Districts on Land cover classes (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Continuous urban fabric	1990	0.00	4.78	8.81	3.69	0.00	0.00	7.99	0.00	0.00	0.00	0.00	20.51	46.07	8.15	0.00
	2000	0.00	4.79	12.49	0.00	0.00	0.00	7.99	0.00	0.00	0.00	0.00	20.51	46.07	8.15	0.00
	2006	0.00	4.79	12.49	0.00	0.00	0.00	7.99	0.00	0.00	0.00	0.00	20.51	46.07	8.15	0.00
	2012	7.09	5.18	0.00	0.00	0.00	6.13	10.29	0.00	6.05	0.00	4.98	21.28	23.75	7.43	7.81
Discontinuous urban fabric	1990	7.08	7.76	8.83	8.16	9.79	4.53	9.18	7.79	8.54	5.91	7.38	4.96	5.16	2.23	2.70
	2000	7.05	7.79	9.32	7.54	9.60	4.74	9.32	7.83	8.89	5.85	7.49	4.77	4.98	2.22	2.61
	2006	6.94	7.52	9.36	7.56	9.43	4.75	9.57	8.11	9.03	5.86	7.48	4.55	4.85	2.45	2.55
	2012	6.98	8.15	9.42	6.99	9.40	4.68	10.57	7.76	9.34	5.48	7.87	4.20	4.60	2.23	2.33
Industrial or commercial units	1990	7.53	4.56	2.97	4.35	8.02	2.37	9.98	3.78	12.75	5.12	10.09	7.39	10.76	4.33	6.00
	2000	6.30	4.36	3.39	3.93	7.71	2.41	10.31	4.56	11.85	5.20	10.07	7.64	11.23	4.70	6.36
	2006	7.39	5.48	3.80	4.21	7.93	1.99	9.59	4.97	12.31	5.11	10.84	6.86	9.62	4.43	5.48
	2012	5.85	4.95	9.53	4.29	6.91	3.18	7.65	10.82	10.60	5.87	8.70	6.10	7.87	3.29	4.40
Road and rail networks and associated land	1990	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	46.91	12.18	24.39	16.51
	2000	0.00	0.00	10.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	47.62	9.72	19.47	13.18
	2006	0.00	0.00	5.94	0.00	0.00	0.00	0.00	0.00	0.00	14.54	14.17	30.06	15.90	11.57	7.83
	2012	0.00	0.00	0.00	0.00	0.80	0.00	10.78	0.00	5.94	0.00	17.14	35.50	12.53	7.92	9.39
Port areas	1990	4.88	2.70	0.00	5.19	2.08	0.36	1.28	4.86	0.00	0.00	0.00	20.90	47.61	10.13	0.00
	2000	5.74	2.68	0.00	5.16	2.06	0.36	1.27	4.82	0.00	0.00	0.00	20.71	47.17	10.03	0.00
	2006	9.48	2.57	0.00	4.96	1.98	0.35	1.22	4.63	0.00	0.00	0.00	19.88	45.30	9.64	0.00
	2012	0.00	0.00	12.18	0.00	0.00	4.40	12.70	0.00	0.00	0.00	0.00	15.11	51.35	4.27	0.00
Airports	1990	1.54	0.00	36.17	0.00	5.61	0.00	8.53	25.72	2.33	4.25	0.00	5.10	7.10	2.20	1.45
	2000	1.52	0.00	35.79	0.00	5.55	0.00	8.43	25.45	3.37	4.20	0.00	5.04	7.02	2.18	1.44
	2006	1.53	0.00	34.55	0.00	5.57	0.00	8.46	25.54	3.71	4.22	0.00	5.06	7.05	2.87	1.44
	2012	1.83	0.00	36.32	0.00	0.00	0.00	12.04	24.92	2.90	5.55	0.00	5.17	6.14	3.45	1.58

Table 7. Percentages of areas of the districts in land cover classes of Schleswig-Holstein for the years 1990, 2006 and 2012.

Land Cover classes	Year	Percentage of Areas of Districts on Land cover classes (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Mineral extraction sites	1990	2.62	5.44	3.79	9.37	3.70	0.00	9.30	10.81	24.76	16.62	10.62	0.00	2.95	0.00	0.00
	2000	3.19	3.63	2.89	7.11	3.08	1.05	15.17	11.80	28.80	13.24	8.00	0.00	2.05	0.00	0.00
	2006	1.71	2.38	4.92	5.85	3.29	0.79	15.05	16.61	28.09	11.03	6.19	0.00	4.08	0.00	0.00
	2012	3.68	2.03	4.34	7.16	2.18	2.09	16.55	17.00	30.82	8.13	3.67	0.00	2.36	0.00	0.00
Dump sites	1990	4.35	10.57	0.00	7.37	4.33	6.33	42.90	0.00	6.97	6.69	0.00	0.00	4.23	0.00	6.27
	2000	1.92	14.09	0.00	8.95	3.73	8.52	43.41	0.00	4.58	5.76	0.00	0.00	3.64	0.00	5.40
	2006	1.77	12.25	0.00	8.27	3.45	7.00	45.54	0.00	7.35	5.32	0.00	0.00	3.37	0.00	5.68
	2012	0.00	7.49	0.00	0.00	8.27	11.11	15.83	0.00	11.39	13.87	0.00	0.00	17.66	0.00	14.38
Construction sites	1990	43.88	0.00	0.00	0.00	0.00	0.00	15.42	0.00	0.00	0.00	0.00	40.70	0.00	0.00	0.00
	2000	0.00	0.00	0.00	6.65	0.00	5.27	9.08	0.00	0.00	0.00	34.26	0.00	27.44	17.31	0.00
	2006	9.63	0.00	6.99	8.43	0.00	0.00	0.00	0.00	11.30	0.00	23.19	0.00	40.47	0.00	0.00
	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	51.65	0.00	48.35	0.00	0.00	0.00	0.00
Green urban areas	1990	0.00	2.62	0.00	7.21	2.97	0.00	8.28	0.00	0.96	0.00	10.72	24.61	20.09	6.36	16.18
	2000	0.00	2.55	0.00	7.02	2.89	0.00	8.17	0.00	0.94	0.00	10.44	24.34	19.57	6.82	17.26
	2006	0.00	2.55	0.00	7.02	2.89	0.00	8.17	0.00	0.94	0.00	10.44	24.34	19.57	6.83	17.26
	2012	0.00	1.99	0.00	3.11	9.86	2.93	9.18	1.45	10.68	3.74	9.28	18.94	11.53	10.58	6.74
Sport and leisure facilities	1990	2.08	2.70	6.82	12.25	3.56	8.80	10.71	1.88	3.92	3.02	5.28	19.75	9.02	5.58	4.64
	2000	3.36	6.57	8.26	10.26	7.40	8.26	9.82	1.53	5.22	2.46	5.36	15.26	7.91	4.54	3.78
	2006	4.22	5.39	8.62	11.58	8.19	8.62	10.42	1.85	6.21	2.34	6.60	12.78	6.97	3.11	3.10
	2012	3.05	7.76	8.11	12.54	10.15	6.28	13.82	2.24	8.91	1.32	7.38	8.18	7.37	0.88	2.02
Non-irrigated arable land	1990	7.53	10.29	8.73	14.42	2.45	8.69	12.46	11.97	9.60	4.90	7.08	0.33	1.13	0.17	0.26
	2000	3.36	6.57	8.26	10.26	7.40	8.26	9.82	1.53	5.22	2.46	5.36	15.26	7.91	4.54	3.78
	2006	8.04	9.91	11.64	11.64	2.31	8.60	12.82	12.97	9.07	4.77	6.60	0.32	0.94	0.13	0.23
	2012	8.59	8.20	12.85	10.33	2.80	8.44	13.68	15.41	8.32	4.85	5.35	0.24	0.61	0.12	0.21

Table 7. Percentages of areas of the districts in land cover classes of Schleswig-Holstein for the years 1990, 2006 and 2012.

Land Cover classes	Year	Percentage of Areas of Districts on Land cover classes (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Fruit trees and berry plantations	**1990**	0.00	0.00	0.00	33.40	66.60	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	0.00	16.50	83.50	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	0.00	28.36	71.64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	28.48	48.19	0.00	0.00	0.00	0.00	23.33	0.00	0.00	0.00	0.00	0.00
Pastures	**1990**	13.50	1.73	22.04	1.84	4.94	2.51	15.66	16.85	6.80	10.83	2.12	0.23	0.40	0.23	0.30
	2000	13.38	1.83	22.09	1.87	4.93	2.50	15.66	16.82	6.80	10.83	2.12	0.23	0.42	0.22	0.29
	2006	14.18	2.34	19.81	2.40	5.48	3.00	15.44	13.68	7.60	12.11	2.57	0.27	0.67	0.15	0.32
	2012	12.59	3.53	19.85	3.32	5.73	4.09	14.51	12.94	7.55	10.71	3.45	0.34	0.78	0.26	0.36
Complex cultivation patterns	**1990**	9.31	2.69	14.05	3.94	9.66	13.32	15.47	19.31	6.26	2.70	1.65	0.58	0.24	0.26	0.56
	2000	9.38	3.05	13.86	3.90	9.65	13.56	15.55	18.57	6.51	2.90	1.61	0.54	0.11	0.25	0.56
	2006	8.66	2.15	21.58	3.23	6.70	7.88	14.84	21.90	5.64	4.53	1.74	0.29	0.06	0.39	0.41
	2012	13.28	0.00	4.27	6.74	17.36	7.84	7.52	10.20	15.37	17.41	0.00	0.00	0.00	0.00	0.00
Land principally occupied by agriculture	**1990**	3.79	11.48	3.20	8.24	9.44	6.76	18.19	9.68	9.76	9.07	7.19	1.05	2.16	0.00	0.00
	2000	3.80	11.50	3.21	8.20	9.48	6.64	18.23	9.70	9.76	9.08	7.21	1.03	2.17	0.00	0.00
	2006	3.31	11.08	3.06	7.93	10.02	6.84	17.88	9.71	9.85	8.38	9.17	1.06	1.70	0.00	0.00
	2012	2.22	16.10	3.63	8.00	7.56	8.41	14.96	9.61	9.03	8.57	5.29	0.87	3.26	0.00	2.50
Broad-leaved forest	**1990**	1.72	24.79	1.85	14.76	2.93	12.38	15.03	6.10	5.24	3.01	8.62	0.71	2.62	0.26	0.00
	2000	1.72	24.79	1.78	14.76	2.93	12.40	15.03	6.11	5.25	3.01	8.63	0.71	2.62	0.26	0.00
	2006	1.76	24.08	1.76	15.07	2.66	12.16	14.74	6.76	5.71	3.09	8.58	0.68	2.61	0.33	0.00
	2012	2.16	21.58	2.34	13.79	2.38	11.97	16.87	7.51	6.39	2.95	7.82	0.72	3.07	0.28	0.17
Coniferous forest	**1990**	4.16	23.50	8.42	1.84	3.39	1.40	10.97	6.63	25.06	8.06	4.28	0.00	1.98	0.16	0.13
	2000	4.11	23.72	8.44	1.85	3.41	1.41	11.06	6.59	25.11	7.67	4.31	0.00	2.01	0.16	0.13
	2006	3.98	23.63	8.37	1.86	3.38	1.41	11.17	6.62	25.37	7.59	4.33	0.00	2.00	0.16	0.13
	2012	4.57	21.86	7.89	1.51	3.83	1.54	11.75	7.04	26.35	8.01	3.97	0.00	1.37	0.21	0.10

Table 7. Percentages of areas of the districts in land cover classes of Schleswig-Holstein for the years 1990, 2006 and 2012.

Land Cover classes	Year	Percentage of Areas of Districts on Land cover classes (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Mixed forest	1990	3.92	20.48	2.66	3.61	0.92	9.03	28.15	10.51	7.03	7.37	3.67	0.00	1.27	0.41	0.96
	2000	3.95	20.63	1.88	3.73	0.92	9.10	28.54	10.59	7.08	7.24	3.70	0.00	1.28	0.38	0.97
	2006	3.80	20.53	2.08	3.72	0.89	8.81	28.07	9.73	8.46	7.59	3.61	0.00	1.50	0.26	0.93
	2012	3.54	28.38	2.52	3.84	2.25	2.33	16.85	6.59	8.94	11.86	10.59	0.18	1.39	0.00	0.75
Natural grasslands	1990	33.81	0.00	24.82	11.49	2.84	2.09	7.48	7.93	4.15	0.88	1.96	0.00	0.00	2.56	0.00
	2000	33.10	0.00	26.39	10.75	2.81	2.06	7.61	7.83	4.10	0.87	1.93	0.00	0.00	2.53	0.00
	2006	33.18	0.00	26.41	11.07	2.89	2.13	6.96	9.58	3.10	0.90	1.99	0.00	0.00	1.78	0.00
	2012	17.17	2.32	24.24	5.73	1.90	1.58	18.18	11.93	5.97	6.50	1.04	0.00	3.44	0.00	0.00
Moors and heathland	1990	0.00	0.00	83.40	0.00	4.61	0.00	1.32	5.49	2.45	2.72	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	83.67	0.00	4.54	0.00	1.30	5.40	2.41	2.68	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	83.45	0.00	4.60	0.00	1.31	5.47	2.45	2.72	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.33	93.08	0.94	0.00	0.26	2.08	0.00	0.78	1.14	0.00	0.00	1.38	0.00	0.00
Transitional woodland-shrub	1990	3.14	0.00	15.49	0.00	1.77	0.00	8.05	37.39	1.04	24.01	9.10	0.00	0.00	0.00	0.00
	2000	4.89	0.00	19.70	5.72	0.94	0.00	9.36	22.09	5.42	27.05	4.83	0.00	0.00	0.00	0.00
	2006	4.73	5.89	18.34	0.00	1.54	0.00	17.85	21.35	6.90	18.74	4.67	0.00	0.00	0.00	0.00
	2012	5.08	3.85	8.16	6.10	4.76	1.66	26.90	11.36	7.02	7.18	8.79	1.41	4.26	3.47	0.00
Beaches, dunes, sands	1990	0.00	0.00	97.87	2.13	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	98.03	1.97	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	97.93	2.07	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	91.24	7.53	0.00	0.34	0.00	0.00	0.00	0.00	0.00	0.35	0.54	0.00	0.00
Sparsely vegetated areas	1990	0.00	19.42	68.73	7.01	0.00	0.00	2.04	0.18	0.00	2.62	0.00	0.00	0.00	0.00	0.00
	2000	0.00	0.00	91.62	5.52	0.00	0.00	2.62	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	0.00	0.00	91.62	5.52	0.00	0.00	2.62	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00

Table 7. Percentages of areas of the districts in land cover classes of Schleswig-Holstein for the years 1990, 2006 and 2012.

Land Cover classes	Year	Percentage of Areas of Districts on Land cover classes (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Inland marshes	1990	5.98	2.69	34.01	22.62	0.00	10.83	9.87	3.27	0.00	3.70	1.06	2.50	3.48	0.00	0.00
	2000	6.03	2.72	43.28	13.81	0.00	10.93	9.72	3.30	0.00	3.10	1.07	2.52	3.51	0.00	0.00
	2006	6.47	4.04	42.60	13.27	0.00	10.51	9.35	3.09	0.00	3.64	1.13	2.43	3.38	0.00	0.00
	2012	24.49	0.00	46.90	1.94	5.34	7.05	5.97	4.82	0.00	0.68	0.81	2.00	0.00	0.00	0.00
Peat bogs	1990	18.13	0.00	8.31	0.00	1.82	0.73	31.01	19.80	10.09	5.09	2.14	0.00	0.00	0.00	2.88
	2000	18.77	0.00	9.66	0.00	1.79	0.72	29.50	19.47	9.92	5.23	2.11	0.00	0.00	0.00	2.83
	2006	17.79	0.00	9.15	0.00	2.86	0.68	27.97	20.43	11.13	5.13	2.19	0.00	0.00	0.00	2.67
	2012	17.76	1.10	7.26	3.79	3.58	1.31	19.74	26.21	9.02	7.14	1.42	0.00	0.00	0.00	1.66
Salt marshes	1990	24.22	0.00	75.78	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	24.03	0.00	75.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	22.95	0.00	77.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	21.42	0.00	77.98	0.00	0.00	0.00	0.00	0.00	0.00	0.61	0.00	0.00	0.00	0.00	0.00
Intertidal flats	1990	11.58	0.00	88.32	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2000	11.46	0.00	88.44	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2006	11.25	0.00	88.65	0.00	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	10.98	0.00	88.59	0.00	0.00	0.00	0.00	0.00	0.00	0.43	0.00	0.00	0.00	0.00	0.00
Water courses	1990	25.81	0.64	5.20	0.00	0.00	0.00	44.23	6.11	0.00	8.42	0.00	1.80	7.79	0.00	0.00
	2000	25.81	0.64	5.20	0.00	0.00	0.00	44.23	6.11	0.00	8.42	0.00	1.80	7.79	0.00	0.00
	2006	29.25	0.57	6.15	0.00	0.00	0.00	39.76	8.03	0.00	7.62	0.00	1.62	7.00	0.00	0.00
	2012	21.28	1.54	3.80	0.00	0.00	2.28	31.18	5.83	0.00	7.72	0.00	1.83	24.54	0.00	0.00
Water bodies	1990	2.10	12.91	7.48	9.00	0.00	33.16	15.61	13.59	4.47	0.20	0.83	0.10	0.10	0.00	0.44
	2000	2.09	12.95	7.79	8.61	0.00	33.16	15.56	13.67	4.46	0.20	0.87	0.10	0.10	0.00	0.44
	2006	1.93	12.51	7.67	8.08	0.00	31.12	14.60	12.83	4.21	0.19	0.82	0.09	5.55	0.00	0.41
	2012	2.24	14.43	9.28	9.92	0.17	36.59	13.51	2.70	5.05	0.26	1.03	0.10	4.20	0.00	0.52

Table 7. Percentages of areas of the districts in land cover classes of Schleswig-Holstein for the years 1990, 2006 and 2012.

Land Cover classes	Year	Percentage of Areas of Districts on Land cover classes (%)														
		Dithmar-schen	Hzgt. Lauenburg	Nordfries-land	Ostholstein	Pinneberg	Plön	Rendsburg	Schleswig	Segeberg	Steinburg	Stormarn	Kiel	Lübeck	Flensburg	Neu-münster
Coastal lagoons	1990	0.00	0.00	3.34	2.98	0.00	0.00	0.00	36.44	0.00	0.00	0.00	0.00	57.25	0.00	0.00
	2000	0.00	0.00	6.31	0.00	0.00	0.00	0.00	36.43	0.00	0.00	0.00	0.00	57.26	0.00	0.00
	2006	0.00	0.00	7.87	0.00	0.00	0.00	0.00	92.13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2012	0.00	0.00	0.07	0.26	0.00	0.00	20.65	78.67	0.00	0.00	0.00	0.00	0.00	0.36	0.00
Estuaries	1990	54.00	0.00	23.55	0.00	9.13	0.00	0.00	5.35	0.00	7.98	0.00	0.00	0.00	0.00	0.00
	2000	54.00	0.00	23.55	0.00	9.13	0.00	0.00	5.35	0.00	7.98	0.00	0.00	0.00	0.00	0.00
	2006	52.65	0.00	25.59	0.00	11.62	0.00	0.00	0.00	0.00	10.15	0.00	0.00	0.00	0.00	0.00
	2012	52.52	0.00	23.53	0.00	12.76	0.00	0.00	0.00	0.00	11.18	0.00	0.00	0.00	0.00	0.00

Table 8. Areas (ha) of land cover changes in Schleswig-Holstein from 1990 to 2000. Land cover classes: 112 Discontinuous urban fabric; 121 Industrial or commercial units and transport units; 122 Road and rail networks and associated land; 123 Port areas; 124 Airports; 131 Mineral extraction sites and construction sites; 132 Dump sites; 133 Construction sites; 141 Green urban areas vegetated areas; 142 Sport and leisure facilities; 211 Non-irrigated arable land; 222 Fruit trees and berry plantations; 231 Pastures; 242 Complex cultivation; 243 Land principally occupied by agriculture, with significant areas of natural vegetation; 311 Broad-leaved forest; 312 Coniferous forest; 313 Mixed forest; 321 Natural grassland vegetation; 322 Moors and heathland ; 324 Transitional woodland shrub; 331 Beaches, dunes, and sand plains; 333 Sparsely vegetated areas; 411 Inland marshes; 412 Peatbogs; 421 Salt marshes; 423 Intertidal flats; 512 Water bodies.

Land cover	Land cover classes (2000)																								
classes (1990)	112	121	122	123	124	131	132	133	141	142	211	231	242	243	311	312	313	321	322	324	331	412	421	423	512
112		54																							
131		20									132	25	24		12				20						
132											33	10								29					
133		51									40														
141	7																								
142	6		34.36						13		7														
211	2740	979			26	764	119	420	17	1014		2994	797	12		44	22	21		211					
222											66														
231	824	309		8		181	54	9	7	64.52	3547		1228					141		26		238			103
242	412	116				101		64		52.02	1308	2129													
243	20					5				8.529															34
311		7				2					7	16				22				42					
312		7				12					10									426					22
313																				267					
321						30					5	8													10
331																			31				17	70	
333											256	45	75											3	
411												42													
412																	88								
421																					11		244		
423																					328				
512																					73				

Table 9. Areas (ha) of land cover changes in Schleswig-Holstein from 2000 to 2006. Land cover classes: 112 Discontinuous urban fabric; 121 Industrial or commercial units and transport units; 122 Road and rail networks and associated land; 123 Port areas; 131 Mineral extraction sites and construction sites; 132 Dump sites; 133 Construction sites; 141 Green urban areas vegetated areas; 142 Sport and leisure facilities; 211 Non-irrigated arable land; 231 Pastures; 242 Complex cultivation; 243 Land principally occupied by agriculture, with significant areas of natural vegetation; 311 Broad-leaved forest; 312 Coniferous forest; 313 Mixed forest; 321 Natural grassland vegetation; 322 Moors and heathland ; 324 Transitional woodland shrub; 331 Beaches, dunes, and sand plains; 411 Inland marshes; 412 Peatbogs; 421 Salt marshes; 423 Intertidal flats; 512 Water bodies.

Land cover classes(2000)	**Land cover classes (2006)**																									
	111	112	121	122	123	124	131	132	133	142	211	222	231	242	243	311	312	313	321	324	411	412	421	423	511	512
112	33		836							33	57		30	20	7	27	8									
121														44												
124										86			43													
131		23	33					24		3	99		107	24		8			73		30					
132											13															
133		121	34	138							181		19													
142		100																								
211		2765	426	7		8	754	58	241.7	919		33	3844	9378	2130	1360	295	400		324	77					44
222		25																								
231		1330	205	83		38	250	18	28	185	17936			66961	953	393	102	46	146	216	97	381	244		22	54
242		547	87	3			148		9.042	78	4303		471		130	58	148	52				14				
243		14								21	30					23		55	14							
311		11	6								24		19	36								154			7	8
312			7.								52		15	9	65	158		212		109						
313																169										
321		32			28	74			2.953	48	15		22		255	28										
322		22							20.42																	
324											101		21			164	27	263								
411													7			27										
412													13													
421									32.19			20												23		
423																							70			
511															20.	5						6				
512					10								5								8					
521																										1707
522																									366	

Table 10. Areas (ha) of land cover changes in Schleswig-Holstein from 2006 to 2012. Land cover classes: 112 Discontinuous urban fabric; 121 Industrial or commercial units and transport units; 131 Mineral extraction sites and construction sites; 133 Construction sites; 141 Green urban areas vegetated areas; 142 Sport and leisure facilities; 211 Non-irrigated arable land; 222 Fruit trees and berry plantations; 231 Pastures; 242 Complex cultivation; 243 Land principally occupied by agriculture, with significant areas of natural vegetation; 311 Broad-leaved forest; 312 Coniferous forest; 313 Mixed forest; 321 Natural grassland vegetation; 324 Transitional woodland shrub; 331 Beaches, dunes, and sand plains; 333 Sparsely vegetated areas; 411 Inland marshes; 412 Peatbogs; 421 Salt marshes; 512 Water bodies.

Land cover classes (2006)	Land cover classes (2012)																															
	111	112	121	122	123	124	131	132	133	141	142	211	222	231	242	243	311	312	313	321	322	324	331	333	411	412	421	423	511	512	521	522
111		636	49	8	3					5	15																			6	4	
112	174		315	38	23	19	28			530	735	426		376	25	163	585	224	110	55	59	93			6		40	14	73	110	19	27
121		1199		39	139	10	4			33	77	189		477	3	38	99	13	15			39							38	0	5	11
122	11	749	35		13					8	4	37		174						1		8										
123	20	177	187							5	0	0		36			2												167	16	10	4
124		7	275								116	49		84			27	8	4	2	7	1							3			
131		73	46			19					73	441		484		83	83	21	2	210	35	78		28						141		
132							87				0	52		69			105	2	10	98	0	120							5			
133		60	88		13						22	12		92		6					5	5					31					
141		422	16	2	5	2					90	4		53		1	65	6	5										3	2		
142		941	133	31			7			217		188		249		23	88	11	7	11	18	11			13		20	6	2	23		
211	11	946	135	116	9	116	810	82	55	205	136		122	751	320	215	632	206	905	770	69	121			160	83	245	64	139	432	74	9
222		14										159		21																		
231	6	643	832	3	15	112	173	33	1	239	655	717			163	112	346	119	490	337	188	710			388	992	880	89	262	322	26	60
242		353	608	3		57	124			47	176	926	49	622		113	163	858	165	278	33	194			71	41	19	41	33	112	11	1
243		122	101	16		44	5			111	438	666		121	16		298	797	685	655	29	366			159	40			21	127	11	

Appendix B. Mapping ecosystem services within qualitative assessments

Qualitative assessments of regulating services

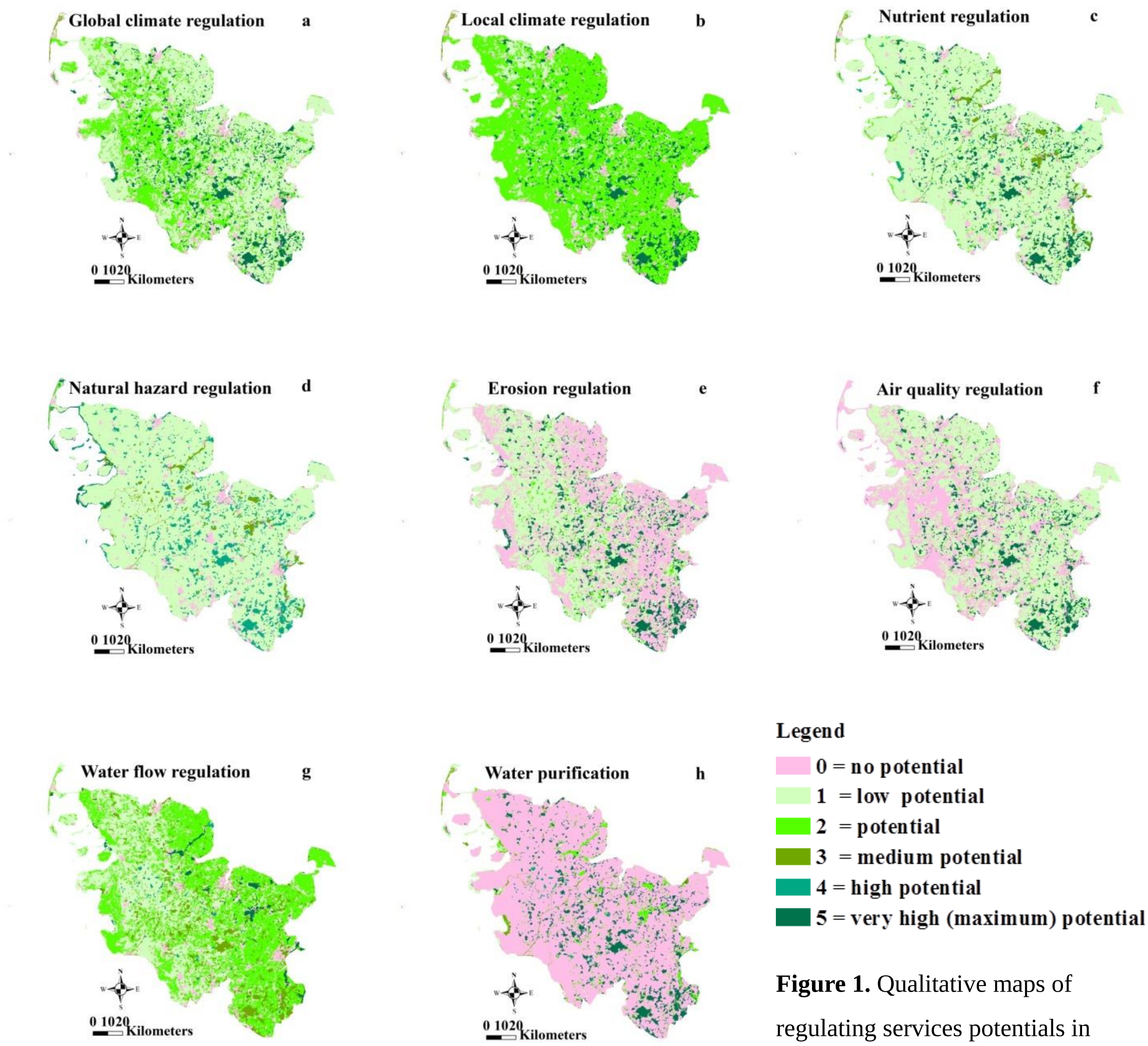

Figure 1. Qualitative maps of regulating services potentials in Schleswig-Holstein.

Global climate regulation (a), local climate regulation (b), erosion regulation (e), natural hazard regulation (d), nutrient regulation (c), air quality regulation (f), water flow regulation(g) and water purification(h), which are critical regulating services in Schleswig-Holstein, have been chosen as indicators for the qualitative assessment of regulating services (Appendix B Figure 1). Most areas of Schleswig-Holstein are occupied by class 1 and class 2 concerning the qualitative estimation of global climate regulation, and class 2 concerning the local climate regulation assessment. The difference mainly results in the estimated value of non-irrigated arable land which accounts for the largest percentage of areas in the state. The qualitative maps of nutrient regulation and natural hazard regulation show that most of the areas of Schleswig-Holstein have weak capabilities of regulating nutrients and natural hazards following the basic matrix valuations of Burkhard et al. (2014). It is a consequence from the fact that the land cover classes with larger areas (non-irrigated arable land, pastures and complex cultivated patterns) have low relevant potentials for the two services. The forest areas have a very high relevant potential on erosion regulation and air quality regulation while most of the areas have no relevant potentials or low relevant potentials for the two services. Non-irrigated arable land, pastures and complex cultivated patterns have better capabilities related to water flow regulation. Water purification in principle has no relevant potential. Meanwhile, broad-leaved forest, coniferous forest and mixed forest have high capabilities.

Qualitative assessments of provisioning services

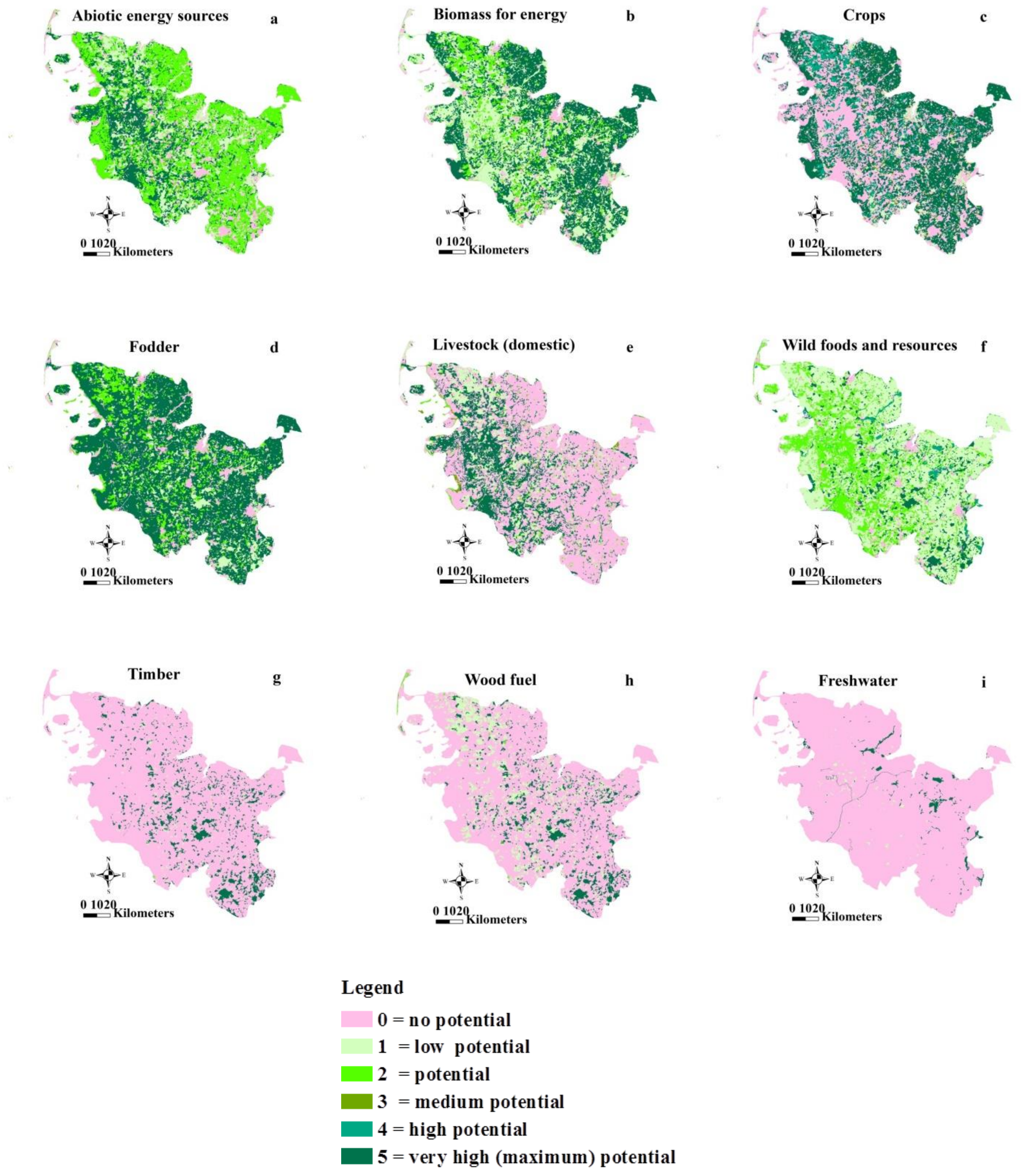

Figure 2. Qualitative maps of provisioning services potentials in Schleswig-Holstein.

Considering the constitutions of the case study area, qualitative provisioning services are assessed as abiotic energy sources (a), biomass for energy (b), crops (c), fodder (d), livestock (e), wild foods and resources (f), timber (g), wood fuel (h) and freshwater (i) (Appendix B Figure 2). The total land cover of pastures had a very high relevant potential for abiotic energy sources. Non-irrigated arable land, natural grasslands and sparsely vegetated areas are the ones with a relevant potential, occupying most areas of the eastern and western part of the state. The ecosystem service potential of biomass for energy based on land cover classes in opposition to the trend of the potential of abiotic energy sources. The non-irrigated arable land which is mainly distributed in the eastern and western parts has a very high relevant potential. Pastures have low relevant potentials of biomass for energy, accounting for most areas of the middle part. Non-irrigated arable land, complex cultivation patterns and fruit tree, and berry plantations have high relevant potentials for the provisioning services. Non-irrigated arable land and pastures are the land cover classes distributing extensively, which support very high relevant potential. The areas occupied by pastures have very high relevant flow for the service of livestock. Forests have very high relevant potential for wild foods and resources, while artificial areas have no relevant potential for this service. Schleswig-Holstein has no relevant or low relevant potential for the services of timber and wood fuel on most land cover classes. Broad-leaved forest, coniferous forest and mixed forest can support high relevant potential for timber and wood fuel production. Following the expert assessments of the matrix approach, except the land cover class of water courses, the state rarely has a capability on surface freshwater provision.

Qualitative assessments of cultural services

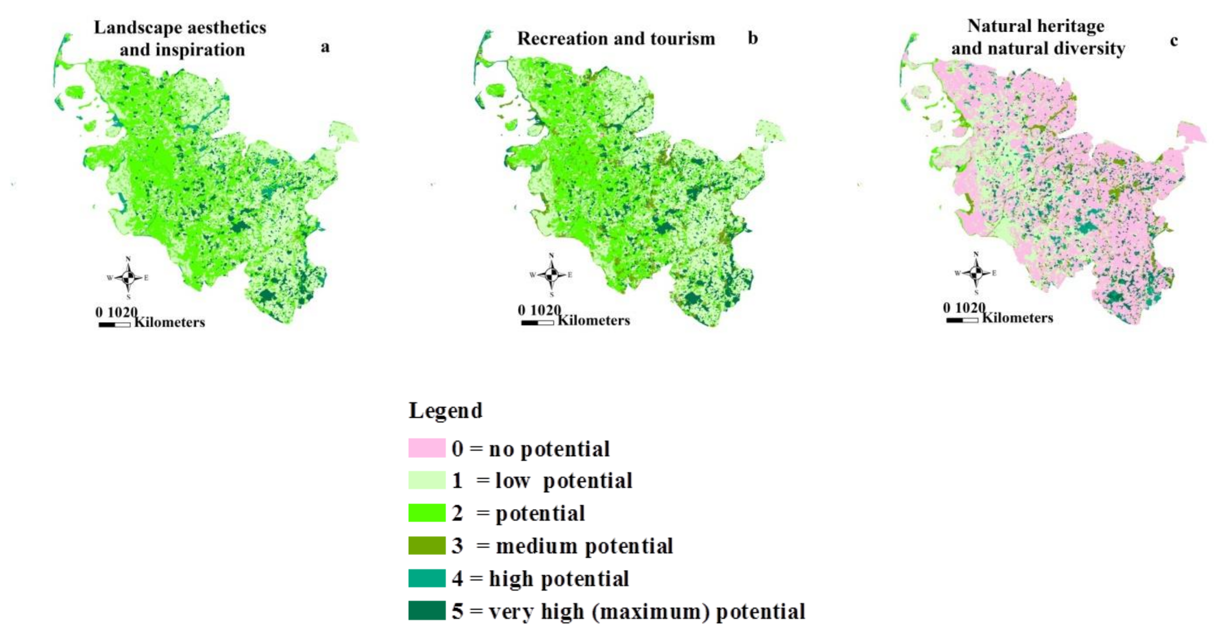

Figure 3. Qualitative maps of cultural services potentials in Schleswig-Holstein.

The cultural services of landscape aesthetics and inspiration (a), recreation and tourism (b), natural heritage and natural diversity (c) have been mapped in Appendix B Figure 3. Forests have a very high relevant potential for the services of landscape aesthetics and inspiration, recreation and tourism. The other land cover classes mainly have low relevant or relevant potential for these services. The state has no relevant or low relevant potential for the service of natural heritage and natural diversity because artificial surfaces, non-irrigated arable land and complex cultivation patterns have weak capabilities on natural heritage and natural diversity. Furthermore, the relations between land cover and cultural services are not as high as they are with respect regulating services and provisioning services.

Appendix C. Annual total GPP or NPP and annual total stored GPP or NPP in Schleswig-Holstein

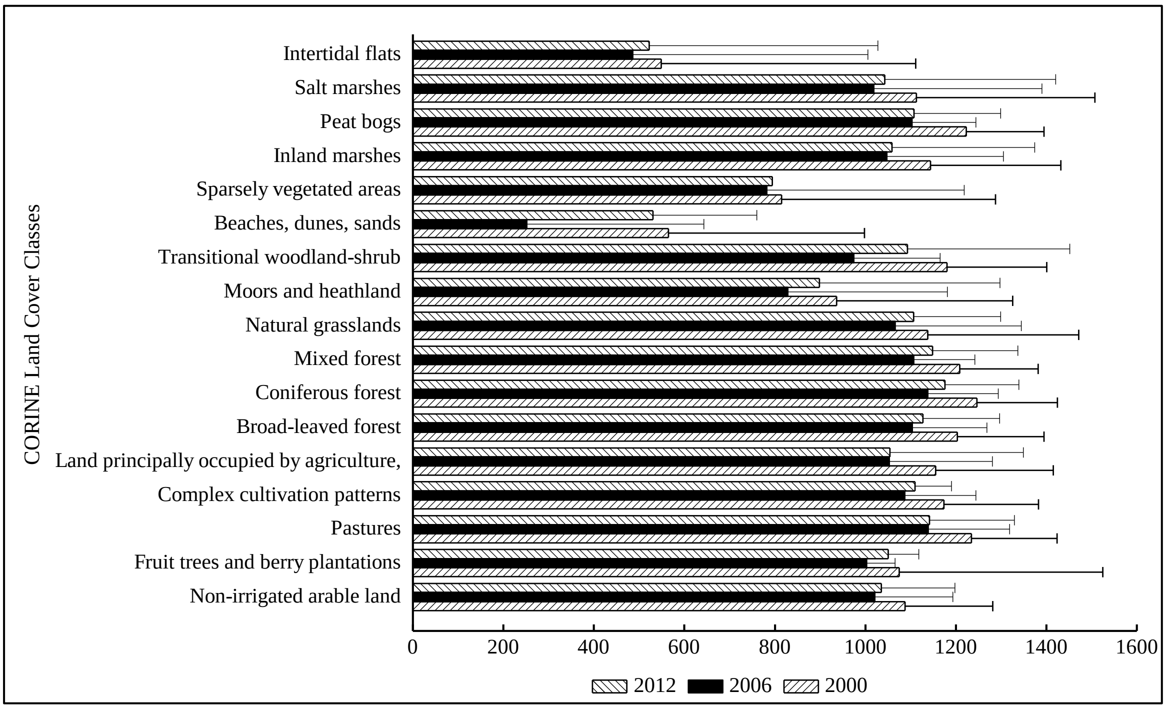

Figure 5. Annual total GPP（g C m^{-2} yr^{-1}）based on land cover classes of Schleswig-Holstein for the years 2000, 2006 and 2012.

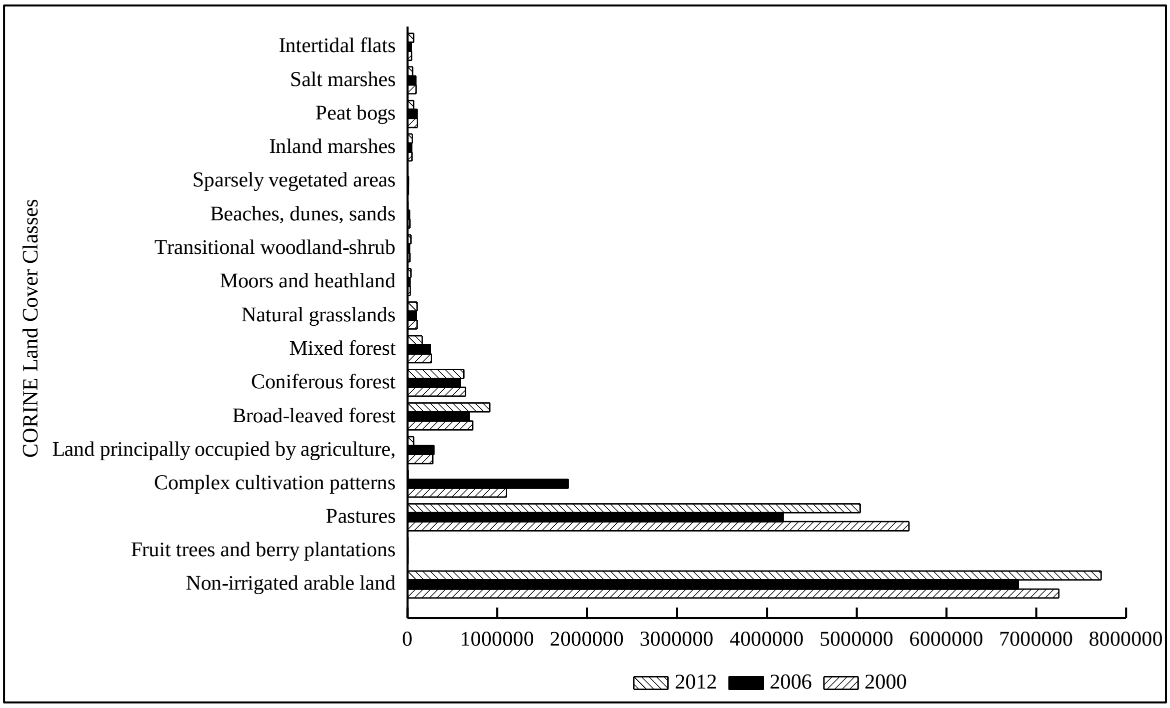

Figure 6. Annual total stored GPP（Mg C yr^{-1}） based on land cover classes of Schleswig-Holstein for the years 2000,

2006 and 2012.

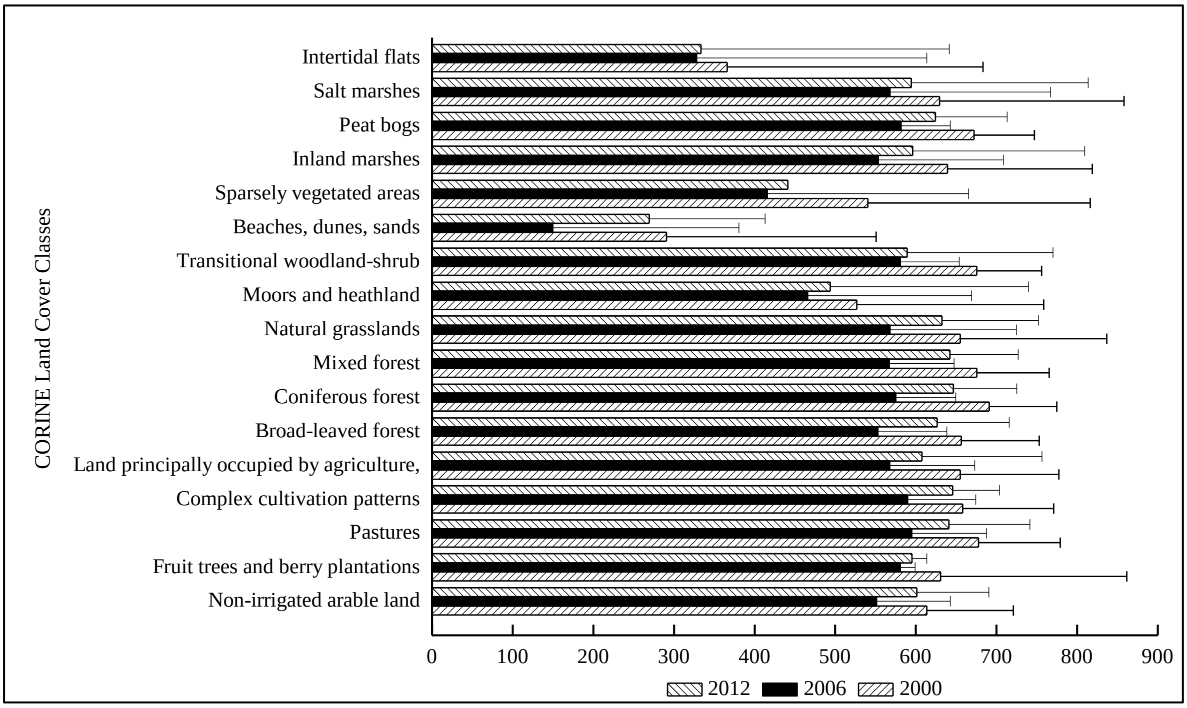

Figure 7. Annual total NPP（g C m^{-2} yr^{-1}）based on land cover classes of Schleswig-Holstein for the years 2000, 2006 and 2012.

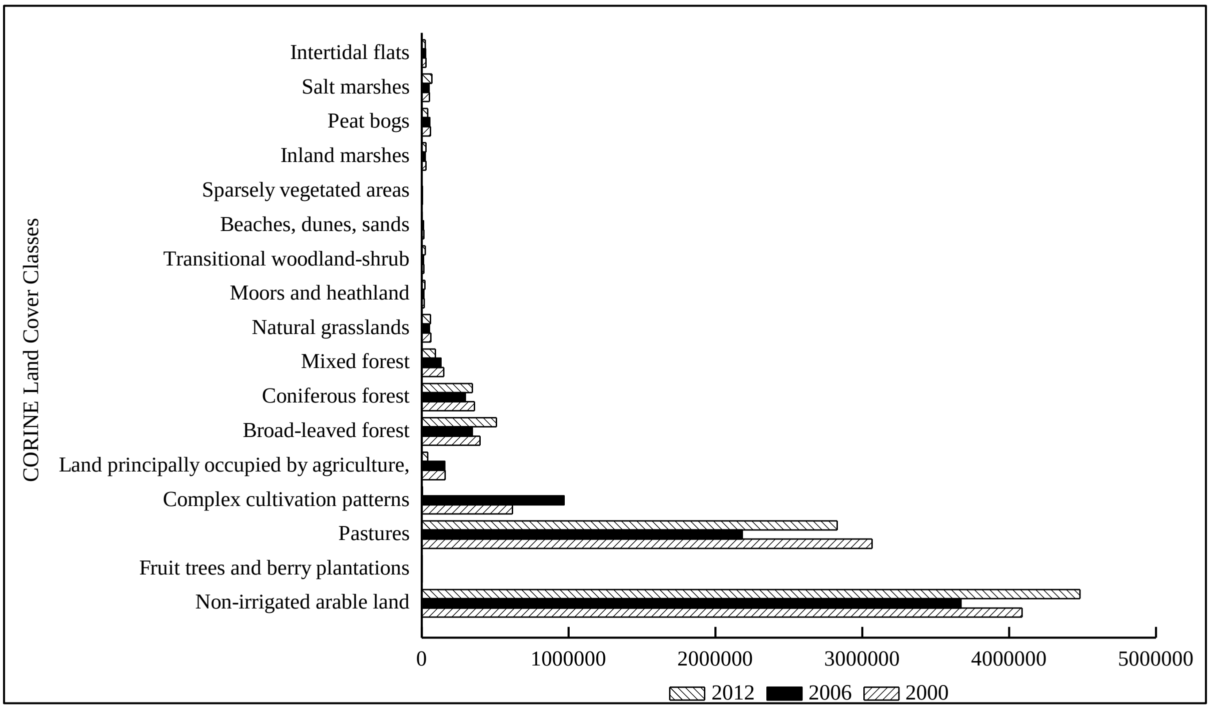

Figure 8. Annual total stored NPP（Mg C yr^{-1}） based on land cover classes of Schleswig-Holstein for the years 2000, 2006 and 2012.

Statutory Declarations

Statutory Declaration: Herewith I declare on oath that the submitted dissertation under the title: "Regional assessments of selected ecosystem services in northern Germany" has been authored independently and without illegitimate external help and that it has not been formerly submitted to another university department.

Kiel, 28.02.2017

Signature Liwei Ma 马莉薇

Herewith I declare, that I am not subject to any pending case of public prosecution.

Kiel, 28.02.2017

Signature Liwei Ma 马莉薇

Herewith I declare, that the dissertation complies with the conventions of proper academic practices as defined by the DFG.

Kiel, 28.02.2017

Signature Liwei Ma 马莉薇

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2010	First Class of National Scholarship, Northwest A&F University
2005-2006	Second Class of Academic Scholarship of Hebei Agriculture University