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Tracking changes in the land use, management and drainage status of organic soils as indicators of the effectiveness of mitigation strategies for climate change

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ABSTRACT

The tracking of land use since 1990 presents a major challenge in greenhouse gas (GHG) reporting under the United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto Protocol because there is often limited availability of data, especially for the base year of 1990. There is even less land management and soil moisture data, which are needed to track climate change mitigation activities since soil moisture is one of the main drivers of GHG emissions of organic soils. Information is also needed for the reporting of land-based activities such as grazing land management or wetland drainage and rewetting of organic soils. Different spatial and thematic resolutions of land-use data produce inconsistent time series with a strong overestimation of land-use change (LUC) if not adequately accounted for. Our aim was to create a consistent time series of land use since 1990 that is in line with GHG reporting under the UNFCCC and the Kyoto Protocol by combining official cadastral data with colour-infrared aerial photography used for biodiversity monitoring in six federal states in northern and eastern Germany. We developed a generic hierarchical classification by land use, management and drainage status, and a translation key for data harmonisation into a consistent time series. This time series enabled the quantification of LUC on organic soils between 1992 and 2013 in a spatially explicit manner. Furthermore we used this time series to develop indicators for changes in land management and drainage to evaluate the success of protection statuses on peatland restoration.

The study area encompassed one million hectares, half of which had some type of legal nature protection status. Areas with no protection status tended to become more intensively farmed and drier, while highly protected areas (*e.g.* Natura 2000) showed the opposite trend. Land-use trends also differed greatly between federal states. In Schleswig-Holstein organic soils tended to become drier during the study period, while in Mecklenburg-Western Pomerania they tended to become wetter overall. The trends and differences in LUC between federal states were linked to German reunification, changes in the European Common Agricultural Policy (CAP) and Germany's Renewable Energy Act (EEG). A large-scale peatland protection programme also had major impact.

In conclusion, our study demonstrates how data derived for biodiversity monitoring and other highly detailed land-use data can be used to track changes in land use, management and drainage status in accordance with the reporting requirements under the UNFCCC and the Kyoto Protocol.

1. Introduction

The second commitment period under the Kyoto Protocol (KP) from 2013 to 2020 offers new opportunities for accounting for greenhouse gas (GHG) mitigation by land use, land-use change and forestry (LULUCF) activities (UNFCCC, 2013). Several countries have selected eligible activities under KP, including "cropland management" (CM), "grazing land management" (GM) or the new activity "wetland drainage and rewetting" (WDR) (*e.g.* Denmark (Nielsen et al., 2015), Portugal (APA, 2015) and the United Kingdom (MacCarthy et al., 2015)). In parallel, the EU LULUCF Decision (Decision No 529/2013/EU, 2013) has introduced manda-

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tory reporting of CM and GM activities, demanding national GHG estimates from these activities in 2022. The reporting of CM, GM and WDR activities must be based on detailed activity data that track land use (LU), management and, in the case of organic soils, drainage status since or compared to 1990 (IPCC, 2014a).

In Central Europe, a large proportion of organic soils have been drained to facilitate agriculture and forestry. Drainage causes oxygen intrusion into the formerly waterlogged soils, microbial decomposition of peat and thus high carbon dioxide emissions (Maljanen et al., 2010; Tiemeyer et al., 2016). Therefore drained organic soils are a major source of GHG emissions from the sectors of agriculture and land use in many European countries (*e.g.* Lapveteläinen et al., 2007; UBA, 2015). Rewetting peatlands by raising the water level to the natural level close to the soil surfaces can initiate peat growth (=carbon sequestration) or at least substantially reduce CO_2 emissions (Wilson et al., 2016). Even accounting for increased methane emissions, rewetting of peatlands offers a high mitigation potential (Freibauer et al., 2009) for reducing GHG emissions, often at a reasonable cost and with multiple environmental benefits (Bonn et al., 2014). The modelling and reporting of GHG emissions require the detection of gross changes in LU and land-use intensity at an adequate spatial and thematic resolution (IPCC, 2014a). Land-use change (LUC) analysis by statistical data alone only allows the detection of net changes and therefore can significantly underestimate LUC (Fuchs et al., 2015). Furthermore, adequate reporting of GHG emissions and accounting for Kyoto activities (such as WDR) on organic soils are especially challenging as water table depth generally determines GHG emissions (Moore and Knowles, 1989; Tiemeyer et al., 2016). Germany currently reports GHG emissions and removals from LUC differentiating between nine land-use categories derived from the ATKIS Basic-DLM (UBA, 2015). Greenhouse gas emissions from drained organic soils are estimated based on national average emission factors by land-use category, which consider the drained area fraction in each land-use category and the drainage level (Bechtold et al., 2014) in a spatially and temporally static manner. Temporal changes in drainage status cannot yet be considered. A feasibility study at project level showed that high resolution LU and vegetation data can be used for a qualitative monitoring of peatland rewetting, but that quantitative estimates of long-term changes in mean water table depth require *in situ* measurements (Untenecker et al., 2016). Therefore suitable indicators are needed as a proxy for drainage status and changes to it over time.

Most countries face great challenges in developing adequate systems for land tracking, particularly with regard to the management intensity of grasslands and the drainage status of organic soils (Weiss et al., 2015). A further challenge is that classification keys are not constant in time or, as in Germany for example, consistent across regions within one country. As Slee and Feliciano (2015) point out, indicators for assessing climate change and climate change mitigation on rural land use have to be generated or improved. Furthermore, feasible approaches for monitoring and reporting land-based activities under KP at national level have yet to be developed.

This study aimed to demonstrate how approaches developed for biodiversity monitoring can be converted to a methodology for monitoring and reporting land-based activities under KP. In detail, we aimed to:

- develop and apply a generic classification method that converts various types of classified aerial colour-infrared (CIR) images from their original purpose of biodiversity monitoring to land-use categories in line with GM and WDR reporting requirements
- detect gross and net LUC as well as changes in the management and drainage status of organic soils in six federal states in northern and eastern Germany since 1990, for which wall-to-wall CIR images are available, and then couple them with digital landscape models of Germany
- attribute the change patterns to socio-economic and legal drivers such as nature protection status to evaluate indicators of climate change mitigation activities.

2. Material and methods

2.1. Definitions

Our definitions follow IPCC Guidelines (IPCC, 2006), the 2013 Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol (IPCC, 2014a) and the Wetlands Supplement (IPCC, 2014b).

"*Organic soils*" are defined in accordance with the IPCC (IPCC, 2006) as soils with at least 12% to 18% soil organic carbon in the upper 20 cm, depending on clay content. We used the geological map of Germany 1:200,000 (BGR, 2007) as a best approximation for organic soils. The map contains bog peat, fen peat and other organic soils. This surpasses the German peat soil classification requiring an organic horizon of >30 cm and thus includes shallow organic soils such as Histic Gleysols.

"*Land-use category*" refers to a classification of human activity according to the six IPCC land-use categories (IPCC, 2006) of forestry, cropland, grassland, wetland, settlement and other land.

"*Land-use sub-category*" (referred to below as "land use") means a refinement of the six IPCC land-use categories (*e.g.* heathland, horticulture *etc.*).

"*Management regime*" further stratifies the land-use subcategories with regard to management intensity (*e.g.* low intensity grassland) or forest type (broad-leaved, coniferous or mixed). Our datasets did not allow the detection of changes in fertiliser application, biomass export or grassland harvest dates, but did differentiate between several broad management patterns.

"*Drainage status*" is defined as the mean annual water table (IPCC, 2014a,b) whereby "deep drained" or "dry" refers to a mean annual water table more than 30 cm below the surface, and "shallow drained" or "moist, periodically wet" to intermediate conditions referring to a water table between 10 and 30 cm below the surface. "Undrained", "rewetted" or "wet" refers to a mean annual water table near or above the surface. The classifications "dry", "moist, periodically wet" and "wet" are derived from the CIR classification and are interpreted to best match the IPCC drainage classes (see Supplement A).

"*Land management type*" is the combination of land use, management regime and drainage status.

Gross changes in land use, management or drainage status cover all changes in all directions in a spatially explicit way, *e.g.* from forest to grassland plus from grassland to forest.

Net change shows the resulting net balance of all changes, *e.g.* the difference between all forest/grassland changes. For example, between two dates if four hectares of forest were converted to grassland and two hectares of grassland were converted to forest, the net change would be two hectares (gain in grassland).

To summarise potential intensification trends and water level changes across LU sub-categories, we defined an "*intensity indicator*" to indicate the quality of changes in land-use intensity and a "*drainage indicator*" for changes in soil wetness.

For the intensity indicator, cropland, settlement and horticulture were defined as the highest intensity level. Heathland, shrubs, forest, fen, bog, water body and abandoned land were defined as the lowest intensity level. Grassland use could be high or low intensity, therefore we set its intensity level to medium for datasets without information on the management regime. Additionally, the attribute "wet soil" also indicated low intensity. We set values of