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The relative importance of geophysical constraints, amenity values, and farm-related factors in the dynamics of grassland set-aside

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ABSTRACT

This study aimed at quantifying the spatial distribution of set-aside – highly valuable biodiversity reservoirs – in a typical lowland agricultural region (Denmark), just before and after the set-aside policy change (years 2007 and 2008), to assess which factors drive farmers' set-aside priorities, and to elaborate the potential consequence of the set-aside spatial transformation from 2007 to 2008 on nature. Multiple regressions were used to test if and how set-aside is linked to three potential groups of drivers: (1) *geophysical constraints* (topographic and edaphic constraints on the farming-suitability of an area), (2) *amenity values* (nature conservation and aesthetic values), and (3) *farming-related factors* (e.g., field size and livestock density).

The spatial distribution of set-aside was influenced by both *geophysical constraints* and *amenity values* and only some extent *farming-related factors*. More specifically, set-aside was predominantly located in areas with steep slopes, high wetness and to a lesser extent low soil fertility, a large nature area, and low livestock densities, though not as pronounced in 2008 as in 2007. These were also the areas with the strongest loss in set-aside area from 2007 to 2008, though these relationships were rather weak, thereby indicating a strongest set-aside loss in areas where set-aside would potentially benefit nature the most. The importance of the different drivers showed strong geographical variation, perhaps reflecting local differences in interacting factors such as farmers' cultural values or socioeconomic circumstances. Overall, it is clear that the distribution and dynamics in grassland set-aside is determined by a complex interplay of agronomic and non-agronomic factors, with geophysical landscape factors as well as amenity values playing important roles.

1. Introduction

Human land-use, agricultural intensification, and the entailing landscape-homogenization are some of the most important factors causing worldwide biodiversity and habitat losses (Benton et al., 2003; Tscharntke et al., 2005; Vitousek et al., 1997). In many lowland agricultural landscapes, only a small proportion of the agricultural land is semi-natural or natural (Waldhardt et al., 2004), and the existence of these areas, such as set-aside fields, in the interface between agriculture and uncultivated natural areas are generally crucial to maintain a high level of biodiversity (Devictor and Jiguet, 2007; Henderson et al., 2000a,b; Kleijn et al., 2006; Levin and Jepsen, 2010) and environmental protection. Specifically, set-aside can provide corridors between natural areas (Samways et al., 2010), bird nesting sites, foraging sites for wildlife (Bracken and Bolger, 2006; Firbank et al., 2003; Hiron et al., 2012), and they act as buffer zones between natural areas and intensive cultivation leading to decreased disturbances and herbicide runoff from arable lands (Stutter et al., 2012).

Despite the numerous potential benefits, set-aside schemes were originally not implemented to reverse the ongoing decline in biodiversity in agricultural landscapes, but as a production-regulating tool. To reduce crop production in the European Union (EU) obligatory set-aside was introduced with the revision of the Common Agricultural Policy (CAP) in the early 1990s forcing farmers to take a relatively small fraction of their agricultural land out of production. By 2007 the world demand for cereals enlarged, and obligatory set-aside was abolished. As a result, set-aside area in the EU declined by up to 69% (European Commission, 2007), and in Denmark by approximately 62% (from 184,000 to

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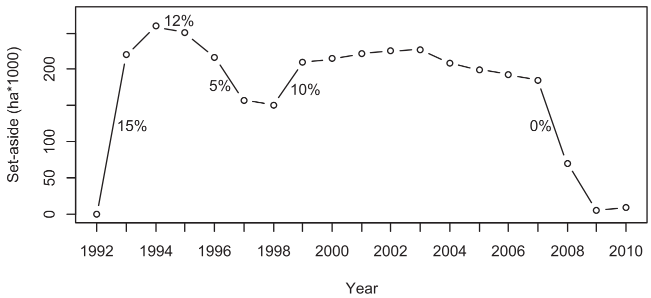

Fig. 1. Development of the total set-aside area in Denmark, 1992–2010 (~80% of this area being grassland) including obligatory set-aside percentages.

71,000 ha) (Statistics Denmark, 2010) with further reductions in 2008–2009 (Fig. 1). Yet, the aforementioned positive effects of set-aside on natural areas and biodiversity have been recognized with the establishment of future goals regarding greening of the European agriculture through changes in subsidy schemes (European Commission, 2011). The greening criteria include a reintroduction of set-aside schemes, with a plan to drive all farmers to set aside 7% of their land through the period 2012–2020, for example for the protection of areas with special ecological value (Cook and Lee, 2011). For the Danish region, set-aside subsidised by agri-environmental schemes are at present not particularly widespread. With the European future greening goals and increased knowledge on the distribution of grassland set-aside, agri-environmental schemes might be increasingly propagated and thereby contribute to more nature conservation, also for the Danish region.

The set-aside landscape dynamics can be assessed by analysing which environmental factors influence the farmer's choice of set-aside locations and thereby the spatial distribution hereof. The importance of these factors is likely to vary geographically depending on farmers prioritizations. Some farmers are purely profit-minded when deciding where to lay out set-aside, while others prioritize recreational or natural surroundings (Busck, 2002). The latter type of farmers will be motivated not only by agricultural profit but also by increased amenity value of their land (Busck, 2002; Wilson and Hart, 2001). Studying the spatial distribution of changes in the set-aside area from 2007 to 2008 yields a unique opportunity to gain insight into the factors determining which fields are set aside in a flat region such as Denmark where landscape structures (such as mountains) are not the obvious primary driver.

Based on the above, it was here hypothesized that set-aside in 2007 and 2008 was located and remained in areas characterized by geophysical extremes, wet soils, low soil fertility, high amenity values, small fields, low animal pressure, and low organic farming area (see Table 1 for hypotheses and references). The aims were to assess which factors have driven farmers' set-aside priorities, and to elaborate the potential consequence of the set-aside spatial transformation from 2007 to 2008 on nature, with particularly interest in the effects of the following three sets of variables: (1) *geophysical constraints* (topographic and edaphic constraints on the suitability of an area for farming), (2) *amenity values* (factors representing nature conservation or aesthetic value of an area), and (3) *farming-related factors*. More specifically, the relative roles of these three sets of drivers were assessed for the spatial dynamics of (1) set-aside in the years 2007 and 2008 at regional scale (i.e. all of Denmark) and at landscape scale (within 10-km quadrates), and for (2) the geographical pattern in set-aside loss from 2007 to 2008 at the two scales.

2. Materials and methods

Denmark (43,098 km^2, 55°43′N, 12°34′E) represents a typical, low lying Western European region, dominated by intensive agriculture (Odgaard et al., 2011). Here, the loss of set-aside from 2007 to 2008 is particularly evident (from 184,449 to 70,662 ha), and there are high-quality geographical data which are needed for small-scale detailed spatial geographical analyses.

All variable resolutions were based on a 1 km quadratic grid covering the study region (Fig. S1a) (Danish Ministry of the Environment, National Survey and Cadastre, 2010; Statistics Denmark, 2010). Only quadrats with a coverage of set-aside and organic farming >0 ha in both 2007 and 2008 were used. Furthermore, a 10 km quadratic grid covering the study region was composed and 10 km quadrats holding less than 25 1 km quadrats were excluded leaving 408 10 km quadrates and a sufficient statistical sample size for the landscape-scale (within 10 km quadrats) analyses. The remaining 1 km quadrats were equally distributed across the study area and made up the basic sample units for both regional-scale (across Denmark, sample size = 25,981 1 km quadrats) (Fig. S1a) and landscape-scale (within each 10 km quadrats, sample size = 25–100 1 km quadrats) (Fig. S1b). The landscape-scale resolution was used to visualize result from the landscape models (Fig. S1c). All the following variables were calculated using ArcGIS10 (ESRI, 2010).

2.1. Set-aside variables

Table data on agricultural land use (Ministry of Food, Agriculture and Fisheries, 2007) was linked to a geographical field-block theme covering all of Denmark (one field block contains 1–15 fields (Poulsen et al., 2002)) and it was subsequently aggregated to fit the 1 km quadrat net. From this data set, information on field and the declared set-aside area (here defined as grassland set-aside, thereby not including areas for oil seed rape production or set-aside receiving subsidies through agri-environmental schemes) in 2007 and 2008 was extracted. Set-aside area in 2007 and 2008 was normalized by total agricultural area from the respective years and the ratio of normalized set-aside area between the two years was calculated (08/07 ratio). Set-aside areas in 2007 and 2008 and the change between the two years were used as response variables in the further statistical analyses.

2.2. Drivers of set-aside area

To test how *geophysical constraints* affect the distribution of set-aside the following variables were employed: terrain slope, a topographical wetness index (TWI), and clay content (weight-% < 2 μm particles) in the top soil (called clay% in the following). Slope and TWI were computed from a LiDAR-based (Light Detection and Ranging) digital terrain model (DTM) (Shan and Toth, 2009) of Denmark named *Danmarks Højdemodel* (Kort & Matrikelstyrelsen, 2011). Prior to slope and TWI calculations its native spatial resolution of 1.6 m was aggregated (mean) to 9.6 m to soften small-scale changes in the surface. The TWI represents water retention in a given area. The index is based on the slope of the focal cell and the catchment area connected to it (Wilson and Gallant, 2000). Low-lying flat areas are assigned the highest TWI values. Data about the clay% in the top-soil originated from an existing map of soil texture for Denmark in a 250 m resolution (Greve et al., 2007). Slope, TWI, and clay% means for each 1 km quadrate were computed.

To evaluate the effect of *amenity values* on the distribution of set-aside data on uncultivated area, surrounding uncultivated area, and distance to nearest water-body (distance to water) were included as explanatory variables. All of these were acquired from the Danish topographical base-map database (TOP10DK) (Danish Ministry of the Environment, National Survey and Cadastre, 2010) containing 11 land-cover themes at a map-scale of 1:10,000 and having a planar accuracy of 1 m. Spatial information on the following major habitat types were extracted: forest, wetland, and heathland.