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Loss of semi-natural grassland in a boreal landscape: impacts of agricultural intensification and abandonment

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ABSTRACT

The long history of human land use have had a strong influence on ecosystems and landscapes in the boreal forest region of Northern Europe and created semi-natural habitats of high conservation value. In this study, we quantify land-cover change and loss of semi-natural grassland in an agricultural landscape (6.2 km^2) in the boreal region of Norway from 1960 to 2015, and document a 49.1% loss of area that was semi-natural grassland in 1960. The remaining semi-natural grasslands became smaller and the connectivity between them decreased. Intensification and abandonment of agricultural land use were of approximately equal importance for the loss of semi-natural grassland although the relative contribution of these processes depended on the topography and distance to farmsteads. The study provides an example of how change in land cover can be estimated and key drivers identified on a scale that is relevant for implementation of management and conservation measures.

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Abandonment; agricultural intensification; semi-natural grasslands; trajectories; land-cover change; land-cover mapping

Introduction

The large changes in agricultural land use throughout the 20th century have been an important driver of landscape change in Europe (Kuemmerle et al., 2016; Plieninger et al., 2016; Stoate et al., 2009). Access to mineral fertilisers and feed concentrates, and the use of new plant breeds together with new agricultural equipment and technology have increased yields substantially (Emanuelsson, 2009). In parallel with the intensification of agriculture in some regions, remote and low-productivity regions have experienced abandonment of agricultural land (Lasanta et al., 2017). Land abandonment has been particularly prominent in mountain areas (MacDonald et al., 2000) but are also known from high latitude boreal regions of Europe (Sang, Dramstad, & Bryn, 2014).

Agricultural intensification and abandonment can have a large impact on multiple aspects of human societies, for example, food production, cultural identity, and tourism, as well as ecosystems and biodiversity (Fyhri, Jacobsen, & Tømmervik, 2009; Kuiper & Bryn, 2013; Pedersen & Krøgli, 2017; Tscharntke, Klein, Kruess, Steffan-Dewenter, & Thies, 2005; van der Zanden, Verburg, Schulp, & Verkerk, 2017). Consequences of agricultural abandonment are often described as negative, although positive outcomes connected to reforestation, carbon sequestration and increase in wilderness area also have been discussed and investigated (Munroe, van Berkel, Verburg, & Olson, 2013; Navarro & Pereira, 2012). Changes in agricultural land use has caused a reduction in

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landscape diversity and ecological connectivity in many European landscapes (Fuller, Williamson, Barnes, & Dolman, 2017). Landscape diversity is typically reduced as the size of an agricultural field increases and the number of linear elements and midfield islets are reduced. The homogenisation of rural landscapes influences species diversity, where heterogeneous landscapes usually support higher species diversity than homogeneous landscapes (e.g. Smith, Dänhardt, Lindström, & Rundlöf, 2010; Weibull, Bengtsson, & Nohlgren, 2000). Fragmentation changes the patch size and the connectivity between similar habitats. Spatial connectivity is particularly important for habitat types that were previously more widely prevalent, but now occur as small patches or islands in the landscape (Hanski, 1999).

Semi-natural grasslands resulting from extensive agricultural land-use practices is an example of a habitat type susceptible to fragmentation and loss of connectivity in modern agricultural landscapes (Eriksson, Cousins, & Bruun, 2002; Reitalu et al., 2012). Semi-natural grasslands are often species rich and key habitats for a number of species including plants, birds, and arthropods (Billeter et al., 2008; Wehn, Taugourdeau, Johansen, & Hovstad, 2017). Semi-natural hay meadows, which is a specific type of semi-natural grassland, are classified as vulnerable in the red lists of habitat types in Norway and Europe (Janssen et al., 2016; Norderhaug & Johansen, 2011). There is also a large number of red-listed species that depend upon semi-natural grasslands (Henriksen & Hilmo, 2015). The main threats to semi-natural grasslands are considered to be loss of habitats due to land use change and deterioration in habitat quality due to abandonment and other changes in management, nutrient deposition from air pollution and loss of connectivity caused by landscape change (Norderhaug & Johansen, 2011). It is therefore important to learn more about the effects of changes in area and management status for semi-natural grasslands.

Studies of landscape change in Europe have primarily focused on Mediterranean and continental parts of Europe, whereas there is a clear lack of studies from the boreal forest zone (Plieninger et al., 2016). In Norway, studies of land-cover change have focused on landscapes with summer farming in alpine areas (Olsson, Austrheim, & Grenne, 2000; Potthoff, 2017), intensive agricultural areas in southern boreo-nemoral areas (Stokstad & Krøgli, 2015), and the fjord landscapes and coastal landscapes of western Norway (Bryn & Hemsing, 2012; Hamre, Domaas, Austad, & Rydgren, 2007; Lundberg, 2011; Straume, 2013). To our knowledge, there are few published scientific studies that have quantified land-cover changes, and semi-natural grassland loss in particular, during the last century in agricultural landscapes in the boreal region of Norway (but see Fjellstad & Dramstad, 1999). In this paper, we will analyse landscape changes in a boreal forest region, exemplified by a study site in central Norway representative for this region. Within the study area, we document agricultural changes in the small-scale agricultural landscape that is common in boreal landscapes in Scandinavia. Specifically, we will (1) identify the main land-cover changes and transitions during the last 55 years, (2) explore spatial determinants of semi-natural grassland loss, and (3) examine how land-cover change has influenced landscape diversity in this time period. This is significant because it addresses great challenges for landscape management and conservation of semi-natural grassland. The study will provide information that adds to the current knowledge about agricultural land-use changes in boreal landscapes as well as it will be used locally to formulate management recommendations.

Methods

Study area

The study area, Mostadmarka, is located in Malvik municipality south of the Trondheim Fjord in central Norway (Figure 1, 63°20′N, 10°49′E). The study area is located in the middle boreal vegetation zone, which is characterized by dominance of coniferous tree species, and a climate with cold winters and relatively warm summers (Moen, 1999). This vegetation zone covers large areas in Norway, Sweden and Finland (Moen, 1999) where it has been subject to a long history of

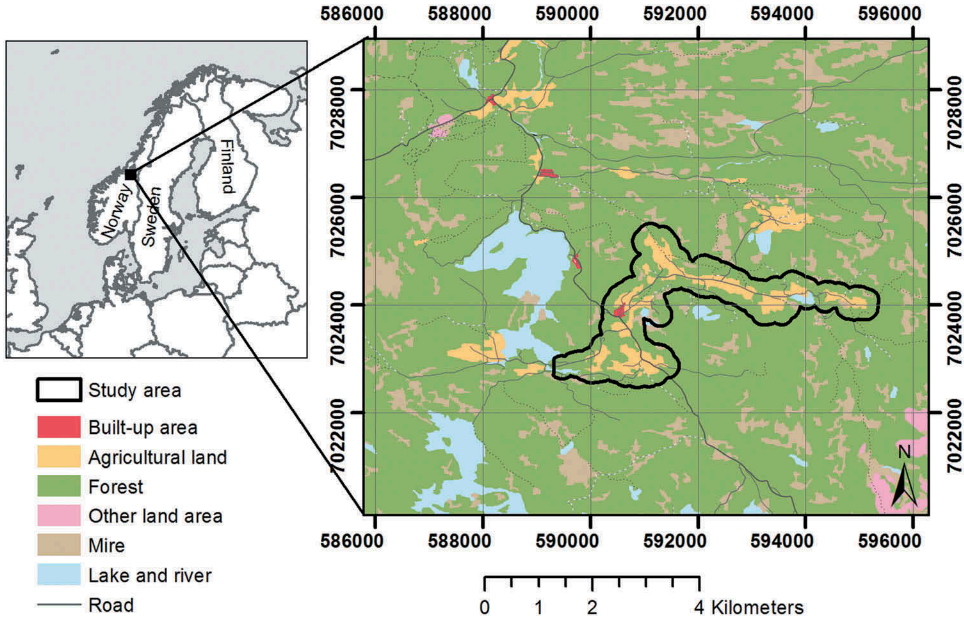

Figure 1. Location of the study area Mostadmarka in Malvik municipality, Norway (WGS84 UTM 32N, source: AR50, NIBIO, www.nibio.no).

agricultural land use. Traditional farming practices followed the infield-outfield system where crop and hay were produced on fenced infields near settlements, while the surrounding land (i.e. the outfields) was used both as grazing land and for collection of winter fodder (Eriksson & Arnell, 2017). The historical utilization of the boreal forest landscapes included a variety of agricultural activities as haymaking on outfields, pollarding and summer farming (Bele & Norderhaug, 2013), which are no longer common.

The mapped landscape area (6.2 km^2) encompasses arable fields and grazing areas surrounded by a 200 m buffer zone. Common forest types in the area are bilberry spruce (*Picea abies*) forest as well as more nutrient demanding low-herb forest and grey-alder (*Alnus incana*) wetland forest. Dry ridges are often covered by heath-dominated pine (*Pinus sylvestris*) forest. The overall topography is characterised by small hills and varies in elevation from 200 to 400 m a.s.l. Metamorphic green schist and greenstone dominate the bedrock, which often is covered by a thin layer of moraine but alluvial deposits, peat and mire cover smaller patches. The soil profile is predominantly podsolic.

Agriculture and forestry is the main land use in Mostadmarka. These means of living were more important and employed many more people in the recent past than they do today. An ironworks operative between 1657 and 1877 had a large influence on the local society and its economic development (Forbord, 1993). The ironworks was located ca. 2.5 km northwest of the study area and the forest in the study area was heavily affected by logging for charcoal production. During the period the ironworks was active the total number of livestock increased. Since the end of the 1800s, the number of farmers has decreased dramatically, while the number of farm animals on each farm increased. From the 1960s to 2015, the number of cattle has decreased, whereas the number of sheep has increased slightly. Within the mapped area, three farms with cattle and two farms with sheep were active in 2015. The outfield areas are still grazed, but mostly by sheep today. There are fences separating all the infields, which today include arable land, fertilized permanent grasslands, farm-near pastures, and some semi-natural grasslands, from the outfields. There is still active forestry in the area with regular logging of spruce.

Mapping of present and historical land cover

To study land-cover changes over time the land cover was mapped in 2015 and 1960s by field mapping and aerial photograph interpretation, respectively. The present land cover was mapped during the summers 2014/2015 using the classification system Nature in Norway (NiN) version 2.0 (Halvorsen, Bryn, Erikstad, & Lindgaard, 2015). The system consists of 68 main land-cover classes divided into basic types based on species turnover along complex structural gradients such as soil moisture, soil nutrients, and land use. Mapping followed the guidelines of Bryn and Halvorsen (2015), adapted for a scale of 1:5000. Delineation of polygons was performed in the field using an Algiz 10× field computer. Colour and colour-infrared (CIR) aerial photographs from 2014 (flight BNO14012-01-04, 0.25 m resolution) were used as background. Stereo Analyst was used for the final digitising. The minimum mapping unit was 100 m^2 for semi-natural grasslands and 250 m^2 for all other land-cover classes. According to NiN, semi-natural grasslands are defined as 'open or wooded grasslands formed through extensive management', and mapping is based mainly on species composition. Although the definition is partly based on land use, we will use the term land-cover class in this paper. The detailed map of land cover in 2015 was reclassified to a coarser map using ten broader land-cover classes that were identifiable on aerial photographs from the 1960s: arable land, bog/fen, farmyard/buildings, forest, wetland forest, semi-natural grassland, semi-natural wetland, water, road and other built-up area. Arable land class includes also cultivated and fertilised grasslands. Built-up area are divided into three classes (road, farmyard/buildings and other) to be able separate changes that results from building of roads or expansion of buildings.

Land cover in the 1960s was mapped via the interpretation of panchromatic black/white aerial photographs from 1963 (flight WF-1395, scale 1:15,000) using the same land-cover classes as for the 2015 map. Aerial photographs from 1959 (WF-2101, 1:25,000) and 1961 (WF-1229, 1:18,000) were used for interpretation of a small part of the study area which was covered by clouds on the 1963 photograph. A retrospective approach was used during interpretation (Skånes & Bunce, 1997), assuming that the basic ecological conditions (e.g. geology, climate, topography) were approximately equal in the 1960s and 2015. Borders from the 2015 map were displayed on the 1963 aerial photographs and used as a starting point for the historical land-cover map. To maintain interpretation consistency, we established a set of rules for interpreting all land-cover classes. These rules make some assumptions, for example that polygons mapped as semi-natural grassland in 2015 were semi-natural grassland or tree covered semi-natural types in the 1960s. A few exceptions were made for reestablishment of semi-natural grassland based on high abundance of forest species during field mapping in 2015 and dense tree cover on 1960s aerial photographs. To determine the 1960 land-cover class on areas where roads, houses, and arable land were later constructed, we used information from neighbouring polygons and comparable areas on the 2015 map. All interpretation was performed by the same person who did the field mapping, thus reducing the potential inconsistency of the interpretation (Hearn et al., 2011). The classification accuracy of the aerial photo interpretation was confronted with a land-cover map from 1963, which subsequently was used to correct classification errors, polygon borders or other inconsistencies. In addition, oblique farm photos from the 1960s and field information (e.g. approximate age and structure of trees in forest patches) were used to correct potential classification errors.

Analyses of land-cover change and semi-natural grassland loss

Analysis of changes in land cover were run on a gridded-point dataset of 10 × 10 m resolution, since polygons have the disadvantage of changing shape and class through time, as well as being varied with respect to slope, aspect, distance to nearest farm, and so forth. A fine-scale resolution was chosen to capture variation in e.g. slope inside grassland patches, since the topography in the study area may vary on distances from 10 m and this may affect the observed land-cover changes. The points were overlaid the polygon (vector) maps, and a code for land-cover class in 1960 and

2015 was extracted in each point along with information if it had remained unchanged over time or changed to another land-cover type. The design provides a representative and unbiased estimation of land-cover within the study area (Nakagoshi, Hikasa, Koarai, Goda, & Sakai, 1998), tested to represent the exact same distribution and area of each land-cover class given by the two polygon maps. Land-cover trajectories were calculated as persistence, gain, loss, swap and net change of land cover classes, according to equations in Pontius, Shusas, and McEachern (2004). Persistence refer to area that have remained in the same land cover class from 1960 to 2015, while net change quantifies the total changes of each class. Gain and loss refer to new areas that have emerged of a land-cover class and to changes to other classes, respectively. Swap measures gain and loss of a land-cover class at the same time at different locations in the landscape. There may be changes in a land-cover class even if there are low values of net change, and this is captured by swap. Percentage change of land-cover class since 1960 was also calculated.

Loss of semi-natural grassland was analysed using logistic regression to explore if and how the probability of loss was related to landscape structure and topography. In this analysis, we examined three types of loss of semi-natural grassland: transition from semi-natural grassland to all land-cover classes, transition to arable land and transition to forest. For each of these three binary response variables, we developed separate models. Data on the three transitions were recorded from the 10 × 10 m gridded-point dataset using only the points that were semi-natural grasslands in 1960 (n = 11,608). To reduce the computational load when fitting the models and also spatial autocorrelation, we sampled 1000 random points for the modelling. The sampling was stratified so that 500 points were semi-natural grasslands with change in land cover after 1960, and 500 points had no change in land cover. The sampling was repeated for each of the three response variables to provide separate datasets for loss of semi-natural grasslands in general to all classes, loss to arable land and loss to forest (i.e. three datasets each with n = 1000). The independent explanatory variables included in the analysis were topographic and distance-based variables that other studies have indicated are of importance for loss of semi-natural grasslands (Gellrich, Baur, & Zimmermann, 2007; Monteiro, Fava, Hiltbrunner, Della Marianna, & Bocchi, 2011). The explanatory variables were aspect, slope, and distances to forest, semi-natural grasslands, and roads in 1960 and 2015 as well as distance to active farms in 2015 and to all farmyards in the area (Table 1). Aspect and slope were calculated using the Spatial Analysis extension using a 10 × 10 m digital elevation model (DEM). Aspect was transformed from a circular to a linear variable with an aspect of 202.5º as the highest value as this is considered to be the most favourable aspect for plant growth (cf. Dargie, 1984). To reduce problems with collinearity (e.g. Graham, 2003), explanatory variables with a high correlation were not included in the same model. All the explanatory variables were standardized by subtracting the mean and dividing by one standard deviation as this makes it possible to compare the estimated coefficients for the different variables. The models were fitted using the glmmPQL function from the MASS package in R version 3.4.1 (R Core Team, 2016) which uses penalized quasi-likelihood estimation to account for overdispersion in the data (Venables & Ripley, 2002). The

Table 1. Explanatory variables included in the logistic regression of loss of semi-natural grassland.

Variables	Definition
Slope	Slope in each change point
Aspect	Aspect in each change point Transformed from a circular to a linear variable
Distance to	Distance from each change point to
…semi-natural grassland edge in 1960	…closest semi-natural grassland patch in the 1960 land-cover map
… forest in 1960	…closest forest patch in the 1960 land-cover map
… roads in 1960	…closest road in the 1960 land-cover map
… semi-natural grassland edge in 2015	…closest semi-natural grassland patch in the 2015 land-cover map
… forest in 2015	…closest forest patch in the 2015 land-cover map
… roads in 2015	…closest road in the 2015 land-cover map
… nearest farmyard	…closest farmyard
… farmyards on farms active in 2015	…closest farmyard on farms active in 2015

binary response variables were all modelled using a binomial distribution. To account for spatial autocorrelation among points, we added a distance-based spatial correlation term as described by Pinheiro and Bates (2000). AIC adjusted for quasi-likelihood (Burnham & Anderson, 2002) was used to compare exponential and Gaussian correlation structures for the spatial correlation term in the models. The final models are all based on Gaussian correlation structure. AIC was also used to select the explanatory variables to include in the final model for each response variable. Estimated effects are given as odds ratios where values less than one denote a negative relationship and larger than one denote a positive relationship. The fit of the models are presented as conditional *pseudo-R^2* using the method presented by Nakagawa and Schielzeth (2013) and the function r.squaredGLMM from the R package MuMIn (Barton, 2018).

Analyses of changes in landscape structure

Four landscape metrics (number of patches, mean patch area, connectance and Shannon's diversity index) were calculated to describe changes in the patch complexity, configuration, connectivity, and diversity of land-cover classes from 1960 to 2015, chosen from numerous landscape metrics with different properties and robustness (Cardille & Turner, 2017). Land-use change does not only affect the total area of each land-cover class, and these widely used metrics were chosen to measure changes in the position and spatial arrangement of land-cover classes within the landscape. Metrics were calculated with Fragstats 4.2 (McGarigal, Cushman, & Ene, 2012), using raster maps converted from the categorical land-cover maps. Patch complexity and connectivity were calculated both for the individual land-cover classes and at the landscape level, while diversity metrics were calculated at landscape level only. The heterogeneity in terms of patch complexity and configuration was measured by number of patches and mean patch area. These metrics reflect fragmentation by measuring emergence or loss of patches, as well as measuring if the main pattern is splitting or merging of patches. Shannon's diversity index describes the distribution of patches of different land-cover classes in the area, and was chosen to measure changes in landscape diversity. The index is positively correlated with evenness, and since the same ten land-cover classes were used in 1960s and 2015, the index is sensitive to the area present of each land-cover class. Landscape connectivity was evaluated using a connectance index, which was selected to reflect fragmentation in terms of spatial distribution of patches. The connectance index is defined as the proportion of distances between patches of the same land-cover class that is less than a threshold distance. We implemented a threshold distance of 100 m based on the topography of the study area with small hills that can separate patches and act as a barrier for dispersal of species or for management, i.e. similar arguments as used by Pitkänen, Mussaari, and Käyhkö (2014).

Results

Land-cover change from 1960 to 2015

The main land-cover changes from the 1960s to 2015 were a reduction of semi-natural grasslands and an increase in the area of arable land and area of land used for infrastructure and buildings (Table 2). In 1960, forest was the most common land-cover class (49.7%) and there was more semi-natural grassland (18.8%) than arable land (15.8%). In 2015, forest (50.8%), arable land (20.4%), and semi-natural grassland (10.6%) were still the most common land-cover classes, although arable land now covered a larger area than semi-natural grassland.

The transition matrix shows that half (49.1%) of the semi-natural grassland in 1960 had changed to other land-cover classes by 2015 (Table 3a; Figure 2). Semi-natural grassland experienced both the highest total changes and the highest loss (Table 3b). The total change was high also for arable land, with high gain (6.0% of the landscape) and some loss (1.4%) to buildings, roads and built-up areas. Forest covered slightly more area in 2015 (313 ha) compared to 1960 (301 ha), and was the land-cover

Table 2. Land-cover statistics as percentage of area in land-cover classes in 1960 and 2015.

Class	1960	2015
Arable land	15.8%	20.4%
Bog/fen	4.9%	4.3%
Farmyard/buildings	1.1%	2.6%
Forest	49.7%	50.8%
Other built-up area	0.2%	1.4%
Road	1.6%	2.3%
Semi-natural grassland	18.8%	10.6%
Semi-natural wetland	0.6%	0.6%
Water	2.9%	3.1%
Wetland forest	4.3%	3.9%

class with highest swap (5.9%). A transition from open to tree-covered classes was seen in the wetlands as well, although there were a negative net change for both bog/fen and wetland forest. Built-up areas such as roads and buildings increased from 2.9% in 1960 to 6.3% in 2015. Roads and buildings appeared mainly on previously arable land or semi-natural grassland, while less forest and wetland areas were transformed to roads and buildings. Other transitions were also detected, such as an increase in water cover (from 2.9 to 3.1%), but these transitions cover small areas.

Semi-natural grassland loss

Semi-natural grassland decreased substantially, with a mean loss rate of 0.9 ha per year. Logistic regression shows that topography and location (e.g. distance to roads, farmyards or to specific land-cover class) explains total loss of semi-natural grassland as well as loss to arable land and forest (Table 4). Loss of semi-natural grassland to all land-cover classes increases close to roads that were present in 2015, and in flat areas, with roads as the explanatory variable with largest effect (odds ratio = 0.72).

Loss of semi-natural grasslands to arable land, i.e. intensification of land use, and to forest, i.e. abandonment, show signs of opposite processes in different parts of the landscape (Figure 3). Intensification was highest in flat areas on south-facing aspects (odds ratio = 0.75 for slope) and close to farmyards (odds ratio = 0.63). Closer to the forest edge and hence closer to the outfield areas, the loss to arable land decreased. In contrast, loss of semi-natural grasslands to forest displayed a negative relationship with distance to forest (odds ratio = 0.34). The transition from grassland to forest also increased with slope (odds ratio = 1.31) and with north-facing aspects, and is positively correlated with distance to farmyards (odds ratio = 1.46). Furthermore, semi-natural grassland close to roads present in 1960 had a higher probability of changing into forest.

Changes in landscape structure

The total number of patches increased between 1960 and 2015 (Table 5). There was a large increase in the number of semi-natural grassland patches (114–174), while patch size decreased by almost two thirds (1.02–0.37 ha per patch). At the same time, the connectivity between semi-natural grasslands decreased (3.15–2.04). The number of patches with arable land also increased (48–54), but unlike semi-natural grasslands, the size of arable land patches increased (2.03–2.33). Shannon's diversity increased slightly from 1.501 to 1.548 between the two maps.

Discussion

Land-cover changes

In the agricultural landscape of Mostadmarka, the main change in land cover was a significant decrease in the area of semi-natural grassland. There are two quite different processes acting simultaneously that cause the loss of semi-natural grassland: intensified management creating a

Table 3. (a) Transition matrix. Percentage area in 1960 within corresponding land-cover classes in 2015. (b) Change statistics. Numbers refer to percent of the landscape.

	2015											(b)						
(a) 1960	Arable land	Bog/ fen	Farmyard/ buildings	Forest	Other built-up area	Road	Semi-natural grassland	Semi-natural wetland	Water	Wetland forest	Sum		Persis-tence	Gain	Loss	Total change	Swap	Net change
Arable land	91.6	0	3.1	1.0	1.0	1.3	1.8	0	0.1	0.1	100	Arable land	14.5	6.0	1.4	7.3	2.7	4.6
Bog/fen	7.1	73.7	0.0	2.0	0.4	0.4	0.1	1.4	3.0	12.1	100	Bog/fen	3.6	0.7	1.3	2.0	1.4	−0.6
Farmyard/ buildings	1.9	0	92.0	1.0	4.5	0.6	0	0	0	0	100	Farmyard/ buildings	1.0	1.6	0.1	1.7	0.2	1.5
Forest	0.9	0.3	1.0	94.0	0.9	1.0	1.2	0	0.1	0.7	100	Forest	46.7	4.1	3.0	7.0	5.9	1.1
Other built-up area	4.8	0	13.7	0.8	79.8	0	0.8	0	0	0	100	Other built-up area	0.2	1.2	0.0	1.2	0.1	1.2
Road	3.4	0.2	5.7	3.9	4.7	79.1	2.5	0	0	0.4	100	Road	1.3	1.0	0.3	1.4	0.7	0.7
Semi-natural grassland	25.4	0	2.7	17.5	1.9	1.3	50.9	0.2	0.1	0.0	100	Semi-natural grassland	9.6	1.0	9.2	10.2	2.0	−8.3
Semi-natural wetland	7.1	0	0	3.3	2.3	0.3	5.6	63.7	0	17.8	100	Semi-natural wetland	0.4	0.2	0.2	0.4	0.3	−0.1
Water	0.1	0.2	0.1	0.6	0.6	0.1	0.1	0	98.3	0.1	100	Water	2.9	0.2	0.0	0.3	0.1	0.2
Wetland forest	6.0	12.6	0.6	9.5	1.6	0.4	0.5	1.4	0.6	66.8	100	Wetland forest	2.9	1.1	1.4	2.5	2.1	−0.4

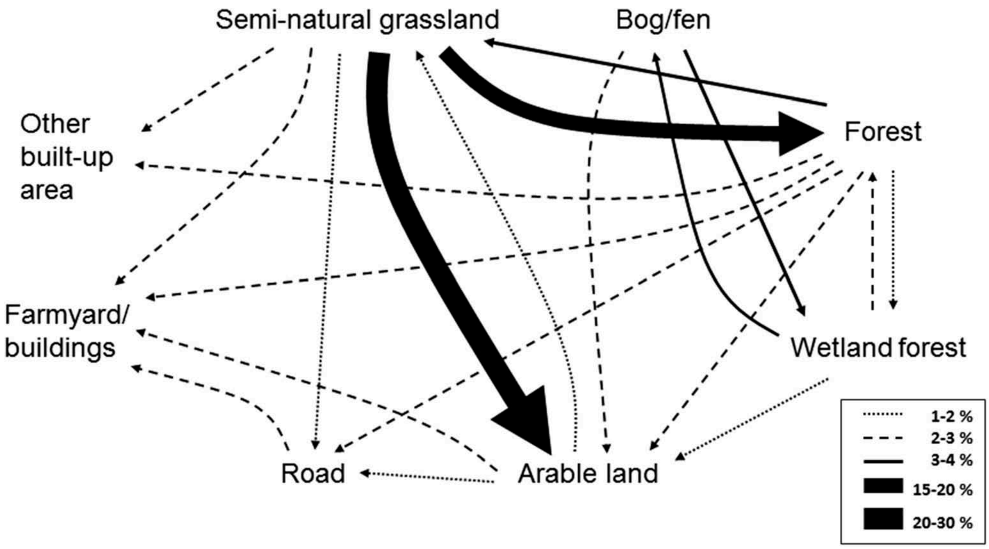

Figure 2. Main land-cover trajectories from the 1960s to 2015. The line style and relative thickness of the lines indicates the percentage of total area changed. Changes less than 1% and land-cover classes with all changes less than 1% (i.e. semi-natural wetlands and water) are not included.

Table 4. Logistic regression of total loss of semi-natural grasslands to all land-cover classes, loss to arable land, and loss to forest. Estimated effect are given as odds ratios with 95% confidence intervals estimated using the Wald method as described by Agresti (2002). *Pseudo-R^2* denote the model fit of each model.

	Semi-natural grassland loss to all land-cover classes	Semi-natural grassland loss to arable land	Semi-natural grassland loss to forest
Pseudo-R^2	0.19	0.42	0.61
Variables			
(Intercept)	1.06 (0.87; 1.19)	0.75 (0.64; 0.88)	0.55 (0.46; 0.67)
Slope	0.86 (0.74; 1.00)	0.75 (0.64; 0.88)	1.31 (1.12; 1.54)
Aspect		1.16 (0.99; 1.36)	0.81 (0.69; 0.96)
Distance to …semi-natural grassland edge in 1960	1.10 (0.97; 1.25)	1.02 (0.90; 1.16)	0.97 (0.85; 1.11)
… forest in 1960	0.88 (0.75; 1.04)	1.33 (1.12; 1.58)	0.34 (0.27; 0.44)
… roads in 1960		0.83 (0.63; 1.09)	0.64 (0.49; 0.84)
… roads in 2015	0.72 (0.57; 0.91)		
… nearest farmyard	0.85 (0.67; 1.07)	0.64 (0.48; 0.84)	1.46 (1.10; 1.93)
… farmyards on farms active in 2015		0.88 (0.74; 1.04)	

shift from semi-natural grassland to arable land and discontinued agricultural management leading to successional change from grassland to forest. The observation that the bi-directional processes intensification and forest regrowth occur simultaneously in the same landscape is corroborated by results from other studies in Norway (Fjellstad & Dramstad, 1999), other Nordic countries (Cousins, Auffret, Lindgren, & Tränk, 2015; Hellesen & Levin, 2014; Luoto, Rekolainen, Aakkula, & Pykälä, 2003), and the Alps (Monteiro et al., 2011). In a review of landscape changes in Europe, Plieninger et al. (2016) found that abandonment was the most important proximate driver of landscape change, while most of the reviewed studies reported a combination of two or more drivers. Plieninger et al. (2016) however, reported a general lack of landscape studies from the boreal regions, and there are few studies to compare our results with. For example, other studies have found that intensification is a more important cause for loss of semi-natural grasslands than

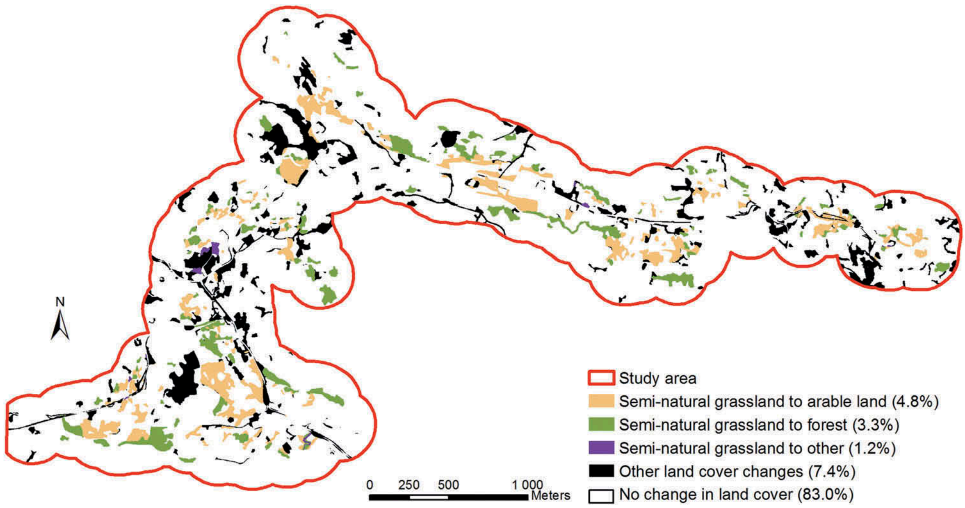

Figure 3. Spatial distribution of land-cover changes from 1960 to 2015 in the boreal rural landscape of Mostadmarka, Norway. Loss of semi-natural grassland to arable land, forest or other land-cover classes are particularly shown. Values denote cover of each change class as percent of the total study area (WGS84 UTM 32N).

Table 5. Landscape metrics. Connectance of semi-natural grasslands is calculated with a threshold distance of 100 m.

	Number of patches		Mean patch area		Connectance index		Shannon's diversity index	
	1960	2015	1960	2015	1960	2015	1960	2015
CLASS								
Semi-natural grassland	114	174	1.02	0.37	3.15	2.04		
Wetland forest	98	86	0.27	0.28	1.64	1.40		
Bog/fen	82	70	0.37	0.38	1.99	2.19		
Forest	69	73	4.44	4.29	4.94	4.79		
Farmyard/ buildings	56	66	0.12	0.24	2.60	2.19		
Arable land	48	54	2.03	2.33	6.47	6.43		
Semi-natural wetland	34	24	0.12	0.15	1.78	2.90		
Road	28	26	0.36	0.55	11.90	18.46		
Water	14	21	1.30	0.92	5.49	5.71		
Other built-up area	10	78	0.12	0.11	4.44	1.86		
LANDSCAPE	553	672	1.12	0.92	3.10	2.61	1.501	1.548

abandonment (Hellesen & Levin, 2014), which corresponds with our results, although we found the loss caused by abandonment and forest regrowth to be of the same magnitude. The rate of semi-natural grassland loss found in this study is lower than reported by Cousins et al. (2015), Hooftman and Bullock (2012), and Johansson et al. (2008). The variation in rate at which semi-natural grasslands are lost can be due to differences between the landscapes studied, but the rate of land-cover change can also be influenced by the type of process driving the change: succession after abandonment is a slow process, whereas intensification results in abrupt changes. In addition, small scale farmers within the boreal region have limited access to land for intensification and semi-natural grasslands are the only available land if they want to expand their production.

Land-use intensification

A quarter of the semi-natural grassland area was lost due to intensification, i.e. converted to arable land. Intensification is often correlated with even terrain (Monteiro et al., 2011) and presence of fertile and productive soils (Cousins et al., 2015), whereas land on drought-prone or otherwise less productive soils (Cousins, 2001; Hamre et al., 2007) are more likely to continue as semi-natural grasslands. In our study, semi-natural grasslands were more likely to be converted to arable land or fertilised permanent grasslands if they were easily accessible, i.e. close to the farmstead or roads, or if the terrain was even or with moderate slope. This probably indicates the expected influence of practical management challenges that has increased with the ongoing modernisation of agricultural machinery.

The change in management of grasslands includes increased use of mineral fertiliser, removal of boundaries and field margins to increase the size of individual fields and levelling the terrain to facilitate the use of agricultural machinery. There are no data available on the use of mineral fertiliser in the study area, but information from local farmers indicates that the use of fertiliser increased from the 1950s, which is in line with general trends in Norway (Almås, 2004). When the farmers started to use tractors to harvest the roughage, many of the grassland patches were too small and steep to support the large equipment and they were gradually abandoned. Mineral fertilisers, cultivated leys, and grasslands established with more productive seed mixtures, allowed farmers to produce the winter fodder they needed on arable land or improved semi-permanent grasslands. Thus, the use of outfields for livestock grazing or harvesting of winter forage decreased (Emanuelsson, 2009).

Land abandonment and transition to forest

The transition from semi-natural grassland to forest was the second most frequent land-cover change in this study. This transition was more likely to take place on steep slopes, close to forest edges, and with increasing distance from farms, which has also been documented elsewhere (e.g. Gellrich et al., 2007). This is related to changes in agricultural practices and, more specifically, cessation of mowing and grazing. In 1960, it is likely that all farms in the study area (ca. 20 farms) had livestock, whereas today only five farms with cattle or sheep are still active. Although the number of animals per farm has increased, there has probably been a decrease in the total number of grazing livestock in the study area. The livestock today are grazing on other land than in the 1960s and there is more land available per grazing animal. As a consequence, some of the land previously grazed is either left without grazing or the grazing pressure is reduced. Land that has been abandoned will, without grazing, eventually turn into forest, but this can also happen if the grazing pressure is too low to hinder the establishment of shrubs and trees (Wehn et al., 2017).

The number of active farms both in this area and elsewhere in Norway has decreased substantially throughout the 20th century (Bye, Aarstad, Løvberget, & Høie, 2017). Nevertheless, not much of the arable land in the study area has been lost and the total area of arable land has actually increased. The farmers that quit active farming often rent out their land to other farmers. The increase in rented agricultural land is a common trend in most parts of Norway (Forbord, Bjørkhaug, & Burton, 2014). The increase in forest regrowth farther away from active farms can therefore be explained as a counter-balance to the greater management and higher grazing pressure closer to the farms where convenient enclosures are available and more distant grazing land is no longer required.

Outfield areas are less sensitive to abandonment of individual farms, since sheep and cattle from several farms graze such areas. There are fences within the study area to keep animals grazing in the outfields away from improved grasslands and arable land. These fences are often located 50–100 m away from the arable land, which creates a transition zone between the arable land and the outfield that is susceptible to forest regrowth. Historically, this transition zone was often grazed together with infields in late autumn and, in combination with the cutting of shrubs and trees, this practice kept the areas open. Today the grazing of the transition zone has usually ceased or the grazing pressure is too low to prevent forest regrowth. Forest regrowth in this transition zone will eventually lead to a more homogenous landscape covered by either forest or arable land, while cover of various types of semi-natural grasslands, e.g. wooded pastures, decreases.

There are large interest in conservation of semi-natural grasslands in Norway, and considerable resources are allocated to secure this habitat type through an action plan for conservation of hay meadows (Wehn et al., 2018). However, this effort is directed towards specific grasslands (hay meadows) with high species diversity without emphasizing the landscape surrounding the grasslands. The results of this study points towards a need for a broader spatial management focus as we document loss and fragmentation throughout the landscape. Conservation of semi-natural grasslands and the biodiversity associated with these habitats is challenging as the changing landscape reflects changes in agriculture and society that are likely to continue. If the aim is to conserve semi-natural grasslands, there is clearly a need for measures that effectively can halt the loss and fragmentation of these habitats – perhaps by giving priority to regions with higher density of semi-natural grasslands and encouraging agricultural practices so that productive grasslands can contribute to ecological connectivity among remnant semi-natural grasslands.

Landscape development

The landscape in the study area has not only changed in the composition of land-cover types, but has also been subject to changes in landscape structure. For both semi-natural grassland and arable land, the number of patches has increased. The average patch size increased only for arable land while those of semi-natural grassland became smaller. These opposing trends contribute to the fragmentation of semi-natural grassland patches. Habitat fragmentation is a known problem in landscapes with intensified agricultural land use and forest regrowth, as observed in our study (see e.g. Hooftman & Bullock, 2012; Johansson et al., 2008). A large decrease in the size of semi-natural grassland patches and increasing patch number indicate that large semi-natural grassland patches present in the 1960′ landscape have been split into several smaller fragments by 2015. The reduction in habitat size often increases the distance to similar patches, which is indicated by a reduction in connectivity. Continued fragmentation of semi-natural grasslands poses a threat to the long-term survival of populations of species confined to that habitat (Aavik, Talve, Thetloff, Uuemaa, & Oja, 2017; Henriksen & Hilmo, 2015; Lennartsson, 2002). This threat is further enhanced by the described loss of semi-natural habitats and also by no or insufficient management of the remaining grasslands (unpublished data). The impacts of fragmentation are likely to vary between species and are influenced by the suitability of other land-cover types for the species in focus.

Agricultural intensification is often associated with the homogenisation of landscapes (Hietala-Koivu, 2002; Jakobsson, Fukamachi, & Cousins, 2016; Tscharntke et al., 2005) by for example, amalgamation and enlargement of fields. This was documented in this study as an increase in the size of arable land patches. Nevertheless, landscape diversity metrics did not reflect any overall homogenisation. A slight increase in Shannon's diversity index from 1960s to 2015 indicates a more even distribution of land-cover classes in 2015, probably as a result of an increase in several classes that covered small areas in the 1960s (e.g. roads and buildings). The Shannon diversity index, however, has been applied to a period with agricultural transition that has not yet ended. In line with findings by Hemsing and Bryn (2011) from other rural landscapes in Norway, we suspect that a continuation of the ongoing landscape conversion in our study area will eventually lead to lowered landscape diversity.

Sources of errors and uncertainties

Land cover-change studies based on aerial photography include a risk of interpreting the land cover wrongly (Ihse, 2007). A retrospective approach with clear interpretation rules is a reliable method for landscape-change studies based on historical sources such as aerial photographs or cadastral maps (Käyhkö & Skånes, 2006). The main challenges with aerial photography interpretation in this study were to separate semi-natural grassland from cultivated grassland, and to separate grazed pasture and outfields from grass-dominated clear-cuts in the greyscale aerial photographs from the 1960s. Classification, however, was aided by other data sources, and inconsistent classification was reduced by using only one interpreter. In addition, the study area was thoroughly field checked to create the 2015 map with visits of all map polygons and this ensured that the interpreter had good knowledge of the area. Therefore, although there is potential for errors, we have mitigated them as much as possible and have confidence that the land cover-change patterns in this study are clear.

Many of the studies on semi-natural grasslands vary with respect to important issues such as temporal scale (investigated time-span), spatial resolution, extent of study area, agricultural development, and the natural resource base. For example, processes of land-use intensification or abandonment are closely connected to the existing natural resources base (e.g. slope, soil depth) and the specific agricultural policy implemented (Sang et al., 2014). Although the processes leading to land-cover changes are similar, the patterns of change vary between remote rural regions and more centralised high-income agricultural regions of Norway (Bryn & Hemsing, 2012; Stokstad & Krøgli, 2015). This fact makes it difficult to compare the results among studies. The status and development of semi-natural grasslands in Norway is based mainly on expert assessments (Framstad, 2015), and there are no spatially unbiased and area representative datasets for this nature type. Although this study covers a small area, it adds quantitative information about the decrease of boreal semi-natural grasslands. We suspect that the loss of semi-natural grassland may be even higher in other parts of the boreal region since the studied area has probably retained more semi-natural grasslands than areas with, for example, stronger urbanisation where the general loss of farmland is higher (Skog & Steinnes, 2016).

Concluding remarks

In this study we have examined land-cover change in a landscape dominated by boreal forest, but also influenced by a long history of human land use through livestock grazing and fodder harvest in outfields resulting in large areas of semi-natural grassland. Our results demonstrate that almost half of the semi-natural grassland in the study area has been lost to other land-cover classes over the last 55 years. Forest regrowth after abandonment and intensification of agricultural land use were the main processes causing the change. Topographic position and location within the landscape, such as terrain steepness and distance to farmyards, explain most of the spatially distributed loss of semi-natural grasslands. The number of patches of semi-natural grassland increased, but the size of them decreased. Thus, the landscape development indicates a clear fragmentation of semi-natural grassland areas. There is a large interest in management and conservation of semi-natural grasslands in Norway, and considerable resources are allocated to secure this habitat type for the future (Wehn et al., 2018). To design the appropriate measures for conservation of semi-natural grasslands, it is important to have quantitative estimates of the changes at the scale the measures are implemented on, and to identify and understand the most important drivers of change. The study presented here addresses these needs for information, and also provides estimates for land-cover change and loss of semi-natural grasslands in the less studied region of boreal forests in northern Europe.

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