Landscape Ecol (2007) 22:1563–1574
DOI 10.1007/s10980-007-9154-y

RESEARCH ARTICLE

Land-cover and structural changes in a western Norwegian cultural landscape since 1865, based on an old cadastral map and a field survey

Liv Norunn Hamre · Stein Tage Domaas · Ingvild Austad · Knut Rydgren

Received: 19 June 2006 / Accepted: 20 August 2007 / Published online: 5 September 2007

Abstract Many studies of land-cover and structural changes in cultural landscapes have used historical maps as a source for information about past land-cover. All transformations of historical maps onto modern coordinate systems are however burdened with difficulties when it comes to accuracy. We show that a detailed land survey of the present landscape may enable transformation of an old cadastral map directly onto the present terrain with very high accuracy. The detailed resulting map enabled us to locate remnants of semi-natural grasslands and man-made structures with continuity from 1865 and to test hypotheses about relationships between landscape changes and landscape characteristics. The main land-cover change 1865–2002 was decrease of arable fields, and addition of three new land-cover classes: horticultural, orchard and abandoned areas. Of the 330 man-made structures present in 1865, only 58 remained in 2002, while 63 new structures had been built after 1865. We found that semi-natural grasslands with continuity since 1865 were situated on ground with significantly lower production capacity than mean 1865 production capacity. The man-made structures with continuity since 1865 were also associated with areas with significantly lower production capacity than the 1865 mean, situated in significantly steeper terrain but not further from the hamlet. Our study illustrates the potential of digitised and accurately transformed historical cadastral maps combined with detailed field surveys for analysis of land-cover and structural changes in the cultural landscape.

Keywords Cadastral map · Cultural landscape · GIS · Land-cover change · Man-made structures · Map transformation · Statistical testing · Urnes stave church

Introduction

For centuries land use has interacted with physical geographical features to form the present cultural landscape. The European cultural landscape, including the Scandinavian, has changed dramatically during the second part of the 20th century (Bastian and Bernhardt 1993; Ihse 1995; Fjellstad and Dramstad 1999). Generally, these rapid landscape transformations are caused by intensified use of agricultural land and increasing abandonment of marginal areas (Fry and Sarlöv-Herlin 1997; Haines-Young et al. 2003). The reduced diversity of traditional landscape elements (Kienast 1993; Norderhaug et al. 2000; Jongman 2002), generally

L. N. Hamre (✉) · S. T. Domaas · I. Austad · K. Rydgren
Sogn og Fjordane University College,
P.O. Box 133, Sogndal 6851, Norway
e-mail: liv.hamre@hisf.no

Present Address:
S. T. Domaas
Finnmark County Authority, Vadso 9815, Norway

causes negative consequences for many of the organisms living there (Benton et al. 2003; Luoto et al. 2003; Poschlod et al. 2005), as well as for biological values and cultural heritage (Fry et al. 2004; Daugstad 2005).

The intensification process also threatens man-made remnants of farming activity, e.g. dry-stone walls, terrace walls and clearance cairns (Kristensen 1999; Austad and Øye 2001; Daugstad 2005). Even though these structures may be of crucial importance to the existence of small biotopes and may represent a rich source of material for archaeologists (Pedersen 1990; Austad and Øye 2001), they are often neglected. Unfortunately, both tracing, age determination and evaluation of man-made structures are difficult (Austad and Øye 2001; Domaas et al. 2003).

In many countries large collections of maps on different scales exists (e.g. Kain and Baigent 1992; Kienast 1993; Cousins 2001; Vuorela et al. 2002), and often studies of landscape changes have been based upon digitised historical maps (e.g. Pärtel et al. 1999; Cousins 2001; Domaas et al. 2003; Bender et al. 2005b). In Norway the most extensive material of historical maps is made up by the cadastral maps constructed after the 1857 Land Consolidation Act, which brought about an extensive reorganization of agricultural areas. Because of large scale (1:2000) and very detailed land-cover information, digitised cadastral maps offer a unique possibility for use of GIS (Geographic Information Systems) for detailed spatial and temporal analysis of land-cover and structural changes.

A major problem of old cadastral maps in landscape change studies, compared to modern maps, is the frequent lack of precision in detail (geometrical irregularities). To enhance their usefulness they must be transformed onto a modern coordinate system. Different methods exist for such transformations (e.g. Pärtel et al. 1999; Cousins 2001; Domaas 2005), but a common challenge is obtaining enough common information on the historical and modern maps to validate the transformation statistically (Vuorela et al. 2002).

However, if a thorough field survey is performed, the problem can be reduced or circumvented, but transformation based on such an approach has so far almost never been done (Domaas et al. 2003). A thorough field survey also provides additional information on for example man-made structures and environmental characteristics, and therefore makes possible a more detailed analysis of landscape changes.

The Norwegian mid-19th century cadastral maps do not only provide information on land cover but also provides detailed assessments of production capacity for the different patches. The relation between landscape change and different environmental landscape features have repeatedly been studied (Cousins 2001; Peppler-Lisbach 2003; Hietel et al. 2004; Bender et al. 2005b). However, few studies has focused on the relation between landscape changes and production capacity (Bender et al. 2005a,b; Domaas 2007). Contemporary landscape change typically concerns the fragmentation or abandonment of remnants of semi-natural grassland (Norderhaug et al. 2000; Luoto et al. 2003; Hodgson et al. 2005). They are situated on too steep or too shallow ground to allow use of modern machinery, or they are too small or situated too remote to make cultivation profitable (Losvik 1988; Kristensen 1999; Cousins 2001). Thus, we may expect that remnant grassland patches are now situated on areas that had lower production capacity than the mean for all grasslands that existed at the time of land consolidation. Moreover, we may also assume that the remnant man-made structures in the present landscape are best preserved in areas less suited for agricultural intensification. In addition, areas with low production capacity at the time of land consolidation should hence be situated on steeper terrain and further from the hamlet.

A large number of studies have used GIS for analysing land cover changes and presentation of maps from different time-points, in order to visualize landscape dynamics (e.g. Pärtel et al. 1999; Cousins 2001; Bender et al. 2005b). Statistical testing of landscape change patterns based upon GIS information is, however, rarely seen. We are not aware of any study in which relationships between production capacity, man-made structures and landscape changes have been statistically tested.

Our study is based upon an old cadastral map, a field survey of the present landscape and GIS, and aim to: (1) develop a method for detailed spatial analyses of landscape changes; (2) quantify and analyse land-cover changes since the time of land consolidation until present; and (3), perform statistical testing of relationships between landscape structural changes and production capacity, terrain slope and distance from hamlet. We specifically address the relationships between old (with continuity since the land consolidation) semi-natural grasslands and man-made structures and the production capacity at that time point. Also, the occurrences of these man-made structures and slope or distance from hamlet are analysed.

Materials and methods

Study area

The study took place at Ornes in Lustrafjorden, the inner part of Sognefjorden (Fig. 1). The study area is 43 ha. It covers the part of the Ornes area that was included in the 1865 land consolidation process and is therefore covered by the cadastral map.

Archaeological findings date the first farming activity at Ornes to BC 1940–1490 (Lia 2005). The focal point of the Ornes landscape is Urnes stave church, the oldest remaining stave church in Norway and one of eight Norwegian sites on the UNESCO World Heritage List.

The cadastral map

The study area is covered by a cadastral map dating back to 1865, drawn to scale 1:2000 (Fig. 2). The cadastral map provides detailed information about land-cover, but also indicates point elements such as buildings and clearance cairns and linear elements such as roads, foot paths, dry-stone walls, fences and streams. All elements are represented as polygons on the digitised cadastral map. All the small elements such as stone-walls and clearance cairns are indicated with different shape and sizes on the cadastral map, and we assume that they are drawn in their real size. Overlay analyses of the cadastral map and the 2002 map based on the present terrain confirms this by showing nearly total overlap for big stones present at both times. The written protocol associated with the cadastral map provides additional information on ownership and production capacity for each landscape patch. All patches had a particular owner in 1865, included the different parts in the clustered hamlet. In 1865 all patches, except farmyards and roads were indicated as arable land or meadow, and arable land was used for crops. Production capacity was used to classify land patches according to estimated productivity, to balance for each farmer the value of land lost and land gained by land consolidation. The scale used for assessment of production capacity is unique for each land area subjected to land consolidation, i.e. for each cadastral map. At Ornes, production capacity was divided into 46 classes on a fraction scale from 1 to 300, with 1 as the best and 300 as 1/300 of the best. The most

Fig. 1 Ornes is located in Sogn og Fjordane county, western Norway

Fig. 2 The 1865 cadastral map of the infield areas of Ornes (Nitter and Uchermann 1865). The scale of the enlarged part is the same as on the original cadastral map

valuable areas (tilled fields and high quality hay meadows) were finely divided, so that 17 steps were used for quality classes between 1 and 2, while only 7 steps were used to divide the range 50–300.

The cadastral map was digitised using the software PC ArcInfo for Windows (Anonymous 1994). In order to retain the detailed information on point, line and polygon features, we digitised the map objects in vector format (Domaas 2005). ArcView GIS (Anonymous 1996a) was used for displaying and analysing map files.

The 2002 situation

A complete field survey using a total station was performed in 2002 with an accuracy of 10 cm (A. Lerum pers. comm.). A total station is an optical instrument used in modern surveying. It is a combination of an electronic theodolite, an electronic distance measuring device and software running on an external computer. Our survey included all man-made structures and terrain structures. A vector map of the present landscape was then constructed on the background of the field survey accompanied by additional digitised information from the existing ØK (economic map) of the area (scale 1: 5 000) and for some parts, large scale maps (1:1 000) constructed by the Norwegian Public Roads Administration. The ØK map is based on an aerial photograph from 1964, and the coordinate system used is NGO1948. All man-made structures were surveyed and presented on the map as polygons.

The restricted size of the area also made possible a detailed mapping of land-cover. Aided by the surveyed structures and the present farm boundaries, also this theme was digitised to form a land-cover map for 2002. We used a simplified classification of nine land-cover classes used: arable field, grassland, farmyard, roads and paths, field boundaries and remnants, church and churchyard, horticulture, orchard and abandoned. The classes are the same as on the cadastral map, except for the three last ones that were not present in 1865.

In 1865, grassland was predominantly semi-natural meadows with traditional management, i.e. grazing in spring and autumn and mowing once quite late in the summer (Losvik 1988). The class grassland used for the 2002 map is more broadly delimited, and included meadows cultivated (i.e. being ploughed and sawn with new grass) every 5–7 years, cultivated meadows older than 10 years and pastures.

Grassland present in the 2002 landscape as not cultivated or fertilised with mineral fertiliser since 1865 represent a subgroup called semi-natural grassland with continuity since 1865. Presence of grasslands on an area in 1865 and 2002 does not, however, provide a guarantee for continuity of semi-natural grasslands at the site. There exist no map between 1865 and 1964. We have, however, corroborated our findings by interviewing the farmers, who have knowledge about management practices that date back at least to 1945. In Norway, as in many other European countries, the most intensive agricultural development started after 1945 (Ihse 1995;

Kvamme et al. 1999; Bender et al. 2005a), and we confidently assume that the status of areas in 1945 as not cultivated or fertilised reflected their former history of use as well. Moreover, they are located in marginal areas not very suitable for intensification. Also aerial photos from 1960 and 1984 have been studied, and the chosen areas were uncultivated semi-natural grasslands also at these time-points.

We delineated farmyards in the border to the surrounding arable land at both time-points. The class field boundaries and remnants include man-made structures, outcrops and the small areas of seashore both in 1865 and 2002. We assumed that ploughing and mowing were performed close to field boundaries in 1865, and the size of the field boundaries and remnants constitute the size of the polygons. Field boundaries and remnants in 2002 are also polygons, delimitated from the surroundings where cultivation starts. This delineation is performed by the help of the land survey and measurements afterwards. Other areas not in use today, varying from relatively open land to secondary forests, are classified as abandoned. Because 1865 is around the peak in production in the study area (Timberlid 1988), we assume that no areas were abandoned in 1865.

Map transformation

The digitised 1865 cadastral map was transformed onto the coordinate system NGO1948 to enable comparison with the 2002 land-cover map. The transformation was performed in PCArcInfo (Anonymous 1994) using the affine transformation as described by Domaas (2005), with an improvement. The transformation was carried out using common points on the cadastral map and in the present landscape, instead of common points on the two maps. As many as sixteen points that certainly were the same in the present landscape and on the 1865 cadastral map was found. The even distribution of these points made them well suited for transformation. The transformation accuracy in this case is based on recalculations of the RMS-error for each point into one single positive value and their standard deviation distribution. In this study the standard deviation for the transformed cadastral map turned out to be 1.7 m, which is better than the standard of 2 m set by the Norwegian Mapping Authority, SOSI v. 3.1 for ØK (Statens kartverk 1999). Domaas (2005) has suggested that (with this type of transformation) the minimum width of an object that can be distinguished and the minimum distance between two objects that can be separated can be defined as the SD, and the minimum area we are able to define is SD^2.

Land-cover changes and changes in man-made structures

Analysis of land-cover changes from 1865 until 2002 were performed in ArcView GIS (Anonymous 1996a). Man-made structures existing in 1865, in 2002, and in both years were identified by comparison of the two maps by overlay analysis. Due to the land consolidation a lot of man-made structures were founded after 1865, and many of these are expected to have disappeared before 2002, thus escaping the survey. In this study we focused on three types of structures closely related to meadows and arable fields: dry-stone walls, terrace walls and clearance cairns.

Changes in relation to production capacity, slope and distance from hamlet

A randomization (Monte Carlo) approach (Legendre and Legendre 1998) was performed in Lotus 123 Ver. 9.8 to test the following 4 hypotheses: (1) The semi-natural grasslands [present in the landscape today] with continuity from 1865 ($n = 27$) has lower production capacity than the mean for all grasslands that existed in 1865 ($n = 314$); (2) the man-made structures [present in the landscape today] with continuity from 1865 ($n = 58$) are situated on land with lower production capacity than the mean for all man-made structures found in 1865 ($n = 330$); (3) the man-made structures with continuity from 1865 are situated in steeper terrain than the mean for all man-made structures found in 1865; and (4), the man-made structures with continuity from 1865 are situated further from the hamlet than was the mean for all man-made structures in 1865.

We calculated the production capacity associated with each man-made structure as the mean of production capacities for their bordering land patches, weighted by their length. Mean values for production capacity were calculated after transforming the scale by multiplication with $1/x$ where x is the production capacity. We derived a 3D model of the landscape from the contour lines from ØK using ArcView 3D Analyst (Anonymous 1997). Then slope was calculated, set equal to the angle of inclination of the surrounding terrain. The distance from the hamlet was calculated from a fixed point in the middle of the hamlet, to a point in the middle of the man-made structure, using ArcView Spatial Analyst (Anonymous 1996b).

For all hypotheses, we first calculated the observed mean M_0 for the variable with continuity from 1865. Next, 9999 random sub-samples, with 27 observations for hypothesis 1 and 58 observations for hypothesis 2, 3 and 4 were drawn from the entire sample ($n = 314$ and $n = 330$, respectively), and the mean M_1 calculated for each. The significance P of the test against one-tailed alternative hypotheses was obtained by counting the number s of sub-samples for which $M_1 < M_0$: $P = 0.0001*(1 + s)$.

Results

Land-cover changes

By 1865, complex strip farming had created a mosaic of grassland (61.2%) and arable field (30.9%) patches that differed with respect to size and production capacity (Fig. 3, Table 1). The total number of patches was 459. By 2002, the number of patches in active use was about 60, and each patch was on average much larger than in 1865 (Fig. 3).

The dominant pattern of land-cover change was the decrease of arable fields, from 13.34 ha in 1865 to 0.27 ha in 2002, and the addition by 2002 of the three new land-cover classes; horticulture, orchard and abandoned, comprising 7.6%, 7.9% and 23.8% of the total area, respectively (Table 1). A major part of the former arable fields had become grassland (47.6%), while 15.3% had become horticultural areas, 9.6% orchards and 12.1%, mostly situated in the peripheral parts of the area, had been abandoned by 2002 (Fig. 3, Table 2).

In 2002, grassland was still the dominating land-cover type, covering 36% of the land area, followed by abandoned land (23.8% of the total area). A large part of the area covered by grassland in 1865 had, however, become abandoned by 2002 (36.8%; Table 2). Abandoned areas were mostly located in the outermost parts of the infield (Fig. 3). Of the 26.4 ha with grassland in 1865, only 5.2% remained in the present landscape in 2002, neither cultivated nor subjected to mineral fertilisation during the years (Table 1).

The area of field boundaries and remnants was nearly doubled from 1865 to 2002, from 2.23 ha to 4.02 ha (Table 1).

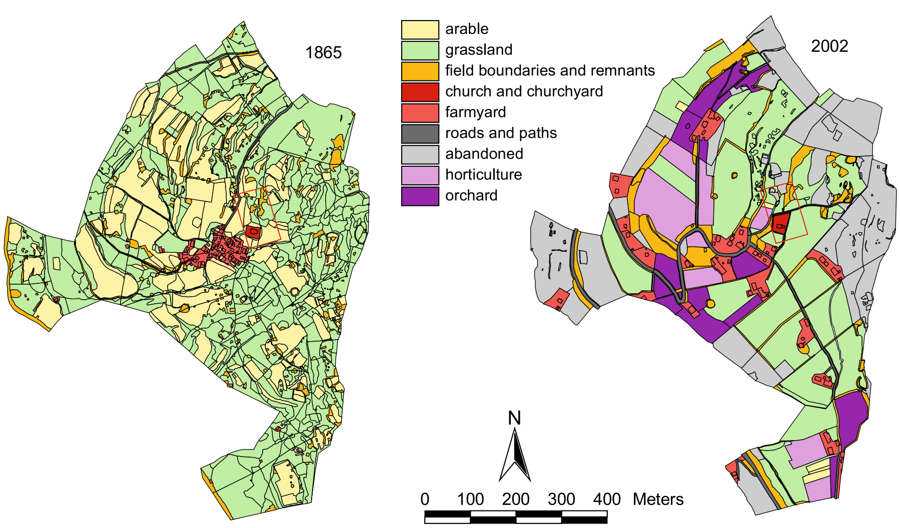

Fig. 3 The distribution of different land-cover classes at Ornes in 1865 and 2002. The enlarged part in Fig. 2 is indicated on the maps

Table 1 The total area of land-cover types given in ha at the two time points

Total area	1865		2002	
	43.12 ha	%	43.12 ha	%
Arable field	13.34	30.9	0.27	0.6
Grassland	26.39	61.2	15.51	36.0
Grassland with continuity since 1865			2.26	5.2
Church and churchyard	0.07	0.2	0.14	0.3
Farmyard	0.80	1.9	2.71	6.3
Roads and paths	0.29	0.7	1.27	3.0
Field boundaries and remnants	2.23	5.2	4.02	9.3
Horticulture			3.28	7.6
Orchard			3.42	7.9
Abandoned			10.24	23.8

Table 2 Transition matrix showing proportional land-cover changes from 1865 to 2002. The largest transition probability in each column in bold-faced types

Land-cover type 1865		1	2	3	4	5	6	7	8	9
2002										
1	Arable field	0.014	0.003	0	0.008	0.003	0	0	0	0
2	Grassland	**0.476**	0.330	0.084	0.271	0.218	0	0	0	0
3	Farmyard	0.054	0.052	**0.495**	0.054	0.094	0	0	0	0
4	Roads and paths	0.021	0.032	0.156	0.111	0.014	0	0	0	0
5	Field boundaries and remnants	0.063	0.096	0.209	**0.297**	0.172	0.040	0	0	0
6	Church and churchyard	0.002	0.001	0	0	0	**0.960**	0	0	0
7	Horticulture	0.153	0.045	0.015	0.033	0.020	0	0	0	0
8	Orchard	0.096	0.074	0.026	0.004	0.068	0	0	0	0
9	Abandoned	0.121	**0.368**	0.016	0.222	**0.410**	0	0	0	0

Changes in man-made structures

Overlay analyses showed that of the 330 man-made structures present in 1865 in the form of clearance cairns, dry-stone walls and terrace walls (Fig. 4), only 58 of these remained in the 2002 landscape, while 63 had been added, giving a total number of 121 (Fig. 4). About one half of the man-made structures with continuity from 1865 were situated on areas still in use in 2002.

Changes in relation to production capacity, slope and distance to hamlet

The mean production capacity of 1865 arable fields according to assessments made during the construction of the cadastral map was 1.60, corresponding to 20.57 for grasslands. This shows that the patches regarded as most productive (compare Figs. 3 and 5) were used for arable crops.

The randomisation test confirmed our hypothesis that grasslands with continuity since 1865 were situated on areas with production capacity lower than the mean for grasslands in 1865 ($P < 0.0001$). The second hypothesis, that man-made structures with continuity from 1865 till 2002 occurred on land with lower production capacity than was generally the case for land with man-made structures in 1865, was also confirmed ($P = 0.018$). These man-made structures were situated in significantly steeper terrain than was generally the case for man-made structures in 1865 ($P = 0.038$). However, they were not situated significantly further from the hamlet than was

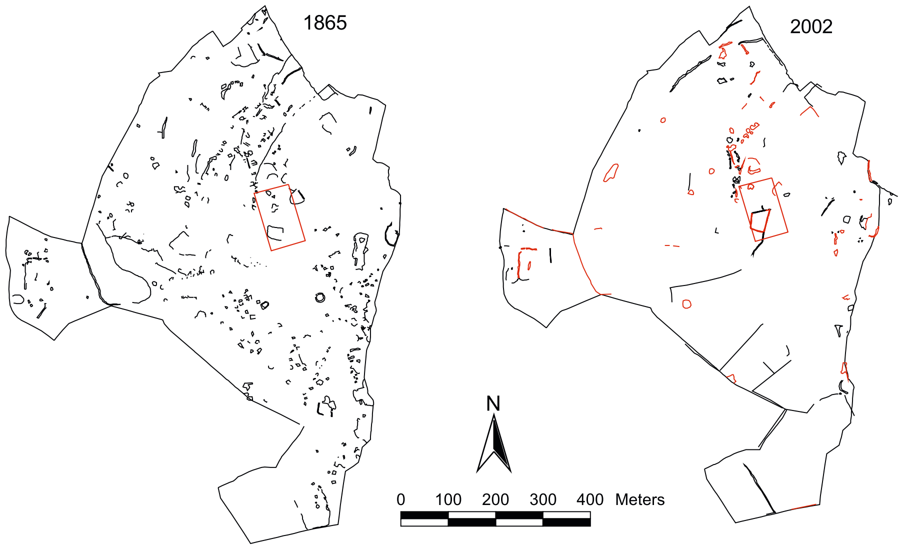

Fig. 4 The distribution of man-made structures (dry-stone walls, terrace walls and clearance cairns) at Ornes in 1865 and 2002. In the 2002 map, structures with continuity since 1865 are red. The enlarged part in Fig. 2 is indicated on the maps

generally the case for man-made structures in 1865 ($P = 0.426$).

Discussion

Map transformation and accuracy

We demonstrate that a detailed and large-scaled digitised cadastral map can be transformed onto a modern coordinate system by means of a detailed field survey of the present landscape, with better precision than demanded for modern maps at similar scales. This means that the limiting factor for accuracy in this case is the ØK map, not the cadastral map. The accuracy is achieved by transforming the cadastral map to the present terrain and by access to evenly distributed common points in 1865 and 2002. Earlier transformations of historical maps, at scales similar to those of Norwegian cadastral maps, have been performed in different ways, but always under the assumption that the modern map is the ground truth (e.g. Pärtel et al. 1999; Cousins 2001; Vuorela et al. 2002; Domaas et al. 2003). Our results suggest that transforming directly to the present terrain is preferential to transformation to modern maps because the uncertainty in modern maps is avoided when past and present are connected. The general problem of finding enough common points on the historical and the modern map (e.g. Pärtel et al. 1999; Vuorela et al. 2002) was avoided in our study area, because of the great detail of the old cadastral map and the hilly landscape.

Our study confirms that appropriately digitised and transformed historical cadastral maps combined with a detailed field survey may be very useful in identifying old man-made structures. The resolution of a dataset defines the smallest feature that can be resolved or separated into its constituent parts (Clarke and Clark 1995). To separate different man-made structures in areas where they occur densely, increased accuracy is of crucial importance. It also enables an evaluation of whether or not parts of man-made structures have been altered (Domaas et al. 2003).

Our transformation method has one drawback: it is time-consuming. Even with a study area as small as 43 ha, the total field survey took about 200 working hours, in addition to the time-demanding process of digitising the old cadastral map. However, data from the field survey are useful not only for the transformation, but also for locating old man-made structures. For this purpose, the ØK map based on interpretation of aerial photographs provides insufficient information, because some of the existing structures are not mapped. In general, maps based upon aerial photography tend to contain less information on site-specific land properties than the older

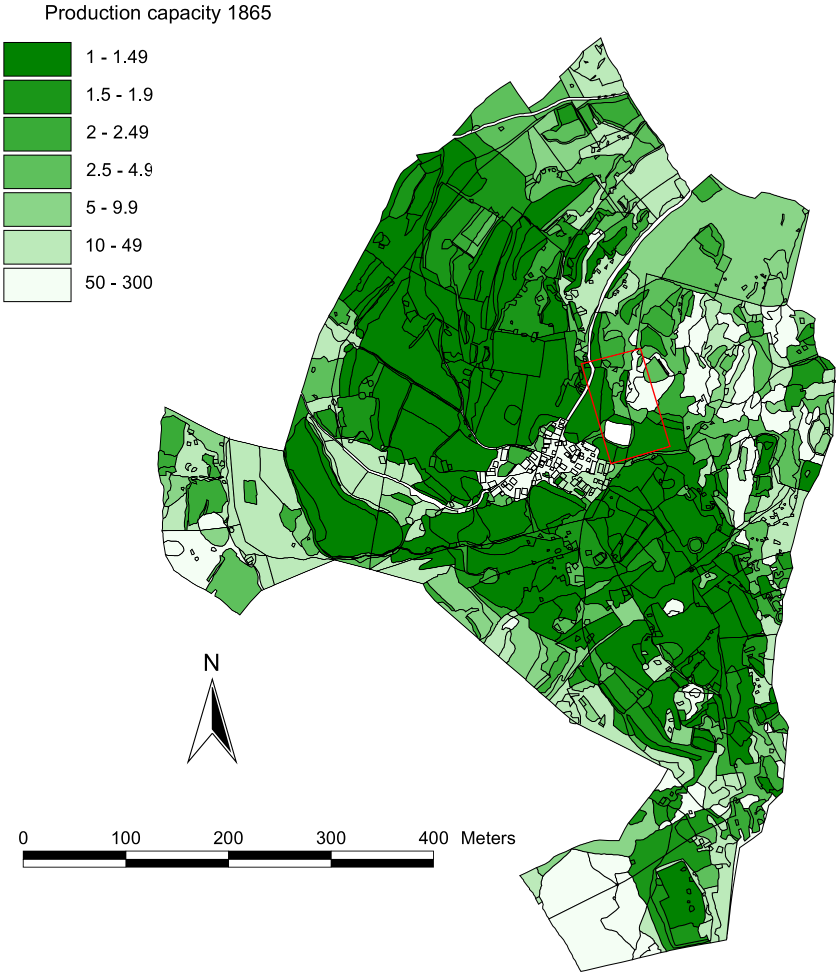

Fig. 5 Production capacity for the different patches at Ornes in 1865. The enlarged part in Fig. 2 is indicated on the map

generation of maps based on ground surveys (Vuorela et al. 2002).

Land-cover changes

The observed land-cover changes (reduction in number and an increase in average size of the landscape patches) following the general trend in Europe during the agricultural industrialisation. These changes have been triggered by a development of new agricultural technology that allows more effective farming over larger areas (Ruuska and Helenius 1996; Fjellstad and Dramstad 1999; van Eetvelde and Antrop 2004).

One of the most noticeable landscape changes at Ornes is the decrease in arable fields in areas with the highest production capacity, giving way to intensively managed grassland, orchards and horticultural production (raspberry). Similar changes are reported also from other parts of western Norway (Lundberg and Handegård 1996; Austad and Øye 2001) as well as in other European countries (Peppler-Lisbach 2003; Bender et al. 2005b). In more intensively managed agricultural areas arable fields are today used for fodder crops (Bakker 1989; Bender et al. 2005a), because of the tendency for husbandry to become an indoor activity (Bender et al. 2005a). The arable fields have gone through many changes since land consolidation, reflecting which agricultural production that gave the best economy for the farmer, be it grain, potatoes, vegetables, fruits or raspberry. Fruit growing started between 1940 and 1950, and raspberry production in the late 1960s. By 2002, a large proportion of 1865 arable fields and grasslands were abandoned. As shown also in other studies (Ihse

1995; Pärtel et al. 1999; Bender et al. 2005b), the fields that are most demanding to cultivate (wet, dry or distant from farm house) are the first to be abandoned. The localisation of abandoned areas to the outermost parts of the area does, however, also coincide patterns of natural productivity; production capacity tends to be lower in the fringes of the infields.

Another distinct pattern of land-cover change is that the area occupied by field boundaries and remnants is doubled from 1865 to 2002, even though the number of patches is greatly reduced. This is in contrast with the general trend reported from Europe (Ihse 1995; Benton et al. 2003; Luoto et al. 2003; Hietala-Koivu et al. 2004). The divergent pattern at Ornes is explained by an increase in width of field boundaries, resulting from the use of modern machinery unable to cut the grass close to for example dry-stone walls (Hamre and Austad 1999). The splitting up of the former clustered hamlet also contributed strongly to the altered landscape structure. Following the 1865 land consolidation the farmers moved their houses to their new land property, resulting in several farmyards today.

Semi-natural grasslands with long continuity

Our results show that the subgroup semi-natural grassland with continuity since 1865 represents a very small proportion (5.2%) of the present land use. Furthermore, most of these are abandoned or in danger of being abandoned, in accordance with the general trend in Europe (Myklestad and Sætersdal 2003; Dutiot et al. 2004; Poschlod et al. 2005).

Test results confirmed our hypothesis that semi-natural grasslands with continuity from 1865 are situated on areas with lower production capacity than the mean for all areas that were semi-natural grasslands in 1865. This shows that the judgement of production capacity performed in 1865 to a large extent is still valid in 2002, and supports the hypothesis that remnants of semi-natural grasslands tend to be situated on steep or shallow ground not suitable for modern machinery (Losvik 1988; Cousins 2001). Topographic and edaphic factors may also delay tree establishment in these sites, stabilising them as semi-natural grassland remnants (Bennie et al. 2006).

The only other study we are aware of that have used production capacity to explain land-cover change is that of Bender et al. (2005b), in which a general trend towards less intensive agricultural use of areas with low production capacity was only partly confirmed. Bender et al. (2005b) found that a large proportion of areas with average production capacity is maintained for arable use, while some areas, both with higher and lower production capacity, were converted to other land categories. On the other hand, Cousins (2001) found that all semi-natural grasslands left with a long continuity of management in an area in Sweden were situated on shallow soils unable to till; most likely with low production capacity. Our result indicates that the production capacity on cadastral maps may give important information about potential localisation of semi-natural grasslands with long continuity.

Man-made structures

Of the 121 man-made structures (dry-stone walls, terrace walls and clearance cairns) existing at Ornes in 2002, 58 were present also in 1865, but some of them have changed by enlargement or partial removal, seen by the detailed overlay analyses of the two maps.

Clearance cairns and other man-made structures have until recently been regarded as a result of meadow clearance in the 19th century or other modern activities, and not as traces of prehistoric agriculture (Pedersen 1990; Widgren 1997). At Ornes 63 man-made structures still present in 2002 originated after 1865, and can thus be considered 'modern'. Clearance cairns and terrace walls were built in the 1930s during a process of clearing of marginal areas encouraged by the Norwegian government (Almås 2002).

A lot of structures disappeared directly as a result of the land consolidation process, but many were probably lost due to farming intensification later on. Still, 58 of the man-made structures date back to pre-1865. These may represent a valuable source for archaeologists (Pedersen 1990; Austad and Øye 2001), although the very oldest man-made structures probably were situated close to the hamlet, and most likely have disappeared. Our hypothesis that man-made structures with continuity from 1865 occur on sites with lower production capacity than the mean for all the man-made structures in 1865 was confirmed, just as the hypothesis that they are situated in terrain steeper than the average. These findings indicate that the structures persist mainly because they have escaped intensification of agricultural use. As man-made structures often are important constituents of small biotopes, our results are in accordance with observations that small biotopes have had the greatest decline in metres and numbers in flat productive areas (Skånes 1990; Ihse 1995; Ruuska and Helenius 1996). At Ornes several of the removed structures are small clearance cairns in relatively flat areas that today are intensively managed meadows.

The hypothesis that the remaining man-made structures with continuity since 1865 are situated further from the hamlet than the mean was in 1865 was not confirmed, even though there is certainly a connection between abandonment and man-made structures, and abandoned areas in general are located in the outermost parts of the study area. One explanation for the non-significant result is that the hamlet in 1865 was split, and new farmyards were established. Thus, the distances from the new farmyards would have been more relevant to include in the analyses than the distance from hamlet. On the other hand, most farmyards are situated in the central parts of the study area. The non-significant result may therefore reflect the restricted opportunities for intensification in the study area.

As a conclusion; major changes have taken place in the Ornes landscape during the last 137 years. These changes have practically divided the landscape in two; cultivated grasslands, orchards and horticulture areas in the centre of the area, and semi-natural and abandoned areas situated more peripherally. Maintenance of historically important areas like Ornes with its stave church requires thorough knowledge of the landscape and its history. Information about the history of a landscape is important for understanding the present landscape, its development till today, and for proper management in the future.

Acknowledgements We acknowledge all the landowners who kindly permitted us to survey their land properties. Asle Lerum, Daniel Lerum, John A. Gladsø, Inger Auestad and Stein Joar Hegland are thanked for inestimable help with the field work. Inger Auestad and Rune H. Økland gave valuable comments on the manuscript. This work is funded by the Norwegian Ministry of Education and Research, project: Landscape changes in rural areas. We have also received financial support from the Norwegian Directorate for cultural heritage and Luster municipality.

References

Almås R (2002) Norges landbrukshistorie IV. 1920–2000, Frå bondesamfunn til bioindustri. Det norske samlaget, Oslo

Anonymous (1994) PC Arc/Info. Environmental Systems Research Institute (ESRI), Inc., Redlands, California

Anonymous (1996a) ArcView GIS 3.2. Environmental Systems Research Institute (ESRI), Inc., Redlands, California

Anonymous (1996b) ArcView Spatial Analyst. Environmental Systems Research Institute (ESRI), Inc., Redlands, California

Anonymous (1997) ArcView 3D Analyst. Environmental Systems Research Institute (ESRI), Inc., Redlands, California

Austad I, Øye I (2001) The traditional West Norwegian farm as a biological and cultural system. In: Skar B (ed) Cultural heritage and the environment. In Norwegian with english summaries. Signatur AS, Oslo, pp 135–205

Bakker JP (1989) Nature management by grazing and cutting. On the ecological significance of grazing and cutting regimes applied to restore former species-rich grassland communities in the Netherlands. Kluwer Academic Publishers, Dordrecht

Bastian O, Bernhardt A (1993) Anthropogenic landscape changes in central-Europe and the role of bioindication. Landsc Ecol 8:139–151

Bender O, Boehmer HJ, Jens D et al (2005a) Analysis of land-use change in a sector of Upper Franconia (Bavaria, Germany) since 1850 using land register records. Landsc Ecol 20:149–163

Bender O, Boehmer HJ, Jens D et al (2005b) Using GIS to analyse long-term cultural landscape change in southern Germany. Landsc Urban Plan 70:111–125

Bennie J, Hill MH, Baxter R et al (2006) Influence of slope and aspect on long-term vegetation change in British chalk grasslands. J Ecol 94:355–368

Benton TG, Vickery JA, Wilson JD (2003) Farmland biodiversity: is habitat heterogeneity the key. Trends Ecol Evol 18:182–188

Clarke DG, Clark DM (1995) Lineage. In: Guptill SC, Morrison JL (eds) Elements of spatial data quality. Elsevier Science, Oxford, pp 13–30

Cousins SAO (2001) Analysis of land-cover transitions based on 17th and 18th century cadastral maps and aerial photographs. Landsc Ecol 16:41–54

Daugstad K (2005) Agriculture's role as an upholder of cultural heritage. TemaNord 576:1–127

Domaas ST (2007) The reconstruction of past patterns of tilled fields from historical cadastral maps using GIS. Landsc Res 32:23–43

Domaas ST (2005) Structural analyses of features in cultural landscapes based on historical cadastral maps and GIS. Dissertation, Swedish University of Agricultural Sciences

Domaas ST, Austad I, Timberlid JA et al (2003) Historical cadastral maps as tool for valuation of today's landscape elements. In: Palang H, Fry G (eds) Landscape interfaces. Cultural heritage in changing landscapes. Kluwer Academic Publishers, Dodrecht, pp 221–236

Dutoit T, Buisson E, Roche P et al (2004) Land use history and botanical changes in the calcareous hillsides of Upper-Normandy (North-Western France): new implications for their conservation management. Biol Cons 115:1–19

Fjellstad WJ, Dramstad WE (1999) Patterns of change in two contrasting Norwegian agricultural landscapes. Landsc Urb Plan 45:177–191

Fry G, Sarlöv-Herlin I (1997) The ecological and amenity functions of woodland edges in the agricultural landscape: a basis for design and management. Landsc Urb Plan 37:45–55

Fry GLA, Skar B, Jerpåsen G et al (2004) Locating archaeological sites in the landscape: a hierarchical approach based on landscape indicators. Landsc Urb Plan 67:97–107

Haines-Young R, Barr CJ, Firbank LG et al (2003) Changing landscapes, habitats and vegetation diversity across Great Britain. J Environm Manage 67:267–281

Hietala-Koivu R, Järvenpää T, Helenius J (2004) Value of semi-natural areas as biodiversity indicators in agricultural landscapes. Agric Ecosyst Environ 101:9–19

Hietel E, Waldhardt R, Otte A (2004) Analysing land-cover changes in relation to environmental variables in Hesse, Germany. Landsc Ecol 19:473–489

Hamre LN, Austad I (1999) Field margin vegetation on farms in Sogn, western Norway. Aspects Appl Biol 54:337–344

Hodgson JG, Grime JP, Wilson PJ et al (2005) The impacts of agricultural change (1963–2003) on the grassland flora of Central England: processes and prospects. Basic Appl Ecol 6:107–118

Ihse M (1995) Swedish agricultural landscapes—patterns and changes during the last 50 years, studied by aerial photos. Landsc Urb Plan 31:21–37

Jongman RHG (2002) Homogenisation and fragmentation of the European landscape: ecological consequences and solutions. Landsc Urb Plan 58:211–221

Kain JPK, Baigent E (1992) The cadastral map in the service of the state. A history of property mapping. The university of Chicago press, Chicago

Kienast F (1993) Analysis of historic landscape patterns with a Geographic Information System—a methodological outline. Landsc Ecol 8:103–118

Kristensen SP (1999) Agricultural land use and landscape changes in Rostrup, Denmark: processes of intensification and extensification. Landsc Urb Planning 46:117–123

Kvamme M, Austad I, Hauge L et al (1999) Kulturmarkene i historisk og regionalt perspektiv. In: Norderhaug A, Austad I, Hauge L et al (eds) Skjøtselsboka for kulturlandskap og gamle norske kulturmarker. Valdres Trykkeri, Fagernes, pp 21–34

Legendre P, Legendre L (1998) Numerical ecology, ed 2. Elsevier, Amsterdam

Lia V (2005) Bruk og uttrykk gjennom tid i et jordbrukslandskap. Ornes i Luster. En arkeologisk landskapsanalyse med punktundersøkelser i innmark. University of Bergen, Hovedfagsoppgave

Losvik MH (1988) Phytosociology and ecology of old hay meadows in Hordaland, western Norway in relation to management. Vegetatio 78:157–187

Lundberg A, Handegaard T (1996) Changes in the spatial structure and function of coastal cultural landscapes. Geo Journal 39:167–178

Luoto M, Rekolainen S, Aakkula J et al (2003) Loss of plant species richness and habitat connectivity in grasslands associated with agricultural change in Finland. Ambio 32:447–452

Myklestad Å, Sætersdal M (2003) Effects of reforestation and intensified land use on vascular plant species richness in traditionally managed hay meadows. Anns Bot Fenn 40:423–441

Nitter C, Uchermann F (1865) Kart over indmark til gaardene Urnæs. Solvorns og Marifjærens Thinglag, Hafslo Præstegjeld, Sogns Fogderi, Nordre Bergenshus Amt. Riksarkivet, Oslo

Norderhaug A, Ihse M, Pedersen O (2000) Biotope patterns and abundance of meadow plant species in a Norwegian rural landscape. Landsc Ecol 15:201–218

Pedersen EA (1990) Rydningsrøysfelt og gravminner—spor av eldre bosetningsstruktur på Østlandet. Viking. Tidsskrift for Norrøn Arkeologi LIII:50–66

Peppler-Lisbach C (2003) Predictive modelling of historical and recent land-use patterns. Phytocoenologia 33:565–590

Poschlod P, Bakker JP, Kahmen S (2005) Changing land use and its impact on biodiversity. Basic Appl Ecol 6:93–98

Pärtel M, Mändla R, Zobel M (1999) Landscape history of a calcareous (alvar) grassland in Hanila, western Estonia, during the last three hundred years. Landsc Ecol 14:187–196

Ruuska R, Helenius J (1996) GIS analysis of change in an agricultural landscape in Central Finland. Agric Food Sci Finl 5:567–576

Skånes H (1990) Changes in the rural landscape and the impact on flora—a retrospective case-study using aerial photographs. Geogr Ann 72:129–134

Statens K (1999) SOSI. Samordnet opplegg for stedfestet informasjon. Et standardformat for digitale geodata, versjon 3.1. Hønefoss

Timberlid JA (1988) Driftsendringar i jordbruket som årsak til forsuring av norske vassdrag? Ein samanliknande studie av utmarksbruken på Vest- og Sørlandet i perioden 1850–1980. Økoforsk rapport 14:1–354

van Eetvelde V, Antrop M (2004) Analyzing structural and functional changes of traditional landscapes—two examples from Southern France. Landsc Urb Plan 67:79–95

Vuorela N, Alho P, Kalliola R (2002) Systematic assessment of maps as source information in landscape-change research. Landsc Res 27:141–166

Widgren M (1997) Fossila landskap. En forskningsöversikt over odlingslandskapets utvecling från yngre bronsålder till tidlig medeltid. Kulturgeografisk Seminarium 1.197, Stockholm