Abstract

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A landscape may appear to be ancient and to contain old man-made structures even if this is not the whole truth. Structures are moved, removed, replaced and added over the years. New users introduce new land use and management regimes. In Norway, information from land consolidation processes is crucially important in gaining a better understanding of the history, dynamics and development of farms, identifying older traces of human activity and selecting important areas for protection and management.

When cadastral maps are transformed, common points are needed during the transformation process and for testing the accuracy of the final transformation. It is often difficult to find enough common points to satisfy statistical requirements. Paper I presents a simple method using buffers based on linear features to evaluate whether or not the accuracy of the transformation results is better than the known accuracy of the source.

Papers II, III and IV show how digitised and geographically referenced historical cadastral maps can be used to reconstruct the situation at various dates back to the 19th century, and for some information back to the 16th century. The digitised cadastral map provides a snapshot of the situation at the time of the land consolidation process, and the information is considered to be very exact. Paper IV also demonstrates how a DEM (digital elevation model) can add significantly to an understanding of the information contained in the land consolidation material.

The use of digitised cadastral maps reveals that many man-made structures generally perceived as old, because they are constructed using traditional techniques, in fact date from after the land consolidation process.

One aim of the new European Landscape Convention is to promote landscape protection, management and planning. It therefore requires identification of landscapes and analysis of their characteristics and the forces and pressures transforming them. Using land consolidation material in a GIS makes it possible to document changes in a landscape and improve understanding of the pressures behind these changes.

Keywords: cadastral maps, GIS, transformation accuracy, cultural landscape, continuity, landscape planning, scale

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Appendix

Papers I-IV

The present thesis is based on the following papers, which will be referred to by their Roman numerals:

I. Domaas, S.T. & Ihse, M. A simple GIS–based method for transformation and evaluation of accuracy of historical cadastral maps on to a modern coordinate system. (Manuscript).
II. Domaas, S.T., Austad, I., Timberlid, J.A. & Norderhaug, A. 2003. Historical cadastral maps as a tool for valuation of today's landscape elements. In Palang, H. and Fry, G. (Eds.): Landscape Interfaces. Cultural Heritage in Changing Landscapes. *Landscape series, vol. 1.* Kluwer Academic Publishers, pp. 217-236.
III. Domaas, S.T., Hamre, L.N. & Austad, I. 2003. Historical cadastral maps as a tool for identifying key biotopes in the cultural landscape. In Tiezzi, E., Brebbia, C.A. & Usó, J.L. (Eds.): *Ecosystems and Sustainable Development IV, vol. 2.* Advances in Ecological Sciences 19, WIT Press, pp. 913-924.
IV. Domaas, S.T. The use of data from historical cadastral maps and 3D modelling to reconstruct past patterns of tilled fields. (Submitted manuscript).

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Introduction

In many cases, key elements of the evidence needed to understand the dynamics of the cultural landscape in the past have vanished from the modern agricultural landscape. This makes it difficult to interpret the landscape even if what we can see appears to be old (Domaas *et al.*, 2001; Paper II). The structures that can be found now are the sum of what has been constructed at different times minus any structures that have been removed.

Since a knowledge of the history of the landscape is important for an understanding of cultural landscapes as whole entities and of their importance in terms of both biology and cultural history (Ihse & Norderhaug, 1995; Norderhaug *et al.,* 1996; Austad *et al.,* 2001; Papers II and III), we need to find ways of overcoming the obstacles to understanding what it is we are really seeing.

In general, the people farming the land today cannot provide precise information from further back than the Second World War (one or two generations) on geographical changes on their holdings (Austad *et al.,* 2001; Domaas *et al.,* 2001). In some cases, there is photographic evidence, but only if the farm has been through a land consolidation process is it possible to obtain maps showing the situation at an earlier date. Since the full potential of historical land consolidation maps can only be realised if they are used in combination with the supplementary written information, geographical information systems (GIS) are needed to handle the huge volumes of information provided by such a map and its accompanying protocols. GIS-based methods can also be used to analyse historical data in combination with more recent data on landscape and land use, provided that ways can be found of overcoming some practical difficulties, such as how to make the information presented by historical cadastral maps available in digital form.

Several different methods can be used to digitise and code historical maps and to transform them on to modern coordinate systems. Depending on the methods used, different problems arise in assessing the correctness of the resulting digital map. So far metadata have been given in many different ways, or simply neglected (Tab. 1), and the scientific reliability of the results achieved in studies of this type is therefore open to query.

This thesis discusses various aspects of the problem complex related to metadata for digital historical cadastral maps, and indicates some ways of ensuring that the results produced by studies of this type can be considered reliable. The discussion here can also be used in a broader discussion of good practice in the use of digital historical cadastral maps. The thesis also explores ways of using the huge volumes of information provided by a historical cadastral map and its accompanying protocols, and looks at their potential in planning processes.

Information on past land use and management can often be the key to managing and protecting the present landscape in a way that maintains biodiversity and promotes sustainable development. Land use and management regimes have been changing throughout history, driven by a variety of social policy instruments including economic instruments and legislative changes. Thus, land use today may

Table 1. Information on the accuracy reached when transforming cadastral maps on to modern map systems. (PME-point mean error, RMS- root mean square error, SD- standard deviation).

Authors	Cadastral map	Modern map	Transformation method	Resolution	Transformation accuracy
Skånes 1996	1:4000 and 1:8000	1:10000	Tollin/manual	5 m and vector	expected PME < 4 m
Lundberg & Handegård 1996	1:2000	1:5000	?	?	?
Pärtel *et al.* 1999	1:5000 (1705)	1:10000	Warping - vector	10 m	23 m (RMS)
Cousins 2001	1:4000 (1688/90 and 1784/99)	1:10000	Warping	5 m	< 5 m
Austad *et al.* 2001 and Domaas *et al.* 2001	1:2000 (1874)	1:5000	Affine - vector	vector	< 2.0 m (PME-line), 4.0 (RMS)
Lundberg 2002	1:2000	1:5000	?	?	?
Vuorela *et al.* 2002	1:4000 (1690)	1:20000	Warping	?	28.1 – 26.2 m (RMS)
Vuorela *et al.* 2002	1:4000 (1846)	1:20000	Warping	?	6.9 – 6,5 m (RMS)
Vuorela *et al.* 2002	1:8000 (1892)	1:20000	Warping	?	4.8 – 3.8 (RMS)
Hjort Caspersen 2002, Fabech *et al.* 2002 and Grau Möller 2004	1:4000 (1770-1810)	1:25000	Warping	vector	10-20 m
Bender *et al.* 2005	1:5000 (1808-1853)	1:25000	? - vector	vector	?
Paper I.	1:2000 (1874, 1910)	1:5000	Affine - vector	vector	< 2.0 m (PME-line), 4.0 (RMS) and 2.5 (RMS)
Hamre *et al.* (pers. comm.)	1:2000 (1865)	+/- 10 cm	Affine - vector	vector	1.7 (SD)

be quite different from the situation earlier in history. This often makes it difficult to determine what it is we are seeing in the landscape.

To be able to study continuity of land use, management and ecosystems further back than the Second World War, it is necessary to extract the information available from historical material and modern maps and records, and use it sequentially. Even before computer-based systems became common, historical material and historical maps were therefore used in a number of geographical, historical and ecological studies to look at larger areas and whole farms (Berg, 1968; Frimanslund Holmsen, 1976; Hovland, 1981; Jones, 1982 and 1988; Sporrong, 1990; Sevatdal, 1991; Foster, 1992; Kienast, 1993; Borgegård, 1994; Riddersporre, 1995).

In 1991, Tollin introduced a method for the manual transfer of information from historical cadastral maps on to modern maps. This made it possible to georeference the most interesting information from a cadastral map and compare it with the corresponding modern map and the situation in the field.

Historical cadastral maps provide information on land use and different types of management practices. They also contain large amounts of information on structures, areas and elements in the agricultural landscape. The maps usually describe not only the distribution of agricultural fields, meadows and pastures, wetlands, heath and bare rock, but also point elements such as buildings and heaps of stones, and linear elements such as roads, footpaths, fences, streams and rivers. In Norway, historical cadastral maps are in most cases supplemented by written documents that describe every parcel of farmland in detail (land use, soil quality, production capacity, owner, user etc.). This written information makes the maps even more valuable for use in different types of landscape studies.

Thus, for farms where cadastral maps are available, it is possible to map land use and physical structures back to a date just before land consolidation, and thus learn more about the continuity and age of the landscape. Since the situation just before land consolidation is shown on the map and described in a protocol, the land consolidation map can in some cases also be used to indicate probable land use at an earlier date.

In the mid-1990s, several groups of scientists therefore started working on ways of making the information presented by historical cadastral maps digitally available. The first works presented were by Skånes and Lundberg & Handegård in 1996. From then on, many studies have been carried out to explore this type of information (Pärtel *et al.,* 1999; Ihse & Blom, 2000; Austad *et al.,* 2001; Cousins, 2001; Domaas *et al.,* 2001; Fabech *et al.,* 2002; Hjort Caspersen, 2002; Lundberg, 2002; Vuorela *et al.,* 2002; Papers II and III; Grau Möller, 2004; Bender *et al.,* 2005).

Several methods are used to digitise historical cadastral maps (manual transfer, manual digitisation, automatic tracing etc.). To make the maps available in modern coordinate systems they have to be transformed. Several methods are used (manual, warping and affine transformation) (Domaas, 2004). So far, no standards have been developed to evaluate the quality of this type of work. Metadata such as positional accuracy have therefore been given in many different ways (root mean square, RMS, standard deviation, SD, point mean error, PME, or intervals) or just neglected, and there is generally no evaluation of other quality aspects, such as completeness, correctness in coding and resolution. For modern digital maps, standards have been drawn up based on such criteria. The Norwegian standard is called SOSI (Statens Kartverk, 1999), and the international standard will be ISO 19100. If digitised and transformed historical cadastral maps do not conform to these standards, it can be questioned whether results based on such maps are scientifically reliable. The reliability of results based on comparisons of different studies using historical maps can therefore also be questioned.

Although some studies have looked more specifically at different methods for transformation of historical maps on to modern coordinate systems and the problems involved (Goodchild & Hunter, 1997; Jerpåsen *et al.* 1997; Pärtel *et al.,* 1999; Cousins, 2001; Vuorela *et al.,* 2002; Grau Möller, 2004; Bender *et al.,* 2005; Paper I), it is difficult to find a single solution to these diverse problems. This is because it is often difficult to find enough common information on the historical maps and modern maps or in the field to make comparisons that satisfy statistical requirements for valid results.

However, the information contained in this type of historical material is crucial to an understanding of the past and thus also to an understanding of present cultural landscapes. One solution is to supplement traditional ways of evaluating the accuracy of maps with new methods that provide acceptable documentation of digital maps based on historical material for the purposes of studies of this type.

Paper I discusses the use of buffers based on linear features for evaluation of accuracy. This also raises the question of which metadata elements are needed. Combining information on accuracy and an appropriate value for resolution should provide adequate documentation for the use of the maps and the information they contain in research of the type described here.

This thesis is derived from a pilot study and deals with how the information contained in historical cadastral maps and adjoining protocols can be used to produce a snapshot of the situation at specific times in history, which can be used in landscape studies and planning. The thesis is based on empirical studies as well as reviews and syntheses of previous work dealing with planning and management in cultural landscapes.

The first objective of the thesis was to develop new methods of using digital historical maps in various types of cultural landscape studies, and adapt existing methods to improve documentation standards for studies of this type.

The second objective was to explore some of the opportunities offered by the huge volumes of information contained in a digital historical map and its accompanying protocol, for example by analysing the persistence of man-made and biological structures in the cultural landscape (including identification of objects and biotopes on the basis of historical and modern data sources) and analysing the structure of the cultural landscape.

The third and final objective was to evaluate the potential of these types of analyses for planning purposes.

Paper I is theoretical and outlines a simple GIS method for transformation of historical cadastral maps on to a modern coordinate system and an additional method for evaluation of the accuracy of the transformation. Papers II, III and IV explore the information contained in a historical cadastral map and its protocol after it has been digitised and transformed on to a modern coordinate system for use as a tool in GIS-based structural analyses of features in cultural landscapes. Paper II explores land use changes and modifications to man-made elements that are generally perceived to be of ancient origin. Paper III looks into the use of historical information as a tool for understanding the underlying ecological situation and thus identifying key biotopes in today's cultural landscape. Paper IV explores the possibility of using the information from the cadastral map and the landscape (slope, aspect, distance from the hamlet and quaternary geology) to reconstruct the pattern of tilled fields back to 1500.

Material and methods

The area investigated

The farm under investigation, Grinde, has a long history of human activity and settlement, traced back to BC 2505 - 2415 (collection of twigs and leaves) and BC 1875 - 1680 respectively (Austad *et al.,* 2001; Øye, 2002). It is located on the slopes of the northern side of the Sognefjord in Leikanger municipality, Western Norway (61° 11’ N, 6° 45’ E) (Fig. 1), and is situated on a terrace 100 - 125 m above sea level.

Grinde was selected as the study area for the thesis because the farm was one of four model farms studied in the major research project “The traditional Western Norwegian farm as a biological and cultural system” (Norderhaug *et al.,* 1996; Austad *et al.*, 2001; Øye, 2002) and the only one of them that had been through land consolidation processes documented by written protocols and maps. This meant that data already collected could be used during the project. The disadvantage was that the farm was not chosen solely on the basis of its suitability for this kind of study.

Several criteria were used to find the farms for the research project on Western Norwegian farms. One of the most important was that the cultural landscape on the farms should have a complex structure. The project team therefore looked for farms where the landscape consisted of a mosaic of different kinds of land use, including a variety of semi-natural vegetation types and a large number of man-made structures. Another criterion was that much of the area should still be managed traditionally and that biodiversity was likely to be high. Historical information and reliable informants also had to be available, and farms with valuable historical buildings were preferred (Austad *et al.,* 2001).

The project included archaeological (Øye, 2002), historical (Domaas, 2002) and

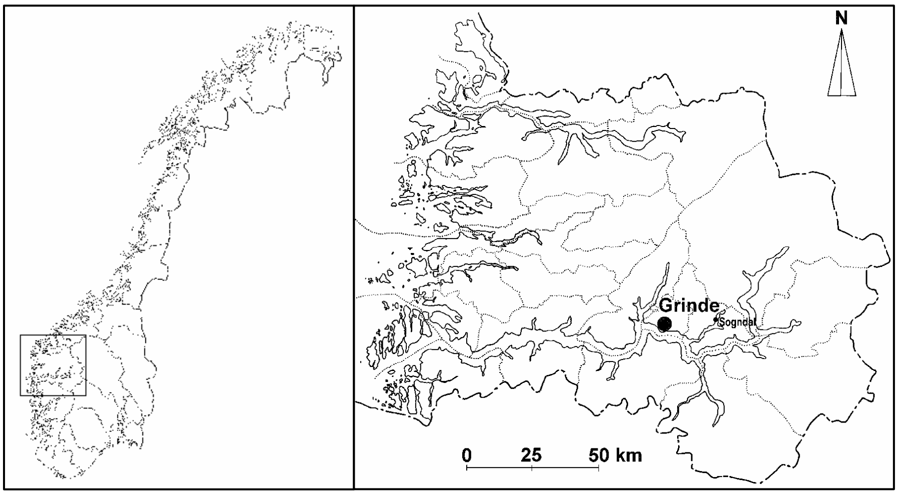


Fig. 1. Location of the study area Grinde in Sogn og Fjordane County, western Norway.

ethnological (Mjåtveit, 1993) investigations including collection of place names and studies of vegetation, ecology and land use at the chosen farms (Austad *et al.*, 2001). Aerial photos of the farms were also taken using infrared film, which is best for vegetation surveys. Earlier aerial photos were also traced and used in the research project.

To ensure that the project was truly interdisciplinary, the full potential of modern computer technology and GIS had to be utilised. In addition, careful coordination of data input was required to make full use of the broad disciplinary scope of the project and the spatial distribution and historical perspective of the different studies. For instance, all surveys (archaeology, vegetation, man-made structures, land use with time stamps, etc.) were organised so that they could be geographically presented as overlays on maps of each farm, and the coding systems used were the same for all the farms regardless of who did the surveys. Care was taken to ensure that it was possible to identify the data recorded with the situation in the field and on the maps. Interdisciplinary analysis and interpretation required data to be sorted and combined in a variety of ways. To make this possible, methods from different disciplines had to be adapted to each other without loss of information during the process. The digital material was edited and databases and maps were prepared so that records from the different disciplines could be entered and linked (Austad *et al.,* 2001).

The complexity of the work involved in the project did not cause problems for the type of studies described in this thesis. However, Grinde also proved to have a complicated history of ownership, including partial, infield land consolidation in 1869 by private agreement and two full infield land consolidations in 1872-76 and 1944-58. In addition, one holding was sold to eight other farmers in 1872. As a result, three new holdings were established, while the rest of the land was added to the existing holdings (Domaas, 2002). In 1875, during the land consolidation process, two of the new holdings were sold to four of the seven remaining farmers at Grinde as additional land. In 1896-98 there was a partial outfield land consolidation, and in 1960 a full outfield land consolidation.

It would probably have been an advantage for studies of this type to select a farm with a less complicated history. However, it proved to be possible to carry out the work by making extensive use of historical information and combining the information in the land consolidation protocols with comprehensive place-name information collected and processed during the research project on Western Norwegian farms.

Today there are 15 holdings and housing units on the farm, while there were 13 holdings and cotter's farms in 1874. The soil consists mostly of minerogenous material, such as moraine and glacio-fluvial deposits (Sønstegaard, pers. comm.). The mean annual precipitation is 979 mm (Førland, 1993), and the mean air temperature is 14.9 ^{o}C in July, and just below 0 ^{o}C in January (Aune, 1993a). The growing season starts during the second half of April and ends in the second half of October (Aune, 1993b). The farm is a typical fjord-hill farm with a vertical distribution of farmland areas and a small-scale structure. The infield areas stretch from sea level to 340 m above sea level. The two lowest-lying summer farms, for spring and autumn use, are situated 250 m above sea level 1.5 km up the

Grindsdalen valley, while a third is situated on the western mountain ridge at 425 m. Two more summer farms are situated at altitudes of 800 and 850 m. The land belonging to each holding is still scattered to some extent. The infield area of the farm has been fairly stable during this period, varying between 630 and 650 da (63 – 65 ha).

According to the survey of valuable cultural landscapes carried out by the Directorate for Nature Management (Hauge, 1992; Austad *et al.* 1993; Direktoratet for naturforvaltning, 1994), the cultural landscape of the farm is one of the most valuable and authentic in the county of Sogn og Fjordane.

The 1872-76 land consolidation at Grinde

In 1857, a new Land Consolidation Act was passed in Norway, further developing the system introduced in the 1822 Act. Before this, strip-farming had been practised on many farms, especially in Western Norway, where it was a result of long-standing agricultural practices. Strip-farming began at quite an early date to ensure that land, particularly areas suitable for grain production, was fairly partitioned between all those entitled to a share of the farmland (both tenants and owners) (Frimanslund Holmsen, 1976; Sevatdal, 1991). Rules for allocating strips of land may be found in the old Norwegian regional laws that were later collected in King Magnus the Lawmender's national code of 1274, and later in the 1687 Norwegian Law Code (Norsk Lov). The 1857 Land Consolidation Act made radical changes to the earlier system. It brought about extensive reorganisation of agricultural areas, partly because land consolidation procedures were now required even if only one of the farmers involved requested this (Frimanslund Holmsen, 1976). Before this all the farmers involved had to agree before land consolidation procedures could be started. These changes were introduced because the central government considered the old system of strip farming to be an obstacle to more efficient, modern farming techniques.

The 1857 Land Consolidation Act was the first law to require land surveys and the production of maps and written protocols. The cadastral maps that resulted provide information on land use and different types of management. The written protocols make the maps even more informative. At Grinde, a land consolidation process took place in the period 1872 – 76, and resulted in a map and written protocols (Sviggum, 1874; Jordskiftedommaren, 1875).

The land consolidation process:

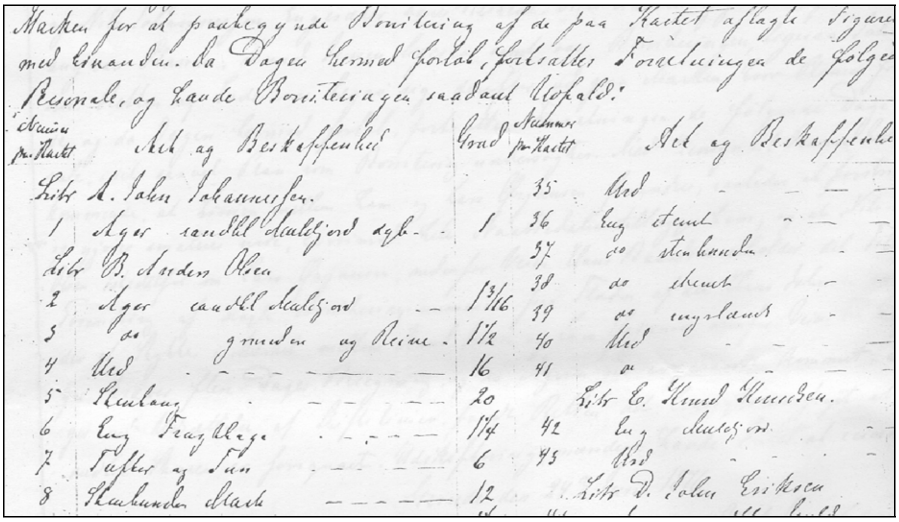
10 December 1872: Three of the farmers request land consolidation
3 April 1873: First session of the land consolidation court at Grinde
29 September 1874: Land consolidation map and written protocol recording parcels of land, production capacity and ownership are completed
12 June 1875: Preliminary land consolidation plan put forward for consideration
19 September 1875: Agreement on changes in land ownership and boundaries
30 September 1875: Agreement on buildings and roads to be moved
Autumn 1875: Appeal lodged
20 June 1876: Reassessment of land consolidation
19 September 1876: Final agreement on land consolidation and boundaries

There may be several reasons why it was these three farmers who decided to request land consolidation. In 1872, they were all around 40 years old, married and had heirs. Two were cousins (their fathers were brothers), and all three had the same great-great-grandfather. They had all bought additional land when the opportunity arose. The first time was in 1853, when the owner of holding 9 had to sell part of his land because he was unable to service his loan. In 1872, the owner of holdings 12 and 13 sold all his land in a number of smaller parcels. In the 1875 census, one of the three farmers was recorded as the owner of holdings 9c, 10, 11, 12 and 13, the second as the owner of holdings 7, 9b, 12 and 13b, and the third as the owner of holdings 8, 12 and 13e. This meant that they owned three of the four largest holdings on the farm. The remaining holdings were owned by farmers who were not close relatives and by members of another family who had not bought extra land in this way. Thus, the three farmers had gradually acquired more and more scattered parcels of land, making their land more difficult to run. It therefore seems likely that it was these three farmers who had most to gain from land consolidation.

Professor Ingvild Austad at the University College of Sogn og Fjordane, who was in charge of the research project on Western Norwegian farms, had previously tried to make use of the information provided by the land consolidation map and the written protocol to answer some simple questions: for example, where were the parcels of land the widow of a cotter was allowed to use, and how good was the soil quality? Even such straightforward questions turned out to be difficult to answer. Nevertheless, Professor Austad realised that this land consolidation material would be extremely valuable if the information it contained could be made available. To investigate the full potential of this material and try to make practical use of it, it was necessary to develop methods of making the information available digitally, which had not previously been done. The map used was the historical cadastral map dating from 1874 (Sviggum, 1874) (Fig. 2), when the fieldwork for the land consolidation process was carried out. The supplementary written protocol (Jordskiftedommaren, 1875) gives information about 1440 separate infield areas on the farm, including ownership, land use, soil description and production capacity (Fig. 3). Production capacity (in Norwegian: bonitet) was used to classify parcels of land according to how much they could produce, to ensure that when a farmer lost a particular area during land consolidation, he was granted land in compensation that would theoretically give an equivalent amount of agricultural production.

At Grinde, production capacity was divided into 44 steps on a scale from 1 to 200. Areas with a production capacity of 1 were the most valuable since they gave the best yield. An area of land with a production capacity of 2 would produce only half as much as an equal-sized area with a production capacity of 1. The most valuable areas (tilled fields and high-quality hay meadows) were very finely divided, so that 12 steps were used between 1 and 2 (Paper II). On the other hand, only 6 steps were used between 50 and 200 (50, 60, 70, 80, 100 and 200). The formula used to find the theoretical value of an area makes this system clearer. To

Fig. 2. The 1874 cadastral map of the farm Grinde in Leikanger municipality including the holding investigated in detail, Eineberg (Sviggum, 1874).


Marken for at paalæggende Bonitering af de paa Kartet aflagte Figurer med Hinanden. Da Dagen hermed forløb, fortsattes Forretningen de følgende Resonale, og lande Boniteringen saadant Udfald:

Numer pr. Kartet	Art og Beskaffenhed	Grad	Nummer pr. Kartet	Art og Beskaffenhed
Litr	A. Johan Johannessen.		35	Ured
1	Ager sandblandet Muldjord dyb	1	36	Eng ditto
Litr	B. Anders Olsen		37	do stenblandet
2	Ager sandblandet Muldjord	1 3/16	38	do ditto
3	do grunden og Reine	1 1/2	39	do myrlandt
4	Ured	16	40	Ured
5	Stenlang	20	41	do
			Litr	E. Knud Knudsen.
6	Eng Fragtbakke	1 1/4	42	Eng Muldjord
7	Tufter og Tun	6	43	Ured
8	Stenblandet Mark	12	Litr	D. Johan Eriksen

Fig. 3. The written protocol gives information about 1440 separate infield areas at the farm, including ownership, land use, soil description and production capacity (Jordskiftedommaren, 1875).

find the value (V) of an area (A), the area was divided by the production capacity (PC):

$$A * \frac{1}{PC} = V$$

The cadastral map covers an area of 630 da, where there were eight holdings and three cotter's farms in 1874. One more farmer and two cotters farmed land in this area, but lived outside it. The buildings belonging to most of the holdings (seven) were situated in a small hamlet in the centre of the area (Fig. 2). One of the holdings, Eineberg, and the three cotter's farms were located outside and to the north of the hamlet in 1874 (Domaas, 2002). The holding Eineberg was selected for detailed studies because there were more man-made structures, traces of former tilled fields and pollarded trees on this holding than on the other holdings.

The property boundaries shown on the map indicate the situation in September 1874 before land consolidation and in September 1876 after land consolidation. The interim situation after two of the farmers sold land to four others and emigrated to America is not shown on the map. Some of the 1874 property boundaries were only two years old, since one holding had been sold (in eight parts) in 1872. Three of these became new holdings, and the remaining five were added to existing holdings. The results of the private agreement on land consolidation in 1869 are not shown on the map either. To reconstruct earlier property boundaries, it was therefore necessary to use court registers and place-name material from the research project on Western Norwegian farms.

Land use as registered in 1874 may mask fairly recent changes. The new owners of the smaller holdings may have started to use their land more intensively and converted meadow to tilled fields. On the other hand, the farmers who bought additional land may have converted marginal tilled fields to meadow. It also seems that the widow at Eineberg, who emigrated to America shortly afterwards, had chosen to reduce the area of tilled fields on her holding. To gain an overview of developments of this kind, it is necessary to use information from traditional historical sources and compare this with the land consolidation material.

Digital representation of the information

Two types of analogue maps were used in this study, the historical cadastral map from 1874 mentioned earlier and two adjoining modern economic map sheets. The historical map is a large-scale (1:2000) map with its own local coordinate system, based on a ground survey. The modern maps are economic map sheets on a smaller scale (1:5000). They were produced in the 1960s, and are the first economic map series covering Sogn og Fjordane, based on signalised aerial photographs. The coordinate system used is NGO1948. To make it possible to describe and compare the landscape at different points in time after land consolidation, it was necessary to carry out a detailed land survey. For the holding Grinde – Eineberg, a survey was completed in 1995 with an accuracy of +/- 10 cm (pers. comm. Asle Lerum).

Both the historical cadastral map and the two modern economic maps were digitised manually. The software PCArcInfo for Windows (ESRI, 1994a and b) was used for digitising and processing, and ArcView (ESRI 1996,a and b; ESRI, 1997) was used for displaying and analysing map files. In order to retain the detailed information on point, line and area features, the map objects were digitised in vector format and coded.

In step 1 of coding the features from the cadastral map, the digitised points and lines were coded continuously, but during interpretation of the map various problems were encountered. Some map symbols were only included as a background or a visual effect, but nevertheless looked like real map elements. This was particularly true of the symbol used for single boulders. Fieldwork was needed to distinguish better between visual cartographic effects and real geographical elements. In the case of lines, it was discovered that a single line on the map could represent several different elements or functions on the ground at the same time. Since we did not know either how many different types of linear elements there were on the map or in how many ways they were combined, we simply assigned each new type or combination a numerical code, increasing the value of the code by ten each time, during the digitising process. A separate table was made corresponding to the description in plain text. Increasing the numerical code by ten each time made it possible to give new, closely related elements neighbouring numbers (e.g. road: 40, planned road: 41). The table was later structured so that the main linear function was in one column with a unique heading, and new columns with unique headings were added whenever a line representing several elements or functions was found. In all, 18 unique codes were used for this process. In the GIS, the table could then be linked to the linear coverage in a "one-to-many" relationship.

Next, the linear historical land consolidation map, with its local, individual coordinate system was transformed on to the coordinate system NGO1948, which was used for the other maps. Fourteen points were found on the land consolidation map that could with certainty be identified on the economic maps. The transformation was carried out in PCArcInfo using affine transformation as described in Paper I (Fig. 4a). Affine transformation scales, rotates and translates all coordinates in the coverage using the same equation.

In step 2 of coding, each polygon in the digitised land consolidation map was automatically given a unique identification number and listed in a table. Elements such as stones, stone walls and buildings, which are not described in the written protocol, were coded at this stage and included in the table. The owner after land consolidation was also listed in this table. A further column was added for the numbers used for parcels of land in the written protocol, which corresponded to many of the polygons.

In step 3 the information from the protocol had to be structured in a table before it could be used in the GIS. A spreadsheet, and not a database, was chosen for storage of the information since it was impossible to foresee all the combinations of information in the protocol. Using a spreadsheet made it possible to add new columns when new types of information turned up without disturbing the data already present. Next, the information from the protocol was linked to the polygon coverage by first using the unique polygon value in the first table (a "one-to-one" relationship) and secondly using the protocol value as identification when linking the protocol table to the first table in a "one-to-many" relationship.

During the land survey, all point and linear elements were coded directly in the field, in the same way as described in step 1 of coding for digitisation of the land consolidation map. This coverage was later manually cleaned and closed polygons were constructed (Fig. 4b). The polygons were then coded manually based on the corresponding point and linear codes.

Fig. 4. Vectorised cadastral map (a), land survey (b) and vectorised economic map (c) presenting the holding Eineberg at Grinde.

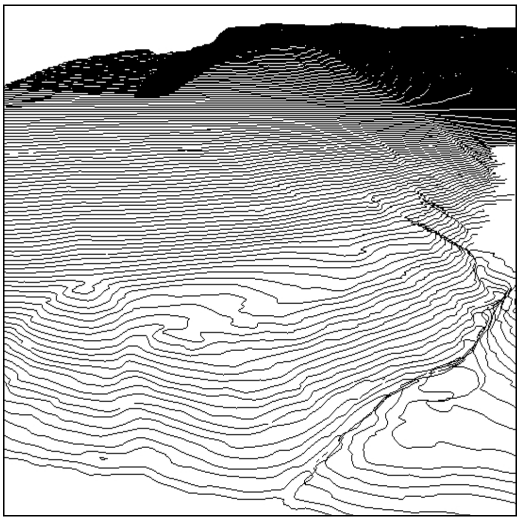


Fig. 5. A digital elevation model (DEM) of Grinde based on the 5 m contour lines from the economic maps.

The elements of the economic maps (Fig. 4c) were also coded directly when they were digitised using the SOSI standard as a basis (Statens Kartverk, 1999). A digital elevation model (DEM) was later constructed based on the contours (height interval 5 m) from the economic map sheets (Fig. 5) (Paper IV).

The digitisation and transformation process automatically gave the area of each polygon in m^2 and the length of linear features in m. Now the different map layers could be explored separately (Fig. 4) or by using overlay analyses. For the studies of changes over time, a Union of different map layers was performed.

For the analyses of tilled fields in Paper IV, raster map layers (1 by 1 m) were constructed based on information from the DEM and the digital land consolidation map.

To establish land use on the holding Eineberg during the Second World War (1940 - 1945) and in the period 1960 - 1965, the current situation (1995), and when man-made structures were removed or new ones made, we had to interview the current owner, Lars Grinde. A new map was constructed by performing a Union of the land survey, the digital economic map sheet and the land consolidation map. The resulting map was presented to the owner, and his information was added. The map was then used to identify changes in land use and man-made structures on the holding at different points in time (Paper II).

A vegetation survey was carried out on the farm using aerial photos, economic map sheets and field observations. All open meadow areas were identified and drawn on modern economic map sheets. The classification system of Fremstad (1997) was used to identify meadow types. The different types were defined by the presence and frequency of the “characteristic” and “common” species given for each group in this classification system. The results of the vegetation survey were digitised and linked to selected information from the digital cadastral map and the protocol (Paper III).

Results

The use of GIS made it possible to study the holdings in detail at different times, for instance the distribution and patterns of different types of farmland and parcels of land, the area of tilled fields compared with that of hay meadows, and how poor soils and high quality soils were distributed on the different properties (Fig. 6, Tab. 2) (Austad *et al.,* 2001; Domaas *et al.,* 2001). The landscape representation could then be compared with other important historical information to give a more precise understanding of the situation for each individual holding, and changes over time could be studied.

Even though the cultural landscape of the farm today includes many old stone constructions and substantial areas of traditional types of cultivated fields, so that it appears to be similar to the landscape in an earlier period of history, dramatic changes have in fact taken place during the last few hundred years.

By comparing the place names found in records of property transactions with the place-name material from the project, and combining this information with the digital land consolidation map in an overlay analysis, it was possible to find out which parcels of land were bought and sold in each transaction. The situation at different dates could then be reconstructed to show the increasingly complex ownership pattern suggested by the traditional material (Fig. 7). It was also possible to see and calculate the number of parcels of land belonging to each

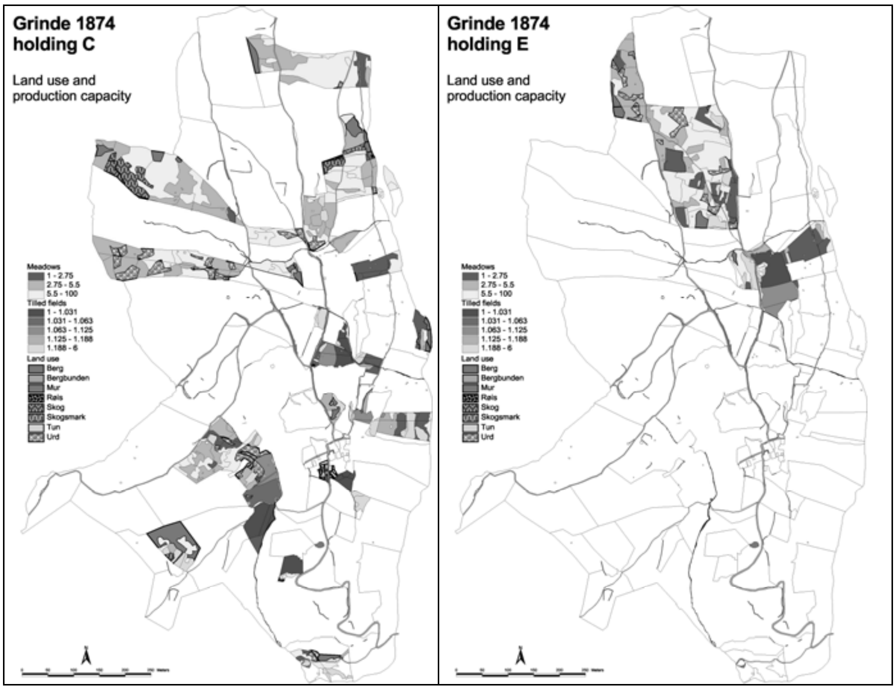


Fig 6. Detailed information on the distribution of production capacity of tilled fields and hay meadows at two holdings, C and E (Eineberg), at Grinde before land consolidation.

Table 2. Information from the digitised map on the first seven entities in the written protocol as they are displayed in the GIS.

Id 1874	Area	Perimeter	Tst 1874j_	Areal-type	Areal-type2	Art og beskaffenhed	Areal-bruk	Areal-bruk 2	Areal-kvalitet	Beskaffenhet	Grad	Brukar	E1876	E1875	Eigar	E1872	E1854	F1	Ager	Verdi	Areal eng og dyrkbar mark	Verdi eng og dyrkbar mark	Areal impedement	Kalk-verdi
1	1307,765	159,1845	1895			Ager og Reine; sandblandet Muldjord	Ager	Reine		sandblandet Muldjord	1	A	A	A	A	A	T	T	1,9	1,9				1307,77
1	111,5519	93,21246	1921		Planl. vei	Ager og Reine; sandblandet Muldjord	Ager	Reine		sandblandet Muldjord	1	A	B	A	A	A	T	T	1,9	1,9				111,55
1	460,2391	98,42263	1925			Ager og Reine; sandblandet Muldjord	Ager	Reine		sandblandet Muldjord	1	A	B	A	A	A	T	T	1,9	1,9				460,24
1	4,913574	11,54608	2021		Reine	Ager og Reine; sandblandet Muldjord	Ager	Reine		sandblandet Muldjord	1	A	B	A	A	A	T	T	1,9	1,9				4,91
1	5,257324	9,699369	2023		Reine	Ager og Reine; sandblandet Muldjord	Ager	Reine		sandblandet Muldjord	1	A	B	A	A	A	T	T	1,9	1,9				5,26
1	12,75854	32,90354	2026		Reine	Ager og Reine; sandblandet Muldjord	Ager	Reine		sandblandet Muldjord	1	A	A	A	A	A	T	T	1,9	1,9				12,76
1	12,70856	17,20693	2081		Reine	Ager og Reine; sandblandet Muldjord	Ager	Reine		sandblandet Muldjord	1	A	A	A	A	A	T	T	1,9	1,9				12,71
2	104,5502	53,37540	2041			Ager; sandblandet Muldjord	Ager			sandblandet Muldjord	1	A	B	A	A	A	A	A	0,91	0,91				104,55
2	779,0903	142,4260	2082			Ager; sandblandet Muldjord	Ager			sandblandet Muldjord	1	A	D	A	A	A	A	A	0,91	0,91				779,09
3	20,81628	20,24352	2054			Ager; grund	Ager		grund		2,25	A	B	A	A	A	A	A	0,04	0,0178				9,25
3	37,41229	31,97838	2071			Ager; grund	Ager		grund		2,25	A	D	A	A	A	A	A	0,04	0,0178				16,63
4	29,82379	21,77682	2074			Eng; stenbunden	Eng		sten-bunden		6	A	D	A	A	A	A	A			0,03	0,005		4,97
4	3,722656	13,90693	2075			Eng; stenbunden	Eng		sten-bunden		6	A	B	A	A	A	A	A			0,03	0,005		0,62
5	21,71008	28,48845	2086			Ager; sandblandet Muldjord; dels grund	Ager		dels grund	sandblandet Muld	1,375	A	B	A	A	A	A	A	0,67	0,4873				15,79
5	630,0991	134,6660	2096			Ager; sandblandet Muldjord; dels grund	Ager		dels grund	sandblandet Muld	1,375	A	D	A	A	A	A	A	0,67	0,4873				458,25
6	1591,584	168,6975	2112			Ager; sandblandet Muldjord; dels grund	Ager		dels grund	sandblandet Muld	1	A	A	A	A	A	A	E	1,6	1,6				1591,58
7	140,7103	82,11545	2176			Ager; grund	Ager		grund		2,5	A	A	A	A	A	A	E	0,13	0,052				56,28
7	152,1309	49,85730	2203	9000		Ager; grund	Ager		grund		2,5	A	A	A	A	A	A	E	0,13	0,052				60,85

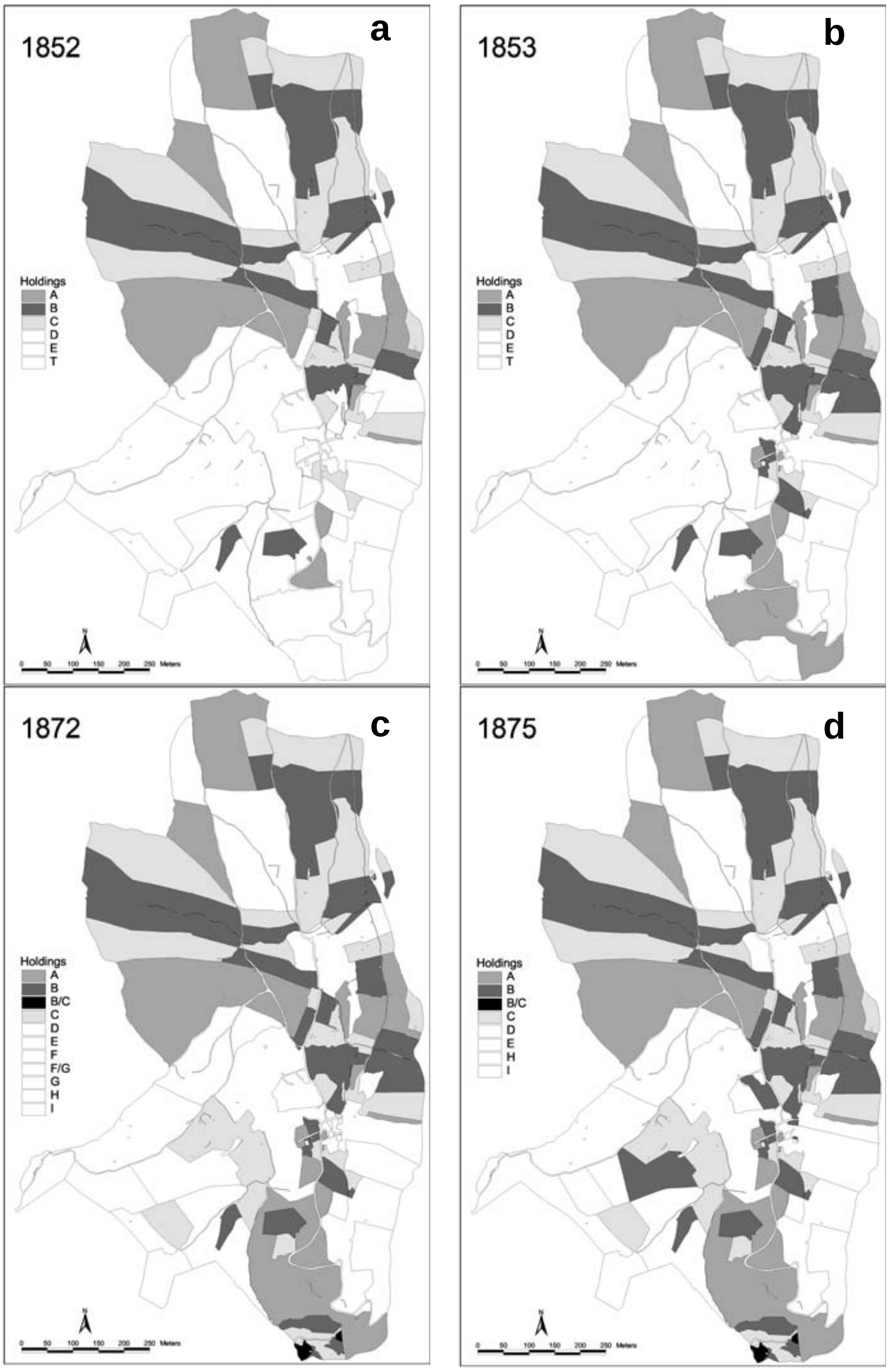


Fig. 7. Parcels of land belonging to the three farmers who requested land consolidation in 1872, at four different dates. 1852 shows the reconstructed situation before the first property transaction (a). 1853 shows the reconstructed situation after the 1853 transaction. (b). 1872 shows the situation after the 1872 property transaction, as shown on the land consolidation map (c). 1875 shows the reconstructed situation after the 1875 transaction (d).

Fig. 8. Parcels of land belonging to the three farmers who requested land consolidation in 1872, as shown on the land consolidation map after the land consolidation process was completed.

holding at different times (Tab. 3) and how the size of the holdings changed over time (Tab. 4). For example, purchases of extra land increased the size of holding B from 14 parcels of land in 1852 to 26 in 1875. After land consolidation, the holding consisted of only four continuous parcels of land (Fig 8).

Traditional historical material provides indirect information on changes in the area of tilled fields, and thus on changes in the relative importance of different types of land use in the infield area, but gives almost no information on the geographical location of these areas. It is logical to assume that as the area of tilled land increased, there was a corresponding increase in labour input. If the information is plotted on a 3-D model, it can be seen that as the area of tilled fields increased, the new areas were further and further away from the farm buildings and on steeper and poorer soils (Fig. 9, Fig 10) (Paper IV). Thus, the increase in labour input in the new areas must have been correspondingly greater. In order to increase production, more and more labour per unit area was needed.

Table 3. Number of parcels of land per holding at different dates, for the three holdings where the farmers requested land consolidation in 1872.

	1852	**1853**	**1872**	**1875**	**1876**
A	10	15	17	17	3
B	14	20	23	26	3
C	20	20	27	27	4

Table 4. Areas of holdings in decares at different dates, for the three holdings where the farmers requested land consolidation in 1872.

da	**1852**	**1853**	**1872**	**1875**	**1876**
A	93.2	118.5	127.8	127.8	134.2
B	84.6	103.5	107.5	120.1	119.4
C	95.4	95.4	125.9	125.9	130.4

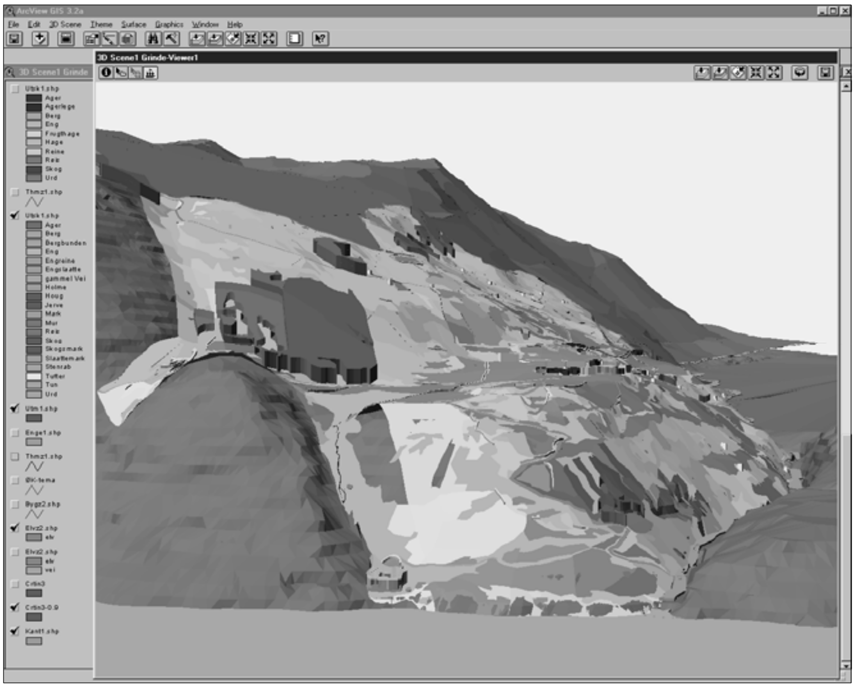


Fig. 9. The digital land consolidation map of Grinde draped over the DEM. View from the south east.

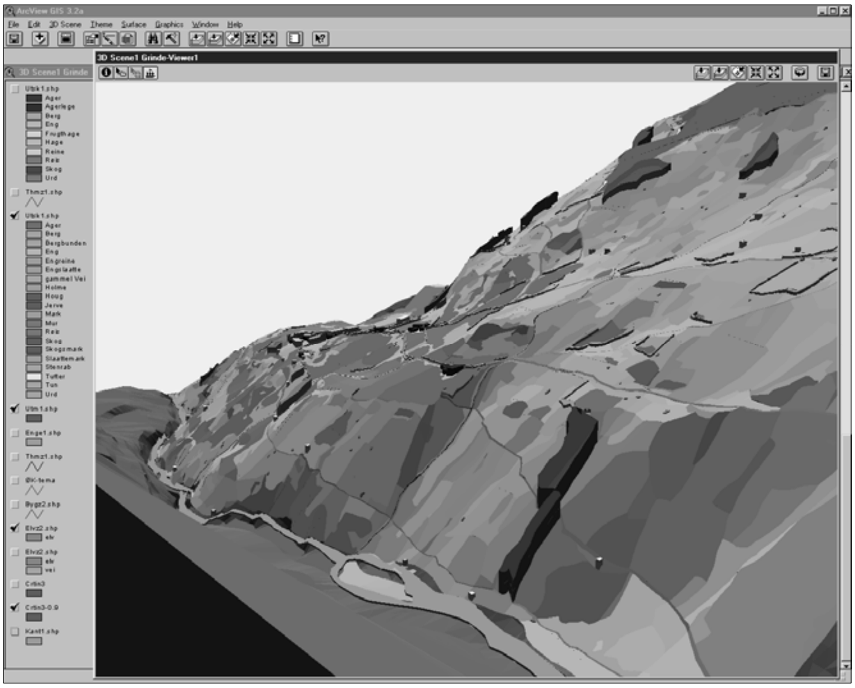


Fig 10. The digital land consolidation map of Grinde draped over the DEM. View from the north east.

Summary of papers

Paper I

Historical cadastral maps provide information on land use and different types of management. They also contain large amounts of information on structures, areas and elements in the agricultural landscape.

The varying geometry and local coordinate systems of historical cadastral maps make it difficult to use them in modern geographical information systems, since they have to be transformed on to a modern coordinate system first. Before this can be done, a sufficient number of common points have to be found that can with certainty be identified either on a modern map or in the field. It has proved to be very difficult to find enough common points both for the transformation and for testing the transformation to satisfy modern standards of accuracy. It was therefore necessary to develop a method of transformation and another method for testing the accuracy of the transformation in a way that was satisfactory for use in landscape studies.

This paper describes a simple GIS-based method for transformation of Norwegian historical cadastral maps drawn on different individual and local coordinate systems on to any modern coordinate system. In this case, NGO1948, which is used for Norwegian economic maps (1:5000), was used as an example. The paper also includes a new, rapid method of assessing transformation accuracy of this type of geographical linear data using a buffer with a pre-defined width, so that the accuracy standard was the same as that applied by the Norwegian Mapping Authority for the map used as a reference source.

The historical maps used were large-scale (1:2000) cadastral maps constructed for land consolidation purposes. Two maps were used, one of the farm Grinde from 1874 and one of the neighbouring farm Engeseter from 1910. All the historical cadastral and modern economic maps were digitised. In order to retain the detailed information on point, line and area features, the map objects were digitised in vector format. The digitised points and lines were coded and grouped according to clearly-defined principles, as a single line on a map may represent several different elements or functions on the ground at the same time.

In geometric transformation from one coordinate system to another a minimum of four common fixed points, tics, must be identified on both maps. If there are non-systematic errors, a larger number of fixed points must be used, and they should be evenly distributed over the mapped area. Several of the common points that were identified initially were found to be misplaced and could not be used in the final transformation.

The transformation accuracy proved to be better than 2 m, the same as the standard set by the Norwegian Mapping Authority for economic maps. Even though this method does not use the complex tools needed to assess the accuracy of complex linear features properly, the results indicate that it is a good supplement to traditional point accuracy. If used as a supplement to point error evaluation, this method can further operationalise the use of historical cadastral maps in landscape studies.

The digitised and transformed 1874 cadastral map of Grinde was used as a basis for the rest of the studies described in this thesis and in other parts of the research project “The traditional West Norwegian farm as a biological and cultural system” (Austad *et al.,* 2001).

Paper II

Using GIS, an old cadastral map from 1874 and its supplementary written protocol were prepared for interpretation of the continuity and age of areas, boundaries and various man-made structures on the holding Eineberg at Grinde. A Union was performed of the digitised and transformed cadastral map and a detailed land survey of the holding. Detailed information from the farmer on land use back to the Second World War was also incorporated into this coverage as two time stamps (1940-45 and 1960-65).

The results revealed that the location of infield areas has varied, even though the size of the holding has been almost constant for the last hundred years. Only 47 % of the infield area in 1995 was identical to the infield area in 1874. Of the 1453 m of fencing that existed in 1995, only 117 m coincided with the boundaries of the holding in 1874, even though the land belonging to this holding was already more or less continuous before land consolidation. However, the results also confirm that natural boundaries and boundaries coinciding with roads, paths and ditches show long continuity. In addition, semi-natural vegetation types such as herb-rich hay meadows and wooded hay meadows on stony ground and on steep terrain proved to have a long history of continuous management with the same vegetation type. This was in contrast to the cultivated fields and fertile meadows, which have undergone considerable changes during the 20th century. The proportion of the area in use changed very little from 1874 (85 %) until 1960 (83 %). But from then on drastic changes have taken place, and in 1995 only 50 % of the area was in use. The results also show that a surprisingly small number of the man-made structures in the cultural landscape today are identical to those indicated on the 1874 cadastral map. In 1874 there were 39 man-made structures on this part of the infields. In 1995 there were 28. But only 13 of these can be traced back to 1874, and five of these contain only small parts of 1874 structures. This means that 26 man-made structures that existed in 1874 have been removed, and a further five have been partly removed. On the other hand, some structures have been enlarged, so that what were several clearly separate structures in 1874 appear to be one structure in 1995.

The conclusion is that even though the present cultural landscape of the holding includes many old stone constructions and traditional types of cultivated fields, and thus appears similar to the landscape in an earlier period of history, dramatic changes have in fact taken place during these 121 years.

Paper III

GIS was used to refine information in an old cadastral map from 1874 and its supplementary written protocol to identify areas of meadow presumed to be species-rich. To do this, information on hay meadows of low production capacity (≥ 2 ¾) and meadows with stony soil was extracted from the cadastral map.

A Union was performed of the digital cadastral map and a vegetation survey carried out in 2002. Five different types of meadows were identified in the study area. *Agrostis capillaries-Festuca rubra-Anthoxanthum odoratum* grassland (type I) and *Deschampsia cespitosa* grassland (type II) were the types that were of most interest for this study.

The material was used to investigate how far areas identified from the 1874 map using four different search criteria (combinations of low production capacity and stony soil) coincided with the five meadow types existing today. The search criteria were production capacity ≥ 2 ¾, stony soil, production capacity ≥ 2 ¾ and/or stony soil, and production capacity ≥ 2 ¾ and stony soil.. The results reveal that 85 % of the biologically most interesting hay meadows found in the area today coincide with areas identified as presumably interesting from the 1874 cadastral map using search criterion 3 (low production capacity and/or stony soil).

To find out which search criteria identified the largest proportion of the interesting areas and at the same time minimised the area it was necessary to study in the field, an efficiency coefficient (e) was calculated as follows: e = [proportion of the area of a particular vegetation type (x) identified using the search criterion : total area of this type (y)] : [total area of hay meadows found by this criterion (z) : total area of hay meadows found in the vegetation survey (t))].

$$e = [(x) : (y)] : [(z) : (t)]$$

The efficiency coefficient for search criterion 3 (low production capacity and/or stony soil) was 1.55, while it was 1.78 for criterion 4 (both low production capacity and stony soil). In other words, the largest area of interesting meadow can be identified with least effort in the field by using criterion 4. This finding could provide a useful tool, especially for exploring large areas of land.

Information from the cadastral map and the protocol also made it possible to combine historical information for all the small parcels of land identified on the cadastral map belonging to each of the five meadow types found today. Historical profiles were constructed for each of the five types showing land use, the amount of stone in the soil and production capacity. Most of the area identified as type I or II today was used as hay meadow in 1874 (83 %). These areas also included a substantial proportion of scree. A relatively large proportion of the area identified as type III, IV or V was used as tilled fields in 1874: 33%, 26% and 63%, respectively. Type V is clearly different from the rest, since most of the current meadow area was tilled fields in 1874.

As expected, the results show clear relationships between production capacity value, the amount of stone in the soil and land use in 1874. What is more surprising is that the historical information on land use, production capacity and the amount of stone in the soil taken from the 1874 cadastral map appears to explain the meadow types existing today to such a large degree, and can help to confirm classification at this level. Thus, this seems to be a good tool for differentiating between meadow types and explaining some of the vegetation variation found on the farm today.

Paper IV

This study presents a methodology for reconstructing former tilled field patterns reasonably accurately using GIS to link information from historical cadastral maps, historical sources and a digital elevation model (DEM). Using established factors for the area in decares that could be sown using one barrel of grain, it is possible to calculate the area of tilled fields on a farm or holding at different times in history back to 1600. However, very few historical sources mention anything about the geographical location of tilled fields (although some information from valuation for tax purposes, perambulations, etc, is available from court registers and registers of mortgages). Historical cadastral maps and protocols from the mid-19th century contain detailed information about land use and production capacity at the time of land consolidation, and they are the first source to reveal the geographical location of the tilled fields directly.

In this study, information on the location of the tilled fields and their soil quality was combined with data on four landscape elements: slope, aspect, distance from the hamlet and quaternary geology.

No definite information was available about the historical location of tilled fields, except for the year 1874. It was therefore assumed that at any time, the farmer used the land that gave the best yield for least effort. This meant that as the need to expand the tilled fields arose, the farmer would have had to use less and less favourable land. By starting with the total area of tilled land on the land consolidation map and removing the area corresponding to one step of the production capacity scale at a time, starting with the poorest areas, until the remaining area was close to the area in one of the years chosen for the study, it was possible to construct a series of map layers (themes) in the GIS showing the geographical positions of these areas.

The best soil was found to be on the relatively flat area near the hamlet. This is also believed to be where the oldest tilled fields were located. As time went on, the farmers needed to cultivate larger areas, and the fields were extended to steeper areas and further away from the hamlet. There was only one major discrepancy in this pattern. Most of the areas in the best production capacity class are also in landscape value class 1 (most favourable) for the different landscape elements. However, in the case of slope, the proportion of tilled fields is higher where the ground is not too flat (landscape value class 2). Thus, the areas that the farmers themselves considered to be best for growing crops in 1874 were those with a gentle slope (not too flat), that faced south-west, were close to the hamlet and were on glacio-fluvial deposits or a thick layer of moraine.

Thus, it can be concluded that for areas where a land consolidation map and a protocol giving production capacity values are available, these can be used directly to indicate the probable pattern of tilled fields at the time. If this information is not available, data from economic map sheets can be used to construct a DEM and make GIS-based calculations of slope, folded aspect and distance from the hamlet.

Furthermore, information on these landscape elements can be used to indicate where the tilled fields are likely to have been on farms where there are no land consolidation maps to show the location of former tilled fields. If the quaternary geology of the area is used in addition, the precision of the results appears to be improved.

Traditional historical material tells us something about the increase in the area of tilled fields, but nothing about their geographical location. It is logical to assume that as the area of tilled land increased, there was a corresponding increase in labour input. According to this study, as the area of tilled land increased, new areas taken into use were further and further from the hamlet, and on steeper and poorer soils. Thus, the increase in labour input in the new areas must have been correspondingly greater. In order to increase production, more and more labour per unit area was needed. This understanding is relevant to discussions of the causes underlying the changes in pre-industrial agricultural societies that ultimately resulted in modernisation.

Discussion

The following issues are considered in the discussion:

- the quality and positional accuracy of maps
- evaluating of the results of transformation of cadastral maps
- resolution, or the minimum width of an object or minimum distance between two objects that makes it possible to separate them on a map
- changes in property areas and boundaries
- the age of man-made elements
- can the information contained in land consolidation material be used as a tool for understanding the underlying ecological situation today?
- can the information contained in land consolidation material be used to explore land use and the geographical location of tilled fields and property areas before land consolidation?
- can a DEM (digital elevation model) add significantly to an understanding of the information contained in land consolidation material?
- can the information contained in land consolidation material be used to improve our understanding of the factors that have determined how the cultural landscape has been used for agricultural purposes?

The first part of the discussion concerns the theoretical framework for digitisation of historical information and assessment of its accuracy.

Map quality is measured by assessing the discrepancy between two data sets, the test data and the reference source. Positional accuracy has been almost the only focus of attention as regards paper maps. In the case of digital maps, other aspects must also be considered, such as the accuracy of the original based on the scale and method of digitisation, when the map was made and when it was last updated, its completeness, and the correctness of the coding.

Positional accuracy can be divided into absolute positional accuracy and relative positional accuracy. Vauglin (1998) recommends assessing planimetric and altimetric accuracy using the same parameters, and presenting them separately. So far, various different methods have been used in work on cadastral maps and GIS to achieve a degree of absolute planimetric positional accuracy. The absolute planimetric accuracy of a geographical feature is given by the distance between the location of the feature and its position on the nominal ground. This accuracy has been expressed in various ways: as point mean error (PME), root mean square (RMS), standard deviation (SD) or as intervals (Tab. 1).

The assessment and representation of the positional uncertainty of linear features is a complex process that requires complex tools (Tveite & Langaas, 1999). Parameters for polylines and surfaces are based on an epsilon band (Vauglin, 1998). Epsilon is often interpreted as the minimum buffer width around a reference object that contains all of the tested object, or vice versa (Goodchild & Hunter, 1997). However, the epsilon band technique is not appropriate for all types of linear and area data. It is best applied to data for linear features in the database that have an unambiguous real-world meaning. Examples are roads, hydrological features and property boundaries. Many natural or interpreted features, including boundaries between soil types, vegetation communities and land cover types, are abstract features without precise real-world locations. For these features, it may be more appropriate to assess thematic accuracy (Veregin & Hargitai, 1995).

When cadastral maps are transformed by warping, common points are needed for use during the warping process, and also for testing the accuracy of the final transformation. It is often difficult to find enough common points to obtain a valid statistical result (Vuorela *et al.,* 2002). Affine transformation gives RMS accuracy directly, and also gives X and Y errors for all points used for the transformation, so that a PME or SD can be calculated. Even so, it is difficult to find enough common points to satisfy the statistical requirements (Paper I). Other, supplementary methods are therefore needed to evaluate the results of transformation of cadastral maps so that the information contained in cadastral maps and their written protocols can be utilised in various types of landscape studies.

Goodchild & Hunter (1997) describe an alternative method for assessing the accuracy of linear elements given a source of known, higher accuracy. The method they propose requires the availability of a reference source containing a complete representation of the feature. Based on the reference source, buffers are produced by monotonically increasing the width around an element. The proportion of each element to be tested that is inside the buffer is calculated for each buffer width. The method gives the buffer width of the elements tested for any chosen confidence interval, often 90 or 95 %. This can be used as a measure of the accuracy of the elements tested.

However, when working with the large-scale land consolidation maps and economic map sheets, it is not possible to be sure that the accuracy of the source is higher, and it is doubtful whether it is possible to obtain a complete representation of the features used for testing the transformation.

Paper I therefore presents a simple method using buffers based on linear features to evaluate whether or not the accuracy of the transformation results is better than the known accuracy of the source.

Even though this method does not use the complex tools needed to assess the exact accuracy of complex linear features properly, the results of the tests described in Paper I indicate that it is a good supplement to traditional point accuracy evaluation, and it seems to satisfy the needs for non-legal studies of this type. The use of this method as a supplement to point error evaluation can further operationalise the use of historical cadastral maps in landscape studies.

The different approaches taken to describing positional accuracy make it difficult to compare the results of studies based on cadastral maps. It would therefore be useful to agree on a standard way of describing positional accuracy. Drummond (1995) discusses several ways of describing positional accuracy in a GIS and concludes that standard deviation is most appropriate.

Resolution, or rather a failure to specify it, also makes it difficult to compare the results of different studies (Tab. 1). The resolution of a data set defines the smallest feature that can be resolved or separated into its constituent parts (Clarke & Clark, 1995) and it can also be described as a geometric threshold such as minimum area or minimum width (Morrison, 1995).

If the data sets used are rasters, the resolution will be the size of the raster cell, but it is nevertheless possible to use a resolution that is finer than is justified by the quality of the original material (Statens Kartverk, 1999). If the data sets are vectors there is no way of determining the appropriate resolution, or the minimum area or width that can sensibly be used in calculations, without thorough testing.

A possible operational solution to these issues is to use the accuracy term SD. The minimum width of an object that can be distinguished and the minimum distance between two objects that can be separated can then be defined as the SD, while the minimum area (A_{min}) can be defined as:

$$A_{min} = SD^2 \quad \text{for square areas or}$$
$$A_{min} = \Pi * (SD/2)^2 \quad \text{for circular areas}$$

This should give a probability of more than 68 % that part of a feature will be inside its digital representation. In cases where there is only one object of a kind for quite a distance, and the digital representation of it on the cadastral map is 3*SD or even more distant from its representation based on the modern map sheet or survey, it will still be justifiable to consider these to be representations of the same object. According to the Norwegian Mapping Authority's standard, it is acceptable for up to 5 % of the elements to be drawn more than 3*SD away from their real location (Statens Kartverk, 1999; Paper I).

The problems related to metadata in work that involves digitising and georeferencing historical maps were discussed at a workshop held by the Danish HisKIS network ("historical-cartographic information systems") (Domaas, 2004).

The participants doubted whether detailed accuracy standards such as those described above are the way to go at present. Instead, it was suggested that it would be better to start developing a guide to good practice in this research field.

Provided that the theoretical considerations described above are kept in mind, the use of GIS allows for exciting advances in landscape studies and a number of other fields. A landscape may appear to be ancient and to contain old man-made structures even if this is not the whole truth. Changes in property areas and boundaries are relatively infrequent and are often difficult to trace geographically, and changes in land use and management change the appearance of the landscape. The appearance of the landscape today is the result of all changes that have taken place over the years (Widgren, 1998). Structures have been moved, removed, replaced and added. New users often introduce new land use and management regimes.

In Norway, the information provided by a land consolidation process is of crucial importance in obtaining a better understanding of the history, dynamics and development of a farm and identifying older traces of human activity back to the 16th century and which areas it is most important to protect and manage suitably. If this is not available, the oldest situation that it is possible to reconstruct geographically without archaeological excavation will depend on which informants are available. They are usually the farmer and his family, and it is therefore becoming increasingly difficult to obtain information about land use and management before the Second World War. Property areas and boundaries can be traced back to the result of the latest land consolidation process, but not usually any further back. This means that it is only the "modern" information in the landscape that is readily available without data from a land consolidation process.

Papers II and III show how the use of digitised and geographically referenced historical cadastral maps makes it possible to reconstruct the situation in the second half of the 19th century. The digitised cadastral map provides a snapshot of the situation when the land consolidation process took place. The information collected was used to ensure that each owner's property was equal in value before and after land reallocation, and not for military or taxation purposes. Cadastral material is therefore considered to be very exact and a good historical source (Domaas, 2002).

The use of digitised and geographically referenced historical cadastral maps in this study has revealed that many man-made structures generally believed to be old in fact date from after the land reallocation process. Because the techniques used to build the structures are old, the structures have been presumed to be old as well. There are also significant numbers of old structures left in the area, but it would be difficult to distinguish them without the information from the land consolidation process.

It may be possible to understand more by comparing property boundaries at different dates with the location of man-made structures. There are indications that some man-made structures tend to grow up on the boundaries between properties. This can perhaps be used to date structures tentatively as "younger than" a date between that of the cadastral map and the 16th century.

Thus, archaeologists might also find land reallocation material useful when deciding where to focus their investigations. They would be able to choose old structures more easily, which would increase the likelihood of obtaining interesting results. Sampling would also be more cost effective since newer structures could be eliminated in the process of choosing sampling areas.

The possibility of using information from the cadastral maps as a tool for understanding the underlying ecological situation and thus for identifying key meadow biotopes in today's cultural landscape has also been explored. Five markedly different types of meadows were identified in 2002, and historical profiles were constructed for each type. These show that earlier land use appears to have had a strong influence on more recent use. Without the use of the information contained in the digitised historical cadastral map and its written protocol, it would not have been possible to demonstrate such a strong influence over such a long period of time.

Using the information from a geographically referenced historical cadastral map, it also proved possible to construct snapshots of the situation at various dates back to the 16^{th} century (Paper IV). The same paper also demonstrates how a DEM (digital elevation model) can add significantly to an understanding of the information contained in the material from the land consolidation process. Thus, the areas that the farmers themselves considered to be best for growing crops in 1874 were those with a gentle slope (not too flat), that faced south-west, were close to the hamlet and were on glacio-fluvial deposits or a thick layer of moraine.

Water supplies, aspect, good drainage and proximity to the hamlet appear to have been important factors in determining how the cultural landscape was used for agricultural purposes from the 16^{th} century until the mid-19^{th} century. The oldest traces of agricultural activity in the archaeological material from Grinde are from the terrace south-west of the current position of the hamlet (Øye, 2002), indicating that these factors may in fact have had an influence for a very long time (back to BC 1875-1680). By using the archaeological information in a GIS and comparing the locations and dates with information from a DEM, see paper IV, it would be possible to test how much each factor influenced the location and expansion of tilled areas even before 1500.

Thus, land consolidation material can also help to bridge the gap between archaeological information and traditional historical information by opening up opportunities to date man-made structures and changes in the use of the agricultural landscape that are too recent for C14-dating to be of practical use.

The findings described in these papers are also relevant to discussions of the causes underlying the changes in Western Norway's pre-industrial agricultural society that ultimately resulted in modernisation.

The issues presented here by no means exhaust the potential of this material. There are many other questions of interest; for instance, much more reliable data could be extracted on the location and quality of land held by the cotters. The actual areas of tilled fields could be compared with the production information declared in land registers and censuses, making it possible to evaluate the extent to which crops and livestock were underreported. The farm structure and its history also deserve further investigation. Preliminary analyses suggest that the origins of the mosaic-like structure can be traced back further than the 16th century, the earliest date for which any estimates have been made in this study. It is possible that the patterns that can be traced in the material reflect the situation when the property was first divided up in Viking times or even earlier. The potential offered by use of a DEM (digital elevation model) is also greater than it was possible to demonstrate in the work for this thesis. It might be of interest to make an overall analysis of production capacity against slope, aspect etc, and to continue the analyses described in Paper III using other ecological parameters that can be calculated using a DEM.

Land use and management regimes have been changing throughout history, driven by changes in the population and a variety of social policy instruments including economic instruments and legislative changes. To gain a better understanding of the impacts of particular elements on the landscape, it is possible to construct models in which one assumption at a time is changed. These can then be tested separately and against each other. This approach can provide better insight into the dynamics of landscape change.

Digitisation of the cadastral material for Grinde took one person three months. The supplementary written protocol (Jordskiftedommaren, 1875) gives information about 1440 separate infield areas on the farm. This means that the land consolidation process at Grinde was a relatively extensive procedure for this part of the country, and it would probably take less time to repeat the digitisation process for other farms where land consolidation material is available. It was also noticeable that the process speeded up with experience. Nevertheless, the time required to process the material, and the labour costs involved, will probably be the greatest barrier to more general use of this type of material.

Implications for planning and future perspectives

Today, it is generally agreed that information from historical cadastral material is of interest for many planning and management purposes. Several authors have proposed the use of historical cadastral material (Fladby & Andressen, 1981; Jerpåsen *et al.,* 1997; Framstad & Lid, 1998; Jordbruksverket, 1998; Fremstad & Moen, 2001; Skar, 2001). This indicates that there is an unfulfilled potential for the use of this type of material.

At a detailed level, such information may be valuable for farmers in meeting various requirements laid down by the public authorities, such as drawing up environmental plans for their holdings and producing additional information when applying for grants, as explained below.

In Norway, any farmer who applies for an agricultural production grant is required by law to draw up an environmental plan for the holding. The plan must include a map of the agricultural areas belonging to the holding, and of any other areas belonging to it that are relevant to or influenced by agricultural operations. Elements of the cultural heritage, areas that are important for biodiversity, areas where there is a risk of erosion or loss of nutrients, and any other factors of environmental importance must also be mapped and described (Landbruksdepartementet, 2003). Examples of surveys that could be used in drawing up environmental plans are described in England Bergum & Austad (2003) and Røysum *et al.* (2003).

Grants are also available for environmental projects in agricultural areas. Farmers who wish to apply for such grants must have environmental plans that meet additional requirements (Landbruksdepartementet, 2004). The information available from land consolidation material is most likely to be useful in connection with the sections of such plans that deal with projects to maintain biodiversity and traditional farmland, projects to increase biodiversity, and projects related to the management, maintenance and restoration of the cultural heritage and cultural environments. Farmers can improve their chances of receiving grants from the limited funding available for these purposes by documenting the value of their holdings as well as possible.

Management plans are also drawn up for valuable areas such as national parks, nature reserves and protected landscapes. Knowledge of how such areas have been used earlier in history is of key importance in drawing up appropriate management plans (Norderhaug *et al.,* 1999).

The Norwegian Planning and Building Act can also be used to protect valuable features of the cultural landscape in less formal ways. Areas where the cultural environment is particularly valuable can be indicated on maps and other appropriate planning documents drawn up by municipalities. Although this will not provide binding legal protection, it will spread information on valuable areas and help to increase people's awareness of them. If guidelines for administrative procedures or goals for such areas are specified in addition, this will have an influence on their management (Heiberg, 1999).

In recent years, there has been a growing understanding of the interactions between culture and nature in the agricultural landscape. One result has been a shift in the priorities of the administrative authorities.

Norway's counties are required to draw up strategic plans for the agricultural sector, but are allowed to choose whether to focus on pollution or on the cultural landscape. Sogn og Fjordane has chosen to focus on the cultural landscape. A new survey of biodiversity associated with the agricultural landscape is also to be made at national level. The Directorate for Cultural Heritage is to focus more on the protection and management of entire cultural environments to maintain their value. Information from historical cadastral material has much to offer in all these fields.

This type of detailed information is also of interest for the educational system and nature- and culture-based tourism. In addition, it may help to strengthen the local population's sense of identity.

The European Landscape Convention entered into force on 1 March 2004. One of its aims is to promote landscape protection, management and planning. It defines a landscape as an area whose character is the result of the action and interaction of natural and/or human factors.

Article 6C.1.a requires each of the parties to identify its own landscapes and to analyse their characteristics and the forces and pressures transforming them. The type of knowledge discussed in this thesis is perhaps most relevant in relation to this provision of the Convention. By using land consolidation material in a GIS, it is possible to document changes in the landscape and improve understanding of the pressures behind the changes, as the Convention requires.

Conclusions

Norwegian historical cadastral maps are very accurate and can therefore be transformed on to modern coordinate systems quite easily and at an acceptable level of accuracy. If a map is digitised in vector format so that every line and polygon feature can be given a unique identity, it is possible to link the written information in the protocols to the map. Once this has been done, a wide range of comparisons can be made both with modern georeferenced registrations and with features of the landscape itself (slope, aspect etc.) Combining this information with traditional written historical records and archaeological material makes it possible to develop methods of visualising historical developments in geographical terms and comparing the results with landscape information (slope, aspect, quaternary geology, distance between features etc.)

Digitised and transformed Norwegian historical cadastral maps are very useful for identifying old man-made structures and the history of biotopes in the cultural landscape. Without this material, it can often be impossible to distinguish between old man-made structures and newer structures built using old techniques. Linking information from a written protocol with the corresponding cadastral map makes it possible to study how soil quality was evaluated at the time of land consolidation and compare this with current knowledge. The digitised land consolidation material can also be used to analyse changes in land use and thereby changes in biotopes. The results of such analyses can then be used to gain a deeper understanding of the history of the most interesting biotopes.

Without the information from historical cadastral maps and written protocols, it is becoming increasingly difficult to obtain information about land use before the Second World War. It is also difficult to identify property boundaries before land consolidation. Using historical cadastral maps and information on the situation today and within living memory, it is possible to analyse the changes that have taken place. Combining information from the cadastral map, other written historical sources, archaeological material and the information in a DEM makes it possible to reconstruct land use and property boundaries back in time with a high degree of certainty.

Thus, using digitised land consolidation maps makes it possible to gain a better understanding of the history of an area. Elements of the cultural heritage and cultural environments can be evaluated much more thoroughly than if only information from today's users and the modern landscape is available. The more valuable an area is considered to be, the more important it is to use studies of this kind to provide a better basis for planning.

On a smaller scale, information from land consolidation material is of direct practical use for farmers in drawing up the environmental plans they are required to develop for their holdings. Documentation of this kind will also increase a farmer's chances of being awarded funding through grant schemes.

Further studies should be carried out on other farms where similar material is available. There may be regional differences that are reflected in historical cadastral material, and this should be kept in mind when new study areas are selected.

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