Hedgerow planting activities by Danish farmers: a case study from central Jutland

Søren Pilgaard Kristensen

Abstract

This paper examines the dynamics of hedgerow planting and removal in a study area with marginal agricultural potential in central Jutland. The study is based on a questionnaire survey with farmers in two parishes supplemented by aerial photo interpretation. The first section examine changes in hedgerow network parameters between 1972 and 1995. The length of the hedgerow network declined by 9% during this period. The connectivity of the hedgerow network was very low in both years, indicating that options for species dispersal along hedgerows was poor. The second section analyses the net effect of planting activities between 1987 and 1997 and the motives behind them. Full-time farmers were the most active farm group concerning the proportion of farmers planting hedgerows. Hobby farmers planted more hedgerows than other farm groups. Most hedgerows have been planted in the parish with the greater agricultural potential and lesser need for shelter against wind erosion. This surprising result indicates that subvention had a strong impact on planting activities. Motives related to agricultural production were the dominant reasons for hedgerow activities. More hedgerows were planted than removed between 1987 and 1997, leading to a net increase in the length of the hedgerow network in the study area.

Keywords

green corridors, hedgerow network, landscape changes, landscape connectivity, landscape ecology

Søren Pilgaard Kristensen, Institute of Geography, University of Copenhagen, DK-1350 Copenhagen K., Denmark.
e-mail: sk@geogr.ku.dk

Geografisk Tidsskrift, Danish Journal of Geography 101: 101-114

Hedgerows fulfil a variety of functions in agricultural landscapes. These include production-oriented functions, such as providing shelter against wind erosion, improvement of micro-climate on fields, provision of habitats and corridors for wildlife and plants, but also socio-economic functions, such as demarcation of property boundaries and contribution to the amenity value of the farm (Kuhlmann, 1976; Andreassen, Fauske & Steinset, 1995; Burel, 1996; Hammershøj & Madsen, 1998). The latter function appears to be gaining importance, as many rural residents today are involved in farming on a part-time basis and the motivation for hedgerow planting is no longer as closely related to optimizing crop growth conditions as before (Christensen & Primdahl, 1999). This trend is reflected in the increase in hedgerow planting in Eastern Denmark, an area which is not as exposed to wind erosion as the traditional shelterbelt landscape in central and western Jutland (Højring & Caspersen, 1999). While traditional motives for hedgerow planting were closely linked with production motives, the present situation, with its more diverse motives influencing hedgerow planting, makes it difficult to monitor and predict future hedgerow activities (hedgerow planting and removal). Consequently, little knowledge exists regarding the driving forces behind current hedgerow activities and the spatial consequences of hedgerow planting and removal.

The purpose of this paper is to analyse trends in hedgerow network dynamics and to investigate how they relate to biophysical factors or socio-economic farm characteristics. In order to do so, the paper is divided in two sections. Firstly, changes in hedgerow network parameters in a heterogeneous agricultural landscape between 1972 and 1995 are analysed through a GIS analysis. The ecological effects of these changes are assessed through an investigation of changes in hedgerow connectivity in the study area between 1972 and 1995. This analysis will yield valuable information on changes in the habitat and dispersal qualities of the hedgerow network during this period. Secondly, a questionnaire survey with farmers in the study area investigates hedgerow activities in relation to farm type and subsidy use, as well as the range of motives that influence farmers' hedgerow activities. It is envisaged that this information will provide insight into the dynamics of hedgerow activities, thereby providing important information to physical planners and nature conservation interests at the local and regional level.

Historic background for hedgerow planting in Denmark

Widespread soil erosion caused by the windy Danish climate gave rise to the planting of hedgerows on farmland already in the 19th century and from 1880 the process became state-subsidised (Knudsen, 1983). Planting activities intensified in 1938, when a national unemployment scheme took up hedgerow planting to create shelter belts on farm land. During the 25 year period from 1938 to 1963 when the program ended, 43.350 km. of hedgerows were planted as shelterbelts, mainly composed of coniferous species (white spruce) on sandy soils in Jutland. A major reason for the success of the programme was the fact that the state reimbursed the planting costs and 50% of the costs of the plants.

Hedgerow planting in Denmark remains a popular and strongly subsidised activity, with an annual budget of 3-5 million Euros. The current subsidy scheme for hedgerow planting on agricultural land covers 50-65% of the farmers' costs and has had a positive effect on the proliferation of a new type of hedgerow composed of deciduous species since its inception in 1977 (Pedersen, 1996). Most of these funds are used by Danish farmers, who plant 800 km of new hedgerows annually (Jørgensen, 1993). As a result, hedgerow planting constitutes an important landscape management activity on agricultural properties.

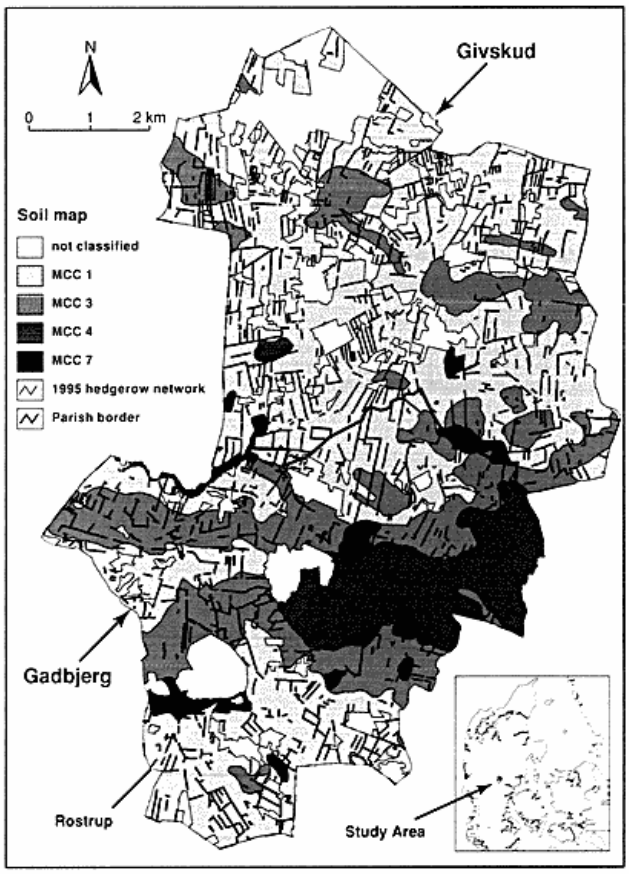
Presentation of study area

Gadbjerg and Givskud parishes are located in Give municipality, Vejle County in central Jutland (Figure 1). Each parish measures approximately 3500 ha.

The agricultural potential of Gadbjerg and Givskud is below average, mainly due to the dominance of sandy soils, in particular in the northern area, corresponding to most of Givskud parish (Figure 1). Another smaller area of sandy soil is found in the extreme southern part of Gadbjerg parish, in the area south of Rostrup and the east-west going belt of loamy soil dividing the two sandy areas. The sandy soils correspond to heathland areas, which were the last areas to be cultivated in Jutland. Large, continuous areas of sandy loamy soils are found in the central and eastern part of the area corresponding with an area of relative high altitude which was formed as a glacial till deposit. These areas have slightly better agricultural potential. The higher proportion of sandy soils in Givskud compared with Gadbjerg (70% and 41% respectively) results in a poorer agricultural potential in Givskud parish from a biophysical perspective. According to Breuning-Madsen & Holst (1988), soils with a root zone capacity below 80 mm for barley and grass production can be classified as marginal soils from a plant growth perspective, and will normally require irrigation to sustain crop production. 66% of Givskud and Gadbjerg is marginal for crop production according to this definition.

Gadbjerg and Givskud parishes are located in the region in central Jutland where large areas of marginal land were expected to be withdrawn from agriculture during the agricultural crisis of the 1980s (Jensen, 1986). The agricultural land use pattern in the area is therefore considered highly unstable, with areas being withdrawn from agriculture or cultivated according to the fluctuating economic conditions for agriculture. The two parishes were selected as study area because the heterogeneous physical environment makes it likely that it contains characteristic trends of both the fertile eastern part and the less fertile western part of Denmark within a short distance. This aspect was highlighted by Jensen & Jensen (1977) in their survey of agricultural dynamics in the same area in 1972. Data from their

Figure 1. Soil map and 1995 hedgerow network in study area.



work forms the background for the analysis of agricultural restructuring in the study area between 1972 and 1997.

Seen in a European perspective, the area is situated on the border between the 'former open field landscape' which is characteristic of eastern Denmark and the 'hedgerow network' landscape of western Jutland according to Meeus et al (1990). The intermediate character of the area means that the hedgerow network pattern of Gadbjerg and Givskud is not as clearly geographically oriented in relation to the dominant wind direction, in order to protect sandy soils from wind erosion, which is typical of areas located further west. On the other hand, the large proportion of poor soils means that the hedgerow density is higher than in areas located east of Gadbjerg and Givskud (Højring & Casper-sen, 1999).

Denmark's agricultural sector underwent significant restructuring since 1950 and in particular during the decades up to the study. The number of farms declined from 133.000 to 63.000 between 1973 and 1997 and the proportion of part-time farms increased from 14% to 55% of all farms (Kristensen, 1999). The impact of these processes differed regionally according to local farming conditions and socio-economic factors, such as alternative job opportunities and distances to urban centres. Farm structure in the study area in 1997 reflects the poor agricultural potential characterising large parts of the area. The average farm size in 1997 was 25 ha, which was considerably lower than the national average of 43 ha (Danmarks Statistik, 1998). This small average farm size reflects the predominance of hobby farmers and pensioners, who generally run small operations. The distribution of farm assets by farm type indicates large differences among different types of farmers (see Table 1). In this survey, full-time farmers are defined as farmers deriving > 75% of their income from agricultural production. Part-time farmers receive 50-75% of their income from agricultural production, while the corresponding figure is <50% for hobby farmers. Farms where the only income from agricultural production (if any) comes from renting out land to other farms are classified as non-farming, while pensioners correspond to all farmers receiving pensions, early retirement pension or other social transfers. Pensioners constitute the largest group of landowners. The balance among different farm types differs significantly from the pattern found on a national level, as outlined above (Landbrugsministeriet, 1998). This is partly caused by the use of different definitions of full-time farms by the agricultural census (Kristensen, 1999). Hobby and part-time farmers correspond to 26% of landowners while full-time farms only constitute 22% of landowners but manage almost half the area. The concentration of production on the full-time farms is also found in terms of distribution of livestock and Standard Gross Margin (SGM). The balance between full-time farmers and other farm groups has shifted dramatically over the last 25 years. In 1973, the full-time farms constituted 75% of all farms in the study area (Jensen & Jensen, 1977).

Most full-time farms specialized in either dairy cattle (55%) or pig production (25%) in 1997 (see Table 2). The large proportion of dairy farms is significantly higher than the national average for Denmark. This is another illustration of the marginal agricultural potential, which gives dairy farms a comparative advantage over other production types, due to the large area required for grass and roughage production. Hobby farms are dominated by less intensive

Table 1. *Distribution of farm assets and production in 1997.*

Farm type	No.	%	area owned (% of total)	managed area (%)	average area (ha)	No. of LSU[1]	average no. of LSU	average SGM[2] (ECU/1000)
Full-time	47	22	34	43	61	3 045	65	101
Part-time	3	1	2	2	43	142	47	52
Hobby	52	25	19	18	21	235	4	12
No farming	47	22	8	4	6	53	1	1
pensioner	63	30	20	14	14	274	4	10

Source: 1997 survey.

[1] The calculation of Livestock Units (LSU) is based on the manure production levels for different animal groups defined in (Miljø- og Energiministeriet (1994).

[2] The calculation of Standard Gross Margin (SGM) is based on information about farm production supplied in the 1997 survey according to the definitions used by Danmarks Statistik (1998).

EU code and description of production[1]	1 crops	4.1 dairy cattle	4.4.1 sheep	5 pigs	7 mixed livestock	8 crop and livestock	mink	no production[2]	total
full-time farm	2	26	0	12	3	2	2	0	47
part-time farm	0	0	0	1	1	0	0	1	3
hobby farm	30	0	9	4	1	2	2	4	52
no farming	4	0	13	3	0	0	1	26	47
pensioner	25	0	6	6	1	2	1	22	63
total	61	26	28	26	6	6	6	53	212

Source: 1997 survey. [1](Danmarks Statistik 1997). [2] No livestock or crop production which can be placed in the EU-categories (the farm is mainly used as a residence).

***Table 2.** Farm type and main production type based on the EU classification.*

types of production, such as crop (58%) or sheep production (17%). A significant proportion of the farms without any income from agricultural production raise some sheep (28%) but most of these farms fall outside of EU agricultural statistics classes (55%). A large proportion of pensioners are engaged in crop production (40%) while a similar proportion fall outside of EU agricultural statistics classes (35%). The high degree of specialization found in the study area is a reversal of the situation 25 years ago. In 1973, 75% of the farmers were engaged in mixed livestock farming. This proportion has declined to 3% in 1997. A similar proportion engage in mink production, which is a relatively new enterprise.

Methodology

Landscape ecology provides a framework for the analysis of spatial and ecological dimensions of landscape changes. For the purpose of this paper, special attention is given to the analysis of linear landscape elements, such as hedgerows, and how they provide connectivity in fragmented landscapes. Landscape fragmentation resulting from the intensification of land use is typical of agricultural landscapes in Northern Europe (Agger & Brandt, 1988; Burel, 1996). The ecological importance of hedgerows as conduits and habitats in these landscapes has been documented in numerous studies (Dawson, 1994; Burel & Baudry, 1995; Burel, 1996; Hammershøj & Madsen, 1998). However, the function of hedgerow networks varies according to the species considered and the characteristics of the hedgerow network (Forman, 1996; Baudry, 1998). Species that cannot move across open agricultural fields are very likely to use hedgerows while other species might be able to utilize several types of habitats and are not so dependent on hedgerows for movement across the landscape. Simulation of hedgerow functions in landscapes with habitats of varying quality suggest that connecting low-quality habitats through a hedgerow network may be more harmful for population survival than no connection at all (Forman, 1996).

The analysis of changes in the hedgerow network in Gadbjerg and Givskud was implemented as a GIS analysis of the changes in hedgerow network between 1972 and 1997.The 25 year period corresponds to a period where Danish agriculture underwent significant restructuring processes, as outlined in the previous section. Analysis of hedgerow network changes during this period will therefore allow the estimation of the influence these changes might have had on farmers' hedgerow activities during a period of agricultural restructuring.

The definition of hedgerows used in this analysis includes two types of linear, dry, tree-covered landscape elements: 1) 'real' hedgerows, consisting of one or several rows of trees planted in fields or in field margins; and 2) old earth walls, originally used to demarcate field and property boundaries, which have over time become covered with trees. Both types of linear, wooded landscape elements are included because it is not always possible to differentiate between them on aerial photographs. Only hedgerows longer than 10 metres are included in this analysis, since this proved to be the minimum size for reliable hedgerow recognition on aerial photos. Furthermore, the minimum size corresponds to the definition used for the assessment of linear biotopes by Holmes, Brandt, Bramsnæs, Wind, & Østergaard (1998) in a nation-wide survey. Hedgerows with gaps larger than 10 meters are classified as several distinct hedgerows, as long as they meet the minimum length condition.

The analysis is based on the information about hedgerows contained in the hedgerow theme in two digital topographic maps: the T0 map (Mølbak, 1997) and the TOP10DK map (Kort- og Matrikelstyrelsen, 1995). Hedgerow information in the T0 map was adjusted by the author according to the 1972 aerial photos in order to create a GIS map representative of the 1972 situation. The GIS map of the hedgerow situation in 1995 is based on the hedgerow theme in the TOP10DK map. This map is based on 1995 aerial photographs.

The analysis of the habitat and dispersal characteristics of the hedgerow network was undertaken as a comparison of a connectivity index calculated for the hedgerow network in 1972 and 1995. The connectivity or Gamma ( ) index describes the extent to which different points or nodes in a network are connected. It is calculated as the ratio between the actual number of links and the maximum potential number of links in a network. When used to assess connectivity in landscapes, values range between 0 in a landscape where no points are connected to 1 in a landscape where all points are linked. Hypothetically, a species is expected to move more freely and to be able to exploit different parts of the landscape in a well-connected landscape. The index is calculated by the following formula (After Forman, 1996):

$$\gamma = \frac{L}{L_{max}} = \frac{L}{3(v-2)}$$

L = number of links
V = number of nodes

Links are defined as all hedgerows which were identified in the digital maps (and verified on aerial photos for 1972 and 1995). No differentiation was made along age, species or other ecological parameters of the hedgerows. Wooded forest boundaries are not included in the definition because they are not linear landscape elements per se, but are regarded as the boundary of a wooded patch. Nodes correspond to junctions in the hedgerow network as well as the endpoints of hedgerows. An initial GIS-routine deleted any false nodes in the base map, so that only nodes representing a junction between 3 or more hedgerows were included in the analysis. These definitions correspond to those used by Selman & Doar (1992). Two types of intersections or nodes in the hedgerow network are identified: the X-type, where four hedgerows intersect and the T-type nodes, where three hedgerows intersect. All other things being equal, in a network with a high proportion of X-nodes, more alternative routes for species movement are available than in networks where T-nodes dominate (Forman, 1996). Any L-type nodes, ie. where two hedgerows intersect, were weeded out following the GIS-routine described above, since these types of nodes do not constitute alternative routes in a network.

It should be emphasized that research regarding the relationship between indices of landscape network structures, ie. the Gamma index, different types of hedgerow intersections (X- and T-nodes) and the landscape ecological qualities of a landscape, ie. the dispersal and habitat qualities, is still at an early stage (Forman 1996). In addition, many relevant factors, such as hedgerow length and location are not accounted for by the Gamma-index. The main objective of this paper is therefore to address general aspects of landscape structure and the results should be considered as a contribution to the methodological development of this field of research. Analysis of relationships between landscape structure and the associated landscape ecological qualities for specific species lies outside the scope of this article.

The relationship between hedgerow density and soil type was analysed through a traditional GIS overlay analysis, in which the extent of the hedgerow network was compared with the distribution of different soil types in a soil map. The soil map is a digital version of the Danish soil classification, which shows the dominant soil type in the top soil (Madsen, Nørr, & Holst, 1992).

Data on farmers' hedgerow activities was collected through a questionnaire survey involving all landowners owning more than 2 ha of land in 1997. The minimum area requirement was introduced to exclude properties without any legal obligation to be used for agricultural production. Field work took place in June 1997 and was conducted through personal visits to all owners residing in the 2 parishes who fulfilled the minimum area requirement. A total of 212 landowners were interviewed. In addition to quantitative information about the farm enterprise, such as area cultivated with different crops, livestock, percentage of income derived from different sources, etc., semi-quantitative information regarding the decision-making process was collected through follow-up questions. In this part of the survey, farmers were asked which motives had led them to engage in hedgerow activities. To achieve a common reference period, farmers were asked about activities undertaken since 1987. This was considered a reasonable time length for the recollection of farmers to be still reliable.

Table 3. Change in hedgerow network parameters between 1972 and 1995.

year	no. of hedgerows		length (km)		Average length (m)		density (km/ha) total/agricultural area		connectivity (alfa index)		node type (T/X)	
	Gadbjerg	Givskud	Gadbjerg	Givskud	Gadbjerg	Givskud	Gadbjerg	Givskud	Gadbjerg	Givskud	Gadbjerg	Givskud
1972	758	861	131	142	172	165	3.8/5.0	3.9/6.5	0.193	0.190	108/2	100/6
1995	832	854	119	129	143	152	3.4/4.9	3.5/6.3	0.194	0.191	117/1	104/2

Source: Kort og Matrikelstyrelsen (1998), Ministry of Food, Agriculture and Fisheries (1995), Aerokort (1972).

Hedgerow network changes between 1972 and 1995

A comparison of the two GIS maps shows a net decrease in hedgerow length in Gadbjerg and Givskud from 273 km to 248 km between 1972 and 1995, corresponding to a decrease by 9% in both parishes (Table 3). Hedgerow density is highest in Givskud parish in both years. Seen in a national perspective, it appears that hedgerow density is higher than the national average of 2 km/ha indicated by Holmes, Brandt, Bramsnæs, Wind, & Østergaard (1998), and is even higher if only the agricultural area is considered (excluding roads, buildings, forests, urban areas). 20 km out of the 25 km disappearing between 1972 and 1995 were located on 178 ha of land of marginal agricultural potential. This area was planted with farm woodlots or Christmas tree plantation between 1972 and 1995. One kilometer disappeared as a consequence of a road alignment in Rostrup village area. These processes are described in detail in Kristensen & Caspersen (2001). It should be kept in mind that the net decrease investigated in this paper should be considered as the outcome of a dynamic situation where hedgerow removal exceeded hedgerow planting by 25 km.

Hedgerow network connectivity, as expressed by the Gamma-index, is quite low in both 1972 and 1995 (approximately 0.19 in both years). The low values signify that many hedgerows are isolated and that few routes and loops exist which allow movement of animals along hedgerows without crossing open land (Figure 1). The high ratio of T-junctions to X-junctions also indicates that there are few alternative routes in the hedgerow network.

While it was not an explicit part of the research, changes in the design and composition of hedgerows merit a few comments, as they play a significant role for their habitat quality. Hedgerow design in the study area evolved considerably during the period, as new types of hedgerows with three to six rows of different tree species became popular following the amendments to the hedgerow planting law in 1977 (Olsen, 1979). These new hedgerow types include many deciduous tree species and contribute to the increase of deciduous trees in the agricultural landscapes (Pedersen, 1996).

The distribution of hedgerows on different soil types is closely correlated to differences in the risk of wind erosion (Figure 1). Areas with coarse and fine sandy soils had the highest hedgerow density in both years (Table 4). The decrease in hedgerow density on the coarse sandy soil between 1972 and 1995 was due to afforestation of fields of poor agricultural potential, as explained above. Sandy loamy soil is not so prone to wind erosion, and hedgerow density was the lowest on this soil type in both years. Increases in hedgerow density on organic soils are explained by the planting of hedgerows in a former bog area in Rostrup, which was drained for cultivation. The hedgerows in this area were planted between 1972 and 1995, to prevent wind erosion of the fine-grained organic soil. Aerial photo interpretation reveals that the area with fine sandy soil also underwent considerable changes between 1972 and 1995, although hedgerow density was similar in both years. Gravel excavation in the southern part of Gadbjerg parish was responsible for the removal of hedgerows in affected

Table 4. Soil type and hedgerow density.

Soil type			hedgerow density	
Map colour code[1] (MCC)	description	Area	1972	1995
		(km^2)	(km/ha)	
0	not classified	10.0	0.5	0.3
1	coarse sandy	37.4	5.1	4.5
3	fine sandy	15.5	3.6	3.6
4	sandy loam	6.2	2.4	2.5
7	organic soil	2.0	2.6	3.3
	total area	71.0	3.5	3.5

[1]According to the Danish soil classification (Madsen, Norr. & Holst 1992).

	number of farmers		percentage of farmers		hedgerow planted (m)	
subsidy	Givskud	Gadbjerg	Givskud	Gadbjerg	Givskud	Gadbjerg
none	12	10	52	26	4685	4380
individual	5	7	20	17	2205	2860
collective	6	23	24	57	3350	12980
other subsidy	1	0	4	0	100	0
total	24	40	100	100	10340	20220

Source: 1997 survey.

***Table 5.** Hedgerow planting activity and use of subsidies.*

areas whereas new hedgerows were planted in other areas. The net effect of these changes was a stable hedgerow density in these areas in both years. The values in Table 4 must be interpreted with care, due to differences in the area covered by different soil types.

Farmers' hedgerow planting activities between 1987 and 1997

Hedgerow planting was a very popular activity in Gadbjerg and Givskud between 1987 and 1997, when 64 farmers planted 31 km of hedgerows (see Table 5). The 64 farmers correspond to 30% of the 212 persons interviewed. Planting activity was very unevenly distributed between the two parishes: 20 km of hedgerow was planted in Gadbjerg compared with 10 km in Givskud. Farmers in Gadbjerg have also been more active in hedgerow planting as far as the number of farmers involved is concerned (62% of all farmers who planted hedgerows were from Gadbjerg). This seems surprising at a first glance, as hedgerow density in Givskud was higher in both 1972 and 1995 (Table 3). It would therefore seem likely that the planting pattern between 1987 and 1997 should reflect this trend, especially considering the larger area of sandy soil in Givskud parish. One explanation of this difference relates to the widespread use of the subsidy scheme for planting. The survey information reveals that 65% of hedgerow planting (measured in length) was subsidised (Table 5). A higher proportion of the hedgerows planted in Gadbjerg were subsidized compared with Givskud (74% and 48% respectively). In both areas, the collective subsidy package was used more frequently than individual subsidies, although the difference was more pronounced in Gadbjerg. The collective subsidies are available to groups of farmers who agree to plant more than 20 km of hedgerows in an area (Jørgensen, 1993). Individual subsidies are available to farmers who do not participate in collective planting campaigns. The system operates on a rotational basis, whereby a given area is offered a planting package every 5 to 7 years on average (Hansen, 1998). The planting pattern identified in this survey has been compared with information regarding planting campaigns implemented by the agency responsible for allocating planting subsidies ('Fællesudvalget for Læplanting') in the two parishes between 1987 and 1997 (Knudsen, 1983). This information reveals that most of the campaigns in this period took place in Gadbjerg parish, which correlates well with the information obtained in the 1997 survey. It therefore appears that the system of 'revolving' planting campaigns had an important influence on planting activity in the study area and assists in explaining why planting activity was markedly higher in Gadbjerg than in Givskud parish.

A second part of the survey investigated the patterns of hedgerow planting among different farmers and landowners. Planting activity was analysed per farmer type to identify patterns of correlation (see Table 6). Results from the two parishes are combined in this part of the analysis, in order to increase the number of farmers in different categories. In terms of level of involvement, it appears that a larger proportion of full-time farmers have engaged in hedgerow planting compared with other farm groups (38% of all full-time farmers planted hedgerows). In contrast, there is a very balanced representation of different farm groups among the farmers who have planted hedgerows during the period of investigation (each farm group represents between 19% and 28% of all persons who have planted hedgerows).

Focussing on the results of the hedgerow activities, it appears that hobby farmers plant slightly more hedgerow than full-time farmers in absolute numbers (34% and 31% of the 31 km of hedgerow planted between 1987 and 1997 respectively). Non-farmers (persons who are not personally involved in farm activities) and pensioners have planted far less hedgerow (14% and 21% of the 31 km of hedgerow planted between 1987 and 1997 respectively). The average length of hedgerow planted per farm-type reflects the total length planted per farm-type: hobby farmers have on aver-

Table 6. Hedgerow planting activity by farmer type.

farm type[1]	no. of farmers	percentage of farmers		hedgerow planted			
		of land owners in farm group	of all land owners who have planted	total length (m)	average per land owner (m)	average per area of farms with planting (m/ha)	average per area of all farms (m/ha)
full-time	18	38	28	9350	519	6	3
hobby farm	17	33	27	10430	614	18	9
no farm	12	26	19	4200	350	36	15
pensioner	17	27	27	6580	387	20	8
Total	64	26	100	30560	478	12	6

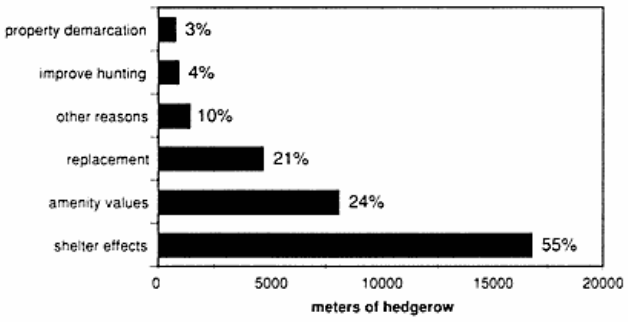
[1]see Kristensen & Caspersen (2001) for definitions.

age planted the longest hedgerow length (614 m per farmer) while full-time farmers, pensioners and non-farmers have planted less (519 m, 387 m and 350 m per farmer respectively). However, if the length of hedgerow planted is seen in relation with the farm area, a different pattern emerges. It appears that non-farms have planted the longest distance per ha (36 m/ha), followed by pensioners, hobby farmers and full-time farmers (20, 18 and 6 m/ha respectively). A similar pattern emerges if the length of hedgerow planted is seen in relation with the total area cultivated or managed by the different farm types in Gadbjerg and Givskud. Non-farms have planted the longest distance per ha (15 m/ha), followed by hobby farmers, pensioners and full-time farmers (9, 8 and 3 m/ha respectively).

Motives for hedgerow planting

Figure 2 lists motives for hedgerow planting as explained by farmers. Farmers were allowed to state more than one reason for planting hedgerows. The value to the right of the graph shows the proportion of the 64 farmers who indicated a specific reason for planting hedgerows. The shelter effect

***Figure 2.** Motives for hedgerow planting between 1987 and 1997 in Gadbjerg and Givskud.*



of hedgerows was the most frequently mentioned reason (55% of the farmers) and accounted for the longest length of hedgerow planting (17 km). The desire to increase amenity values on the property were mentioned by 24% of all farmers and accounted for 8 km of hedgerow length.

A similar proportion of farmers (21%) mentioned replacement of old hedgerows as a motive. However, this reason was only mentioned in connection with 5 km of hedgerow length. Other reasons, such as demarcation of property, the desire to improve hunting conditions or donation of trees from neighbours or relatives were only mentioned by a few farmers (between 3% and 10%) and did not account for a large hedgerow length (between 700 m and 1400 m).

Reasons given by farmers for planting hedgerows are listed per farm type in Table 7, in order to see whether different farm types gave different reasons for hedgerow planting. For example, it could be expected that amenity values and hunting would figure prominently amongst persons who are not involved in farming on a full-time basis, whereas shelter and replacement might be expected to be particularly important among full-time farmers. It appears from Table 7 that the shelter effect was the most prominent reason given by all farm groups, and it is therefore not possible to distinguish among the motives given by different farm types.

In fact, shelter effects were mentioned as a motive more often by hobby farmers and pensioners than by full-time farmers, contrary to expectations. Similarly, pensioners only mentioned amenity values in 10% of the cases as a motive for hedgerow planting, and thus gave this reason less importance than full-time farmers, which is also contrary to expectations. A number of factors help explain this distribution of motives for hedgerow planting. The validity of these factors has not been tested in practice, and they are

Table 7. Motives for hedgerow planting (% of answers).

motives	full-time	hobby	non-farm	pensioner
shelter effect	39	52	39	48
amenity values	22	33	28	10
hunting	9	0	6	5
property demarcation	4	0	6	0
replacement	17	10	11	29
other reasons	9	5	11	10
total	100	100	100	100

Source: 1997 survey.

therefore hypothetical in nature.

1) The shelter effect is a traditional and 'accepted' motive for hedgerow planting and a large proportion of the hedgerows are planted with public subsidies under the hedgerow planting program. This might lead some farmers to only mention shelter effect as a motive, and not consider or mention other options as motives as they deviate from the 'intended' goal of providing shelter effect.

2) The area has a long tradition for hedgerow planting. It could therefore be expected that farmers, even those not engaged in farming on a full-time basis, consider it a 'duty' to plant hedgerows to improve the shelter effect, even if there are no production-related reasons for it (e.g., non-farmers).

3) The farmers have been classified according to their status in 1997, while the analysis is concerned with the changes occurring between 1987 and 1997. It is therefore likely that some farmers have changed status during the period of investigation, with some uncertainty regarding the relationship between farm type and planting activity as a consequence.

Farmers' hedgerow removal activities between 1987 and 1997

47 land owners in Gadbjerg and Givskud removed 17 km of hedgerow between 1987 and 1997. This indicates that both in terms of number of farmers and hedgerow length, the removal of hedgerows is not as common as hedgerow planting activities. The distribution of hedgerow removal between Gadbjerg and Givskud is very similar (51% and 49% of the 17 km of hedgerow respectively). Examining hedgerow removal activity per farm type, a clear differentiation according to farm type emerges (see Table 8). If the part-time farm group is disregarded, due to its very small size, the proportion of full-time farmers involved with hedgerow removal is slightly larger than other farm groups (32% for full-time farms vs. 11% to 25% for other farm types). Full-time farmers have removed the greatest length of hedgerow (35%), followed by pensioners and hobby farmers (26% and 22% respectively). The analysis of hedgerow removal per farm type in relation to farm area or total area cultivated reveals a different distribution. In this respect, the non-farms have removed the longest hedgerow length (70 m/ha) followed by pensioners, hobby farmers and full-time farmers (27, 9 and 5 m/ha respectively). A similar pattern emerges if the length of hedgerow removed is seen in relation with the total area cultivated or managed by the different farm types in Gadbjerg and Givskud. Non-farms have removed the longest distance per ha (9 m/ha), followed by hobby farmers, pensioners and full-time farmers (5, 3 and 2 m/ha respectively).

Motives for hedgerow removal

Figure 3 indicates the amount of hedgerow removed for different reasons and the proportion of farmers mentioning a specific motive as a reason for hedgerow removal. Farmers

Table 8. Hedgerow removal activity by farmer type.

farm type	no. of farmers	percentage of farmers		hedgerow removed			
		of land owners in farm group	of all land owners who have planted	total length (m)	average per land owner (m)	average per area of farms with removal (m/ha)	average per area of all farms (m/ha)
full-time	15	32	32	5870	391	5	2
part-time	2	67	4	320	160	7	3
hobby farm	13	25	28	3740	288	9	3
no farm	5	11	11	2440	488	70	9
pensioner	12	19	26	4325	360	27	5
Total	47	22	100	16695	355	9	3

Source: 1997 survey.

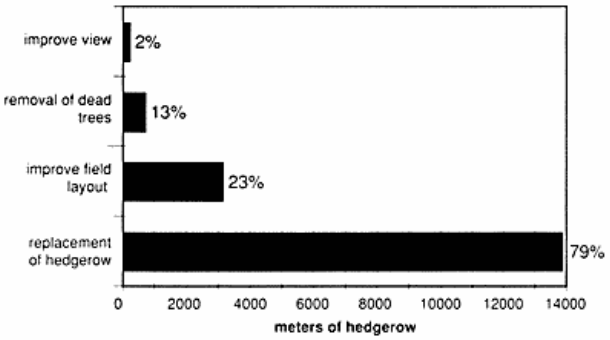


***Figure 3**. Motives for hedgerow removal between 198 and 1997 in Gadbjerg and Givskud.*

were allowed to state more than one reason for removing hedgerows. 79% of all farmers mentioned hedgerow replacement as a motive for the removal of 14 km of hedgerow. Another production-related motive, the desire to improve field layout in connection with field boundary realignment, was mentioned by 23% of the farmers, while the removal of dead or sick trees or the desire to improve the view from the house was mentioned by 13% and 2% respectively.

The sets of motives mentioned by farmers for hedgerow removal are listed per farm type in Table 9, in order to determine if specific patterns of motives can be identified. If the reasons indicated by part-time farmer are disregarded, due to the low number of farmers in this category, it appears that production-related reasons comprise important motives for hedgerow planting for all farm types.

Net effect of hedgerow activities

The comparison of hedgerow planting and removal between 1987 and 1997 indicates that the hedgerow network has increased by 14 km. This result contrasts with the result of the analysis of changes in the hedgerow network between 1972 and 1995 in the first section, which saw a decrease in hedgerow length by 11%. The difference between the two results is most likely caused by the difference in periods of investigation. Farmers' landscape activities prior to 1987 were not analysed, and a period of net removal of hedgerows must therefore precede the results presented here. This would correspond well with the productivist phase of agriculture prior to the mid-1980s.

Discussion and conclusion

This paper has analysed hedgerow planting activities in two parishes in central Jutland between 1972 and 1995. The first part of the paper investigated the changes in hedgerow network parameters in this period. The hedgerow network length in the study area declined by 9% in the two parishes between 1972 and 1995. 20 km out of the 25 km that disappeared were located on land of marginal agricultural potential, which was planted with farm woodlots or Christmas tree plantations. These land use changes reflected the processes of restructuring which characterised the agricultural sector between 1972 and 1995. Concentration and specialisation of production on a declining number of farms, a typical trend in the study area during this period, resulted in a marginalisation of the most unfertile or hilly areas, which were planted with forest. This result indicates that a transformation of hedgerow network landscapes into a forested landscape occurs in areas of marginal agricultural potential. This hypothesis seems to correlate well with findings by Jensen (1976), Primdahl & Bramsnæs (1993) and Niels-Christiansen (1985), who found similar landscape changes in other areas in Jutland. Hedgerow density was intermediate compared to neighbouring regions. It was not as high as the density on more sandy and erosion-prone soils to the west but much higher than in areas to the east of the study area (Højring & Caspersen, 1999). Seen in a national context, hedgerow density was almost twice as high as the national average of 2 km/km2 (Holmes, Brandt, Bramsnæs, Wind, & Østergaard, 1998).

Hedgerow density correlated well with soil type in both 1972 and 1997. Areas prone to wind erosion, comprising

***Table 9**. Motives for hedgerow removal (% of answers).*

	full-time	part-time	hobby	non-farm	pensioner
improve field layout	29	0	33	0	23
hedgerow replacement	64	0	50	100	69
removal of dead trees	7	50	17	0	8
improve view	0	50	0	0	0
total	100	100	100	100	100

Source: 1997 survey.

fine and coarse sandy soils, had the highest hedgerow density in both years (between 3.6 and 5.1 km/ha). Fluctuations in hedgerow density on coarse sandy and organic soils were related to changing land use patterns, resulting from the agricultural restructuring mentioned above, which either caused the removal or planting of hedgerows. Landscape ecological effects of the changes in hedgerow network were negligible, in terms of landscape connectivity. In both parishes, landscape connectivity, measured through the calculation of the Gamma-index, remained at 0.19. These low values indicate a very fragmented hedgerow network with poor potential for species dispersal. Levels of connectivity are of a similar magnitude as values calculated by Selman & Doar (1992) in a study of hedgerow connectivity in an agricultural landscape in Scotland. The high ratio of T-nodes to X-nodes is much higher than values identified in a study from Eastern Jutland, which is another indication of the limited potential for species dispersal along hedgerows (Pinto-Correia, 1993).

The second part of the paper investigated hedgerow activities between 1987 and 1997 in relation to farm type and location. The combined results of both parishes show that farmers had planted 31 km and removed 17 km during this period. 30% of all farmers had planted hedgerows while only 22% had removed hedgerows. Planting activities were greater in the parish that was less sensitive to wind erosion. This puzzling result was partly explained by the differential use of planting subsidies. During the 10 year period, revolving planting campaigns were concentrated in Gadbjerg parish, which also experienced greater hedgerow planting activity. The subsidised hedgerow planting scheme, which has an annual budget of 3-5 mio. Euros, therefore appears to provide an important incentive for hedgerow planting. A higher proportion of full-time farms had planted hedgerows than other farm groups, although hobby farmers had planted the longest average length of hedgerow per farmer. Seen in relation to farm area or the total area, landowners with little involvement in agricultural production, such as pensioners and non-farmers, had planted the longest length of hedgerows.

The dominating motive for hedgerow planting was the creation of shelter effects for all farm types. Thus, contrary to what might be expected, motives related to agricultural production were also important for groups of landowners who were only minimally involved in agricultural production. These results differ from results obtained in another area of Jutland by Christensen & Primdahl (1999). Their results from Bjerringbro indicate that aesthetic reasons and the desire to improve nature quality were the most important reasons for hedgerow planting in that area. One reason for this difference might be the longer tradition for hedgerow planting in Gadbjerg and Givskud compared with Bjerringbro, which is not a traditional hedgerow landscape and where hedgerow planting is a relatively new activity (Primdahl, 1999).

Contrary to hedgerow planting, hedgerow removal was evenly distributed in the two parishes, which underlines the role of subsidised planting. Hedgerow removal was dominated by full-time farmers, both in terms of the proportion of farmers and the length of hedgerows removed. However, seen in relation to the farm size managed by different farm types, non-farmers had removed the greatest length of hedgerows. The two most significant motives for hedgerow removal were the replacement of old hedgerows by new ones and field layout improvement. Hedgerow removal was therefore closely associated with production-related motives for all farm groups.

In summary, this analysis has shown that hedgerow planting in the two parishes involves a large proportion of farmers and landowners, and that the net effect of their activities is an increase in the hedgerow network. The activities were strongly influenced by the subsidy scheme for hedgerow planting. The most common motives for hedgerow activities were production-related, which is surprising, given the small number of full-time farmers in the study area. However, the long tradition for hedgerow planting in the study area may have instilled a sense of 'duty' among farmers to plant hedgerows to improve shelter effects, even among those not involved in full-time agricultural production. The contrasting results of the two surveys that provided the data for the paper are most likely caused by the differences in period of observation. The increase in hedgerow length between 1987 and 1997 documented by the questionnaire survey must have been preceded by a period of hedgerow removal between 1972 and 1987. This would correlate well with information from Agger & Brandt (1988) who reported a decline in the content of linear biotopes in a nation-wide survey in this period.

Several aspects of hedgerow network research to follow up on the results of this paper should be highligh ted. The relation between landscape structure and landscape ecological qualities, as expressed by landscape indices, merits further attention, in particular concerning the impact of changes in hedgerow network parameters on different species. Results from the landscape research programmes conducted in Denmark during the 1990s could provide useful inspiration in this respect (Jensen, 2000). Another aspect requiring further attention deals with the socio-economic

aspects driving hedgerow activities. Many surveys, including the one reported in this paper, have investigated hedgerow planting in 'traditional' hedgerow landscapes in Jutland. However, little is known about the motives and dynamics behind planting activities in areas in eastern Denmark that have experienced rapid increase in recent years. Such information would be an important input to identify regional variations in the driving forces behind hedgerow planting. If landowners in different regions in Denmark engage in hedgerow planting for different reasons there might be a need to re-address the criteria and means available for hedgerow planting to fulfil policy objectives most efficiently.

References

Agger, P. & Brandt, J. (1988): Dynamics of small biotopes in Danish agricultural landscapes. Landscape Ecology 1: 227-240.

Andreassen, H. P., Fauske, J., & Steinset, O. K. (1995): Linære Habitater . Fauna 48: 62-89.

Baudry, J. (1998): Comparative biodiversity along a gradient of agricultural landscapes. Acta Oecologica 19: 47-60.

Breuning-Madsen, H. & Holst, K. A. (1988): A nation-wide mapping of dry soils for plant production - a case study from Denmark. Geografisk Tidsskrift, Danish Journal of Geography 88: 1-7.

Burel, F. (1996): Hedgerows and their role in agricultural landscapes. Critical reviews in plant sciences 15: 169-190.

Burel, F. & Baudry, J. (1995): Social, aesthetic and ecological aspects of hedgerows in rural landscapes as a framework for greenways. Landscape and Urban Planning 33: 327-340.

Christensen, H. S. & Primdahl, J. (1999): Hegnsplantning. Forskningsprojekt 'Grænser i landskabet'. Nyheds-brev 6: 6-11. Hørsholm, Danish Forest and Landscape Research Institute.

Danmarks Statistik (1997): Landbrugssstatistik på kommuner 1996. Copenhagen, Danmarks Statistik.

Danmarks Statistik (1998): Landbrugsstatistik 1997. Copenhagen, Danmarks Statistik.

Dawson, D. (1994): Are habitat corridors conduits for animals and plants in a fragmented landscape? - A review of scientific evidence. Peterborough, English Nature.

Forman, R. T. T. (1996): Land Mosaics: The ecology of landscape and regions. Cambridge, Cambridge University Press.

Hammershøj, M. & Madsen, A.B. (1998): Fragmentering og korridorer i landskabet - en litteraturudredning. Copenhagen. Ministry of environment and Energy, National Environmental Research Institute.

Hansen, H. (1998) Personal Communication. Give, Fællesudvalget for læplantning.

Holmes, E., Brandt, J., Bramsnæs, A., Wind, M., & Østergaard, M. (1998): VLBs landskabsdatabase: Landskabsdata, scenarioteknik og visualisering. Roskilde, Center for Landskabsforskning, RUC.

Højring, K. & Caspersen, O.H. (1999): Landbrug og landskabsæstetik. Hørsholm, Danish Forest and Landscape Research Institute.

Jensen, K. M. (1976): Opgivne og tilplantede landbrugsarealer i Jylland. Atlas over Danmark serie II bind 1. Copenhagen, The Royal Danish Geographical Society.

Jensen, K. M. (1986): Marginale landbrugsarealer. Danish Journal of Geography 86: 69-73.

Jensen, K. M. & Jensen, R. H. (1977): En landbrugsgeografisk analyse af Gadbjerg og Givskud sogne. Danish Journal of Geography 76: 34-51.

Jensen, T. S. (2000): De små pattedyr og de alt for store landskaber. Pp. 225-235 in Møller, P. G., Holm, P., & Rasmussen, L. (eds.) Aktører i Landskabet. Odense, Odense Universitetsforlag.

Jørgensen, K. (1993): Aid Scheme for Shelterbelt Planting in Denmark. Pp. in 123-124. Windbreaks and Agroforestry. 4th International Symposium. Viborg, Hedeselskabet.

Knudsen, H. S. (1983): Det flyvende korps. Viborg, Give, Fællesudvalget for Læplantning.

Kort- og Matrikelstyrelsen (1995): TOP10DK specifikation. Copenhagen, Kort- og Matrikelstyrelsen.

Kristensen, S. P. (1999): Gadbjerg and Givskud revisited - changes in agricultural structure in two parishes in central Jutland between 1973 and 1997. Geografisk Tidsskrift, Danish Journal of Geography 99: 69-80.

Kristensen, S. P. & Caspersen, O. H. (2001): Analysis of changes in a hedgerow network landscape in central Jutland, Denmark. Journal of Environmental Management (accepted).

Kuhlmann, H. (1976): Læhegnenes fysiske indvirkning på landskabet. Ugeskrift for Agron., Hort., Forst., og Lic. 20: 407-409.

Landbrugsministeriet (1998) Landbrugets strukturudvikling- betænkning fra Udvalget vedrørende land-brugets strukturudvikling. Copenhagen, Ministeriet for Fødevarer, Landbrug og Fiskeri.

Madsen, H. B., Nørr, A. H. & Holst, K. A. (1992): Den

aspects driving hedgerow activities. Many surveys, including the one reported in this paper, have investigated hedgerow planting in 'traditional' hedgerow landscapes in Jutland. However, little is known about the motives and dynamics behind planting activities in areas in eastern Denmark that have experienced rapid increase in recent years. Such information would be an important input to identify regional variations in the driving forces behind hedgerow planting. If landowners in different regions in Denmark engage in hedgerow planting for different reasons there might be a need to re-address the criteria and means available for hedgerow planting to fulfil policy objectives most efficiently.

References

Agger, P. & Brandt, J. (1988): Dynamics of small biotopes in Danish agricultural landscapes. Landscape Ecology 1: 227-240.

Andreassen, H. P., Fauske, J., & Steinset, O. K. (1995): Linære Habitater . Fauna 48: 62-89.

Baudry, J. (1998): Comparative biodiversity along a gradient of agricultural landscapes. Acta Oecologica 19: 47-60.

Breuning-Madsen, H. & Holst, K. A. (1988): A nation-wide mapping of dry soils for plant production - a case study from Denmark. Geografisk Tidsskrift, Danish Journal of Geography 88: 1-7.

Burel, F. (1996): Hedgerows and their role in agricultural landscapes. Critical reviews in plant sciences 15: 169-190.

Burel, F. & Baudry, J. (1995): Social, aesthetic and ecological aspects of hedgerows in rural landscapes as a framework for greenways. Landscape and Urban Planning 33: 327-340.

Christensen, H. S. & Primdahl, J. (1999): Hegnsplantning. Forskningsprojekt 'Grænser i landskabet'. Nyheds-brev 6: 6-11. Hørsholm, Danish Forest and Landscape Research Institute.

Danmarks Statistik (1997): Landbrugssstatistik på kommuner 1996. Copenhagen, Danmarks Statistik.

Danmarks Statistik (1998): Landbrugsstatistik 1997. Copenhagen, Danmarks Statistik.

Dawson, D. (1994): Are habitat corridors conduits for animals and plants in a fragmented landscape? - A review of scientific evidence. Peterborough, English Nature.

Forman, R. T. T. (1996): Land Mosaics: The ecology of landscape and regions. Cambridge, Cambridge University Press.

Hammershøj, M. & Madsen, A.B. (1998): Fragmentering og korridorer i landskabet - en litteraturudredning. Copenhagen. Ministry of environment and Energy, National Environmental Research Institute.

Hansen, H. (1998) Personal Communication. Give, Fællesudvalget for læplantning.

Holmes, E., Brandt, J., Bramsnæs, A., Wind, M., & Østergaard, M. (1998): VLBs landskabsdatabase: Landskabsdata, scenarioteknik og visualisering. Roskilde, Center for Landskabsforskning, RUC.

Højring, K. & Caspersen, O.H. (1999): Landbrug og landskabsæstetik. Hørsholm, Danish Forest and Landscape Research Institute.

Jensen, K. M. (1976): Opgivne og tilplantede landbrugsarealer i Jylland. Atlas over Danmark serie II bind 1. Copenhagen, The Royal Danish Geographical Society.

Jensen, K. M. (1986): Marginale landbrugsarealer. Danish Journal of Geography 86: 69-73.

Jensen, K. M. & Jensen, R. H. (1977): En landbrugsgeografisk analyse af Gadbjerg og Givskud sogne. Danish Journal of Geography 76: 34-51.

Jensen, T. S. (2000): De små pattedyr og de alt for store landskaber. Pp. 225-235 in Møller, P. G., Holm, P., & Rasmussen, L. (eds.) Aktører i Landskabet. Odense, Odense Universitetsforlag.

Jørgensen, K. (1993): Aid Scheme for Shelterbelt Planting in Denmark. Pp. in 123-124. Windbreaks and Agroforestry. 4th International Symposium. Viborg, Hedeselskabet.

Knudsen, H. S. (1983): Det flyvende korps. Viborg, Give, Fællesudvalget for Læplantning.

Kort- og Matrikelstyrelsen (1995): TOP10DK specifikation. Copenhagen, Kort- og Matrikelstyrelsen.

Kristensen, S. P. (1999): Gadbjerg and Givskud revisited - changes in agricultural structure in two parishes in central Jutland between 1973 and 1997. Geografisk Tidsskrift, Danish Journal of Geography 99: 69-80.

Kristensen, S. P. & Caspersen, O. H. (2001): Analysis of changes in a hedgerow network landscape in central Jutland, Denmark. Journal of Environmental Management (accepted).

Kuhlmann, H. (1976): Læhegnenes fysiske indvirkning på landskabet. Ugeskrift for Agron., Hort., Forst., og Lic. 20: 407-409.

Landbrugsministeriet (1998) Landbrugets strukturudvikling- betænkning fra Udvalget vedrørende land-brugets strukturudvikling. Copenhagen, Ministeriet for Fødevarer, Landbrug og Fiskeri.

Madsen, H. B., Nørr, A. H. & Holst, K. A. (1992): Den

Danske Jordklassificering. Atlas over Danmark I (3). Kongelige Danske Geografiske Selskab. Copenhagen, C.A. Reitzels forlag.
Miljø- og Energiministeriet (1994): Bekendtgørelse nr. 1159 af 19. december 1994 om erhvervsmæssigt dyrehold, husdyrgødning, ensilage m.v. Copenhagen, Miljøministeriet.
Mølbak, J. (1997): Digitale tekniske grundkort. DAISI-medlemsmagasinet 3: 20-23.
Niels-Christiansen, V. (1985): Udviklingen i de landbrugsmæssige maginaljorder i Danmark. Copenhagen, Naturfredningsrådet.
Olsen, F. (1979): Læplantning: dyrkningssikkerhed, klimaforandring, landskabspleje. Copenhagen, Det kgl. Danske Landhusholdningsselskab.
Pedersen, P. E. (1996): Mange træer plantes i brede læhegn. Vækst 6: 23-24.
Pinto-Correia, T. (1993): Landscape monitoring and management in European rural areas: Danish and Portugese Case Studies of Landscape Patterns and Dynamics. Copenhagen, University of Copenhagen, Department of Geography.
Primdahl, J. & Bramsnæs, A. (1993): Landbrugslandskabets fremtid - et eksempel fra Vestjylland. Byplan 6: 244-249.
Primdahl, J. (1999): Agricultural landscapes as production and living places. Landscape and Urban Planning 46: 143-150.
Selman, P. H. & Doar, N. (1992): An Investigation of the Potential for Landscape Ecology to Act as a Basis for Rural Land Use Plans. Journal of Environmental Management 35: 281-299.