

Loss of biodiversity and its social cost in an agricultural landscape

Reija Hietala-Koivu^{a,*}, Jussi Lankoski^b, Sanna Tarmi^a

^a Department of Applied Biology, University of Helsinki, P.O. Box 27, FIN-00014 Helsinki, Finland

^b MTT Agrifood Research Finland, Economic Research, Luutnantintie 13, FIN-00410 Helsinki, Finland

Received 10 December 2002; received in revised form 2 October 2003; accepted 27 October 2003

Abstract

Changes at the landscape level in a 100 ha area of southern Finland, have led to homogenization over the period 1954–1997, as measured by Shannon's diversity index (SHDI) and Shannon's evenness index (SHEI). Patch numbers (N), class areas (CA), and total edge lengths (TE) of ditch margins decreased markedly due to subsurface drainage. Woodland patches also decreased, as some of them were brought under cultivation, but increased in 1997 due to the demolishing of barns. An assessment of the social costs and benefits of subsurface drainage shows that it is not desirable to replace the few ditch margins that remain in the case area with subsurface drains. The management of field margins, buffer strips along waterways and woodland patches are included in the Finnish agri-environmental programme, but their importance for management of biodiversity in the agricultural landscape should be emphasized. The paper analyses landscape diversity loss at landscape and patch levels, and describes the roles of woodland patches and field margins in an agricultural landscape.

© 2003 Elsevier B.V. All rights reserved.

Keywords: Agricultural landscape; Biodiversity; Field boundaries; Landscape diversity; Social costs and benefits; Woodland patches

1. Introduction

In Finland, a large proportion of the fertile forest land was taken into cultivation in the early decades of the 1900's (Soininen, 1975; Linkola, 1981; YM, 1992; Hagelberg, 1998). Fields were drained by open ditches, so that parcels of agricultural land could be only a few metres wide, due to the soil types and climatic conditions. Field boundaries, i.e. open ditch margins within fields and field margins to non-arable land, are important refugia for the preservation of biodiversity in agricultural environments (Le Coeur

et al., 2002; Marshall and Moonen, 2002; Tarmi and Helenius, 2002). Between 1944 and 1991, however, Ruuska and Helenius (1996) reported a 50% decrease in the length of open ditches in an agricultural area of 324 ha in central Finland. Similarly, Hietala-Koivu (1999) showed a 91% decrease in ditch lengths between 1958 and 1997 in an area of 2400 ha in southwestern Finland. Such enormous decreases in boundary patches are considered one of the reasons for the Finnish agricultural landscape becoming more homogeneous. Corresponding decreases in linear field boundaries and hedgerows have been reported in the UK, northern Ireland, and France (Le Coeur et al., 2002).

Mikk and Mander (1995) investigated some parameters of woodland patches and connected these

* Corresponding author. Tel.: +358-9-191-59738;

fax: +358-9-191-58463.

E-mail address: reija.hietala-koivu@helsinki.fi (R. Hietala-Koivu).

with species richness in areas of Finland, Estonia, and Lithuania. The best correlation was found between the number of species and the area of the woodland patch. Hagelberg (1998) pointed to an apparent connection between agricultural land over 200 years old and the richness of small biotopes. Hietala-Koivu (1999) suggested that the area of woodland patches in Yläne, southwestern Finland had increased slightly between 1954 and 1997. According to Agger and Brandt (1988) small biotopes, e.g. woodland patches, have substantially decreased in western Europe. Skånes (1990), Ihse (1995), and Björklund et al. (1999) estimated that small, uncultivated biotopes have declined by an average of 50% during past decades on Swedish agricultural land.

Landscape maintenance and the promotion of biodiversity are included in the Finnish agri-environmental programme which covered the periods 1995–1999 and 2000–2006 involving 96% of the arable area in 2001 (MTTL, 2002). The programme aims at maintaining woodland patches and stony open patches and ecotones between field and forest in agricultural landscapes. Furthermore, field boundaries have to be at least 1 m wide, but do not need to be managed by mowing. Field margins along a relatively wide brook or beside a river, pond or lake, have to be at least 3 m wide. If such buffer strips are mowed, the resulting biomass has to be collected (MMM, 2001).

The purpose of this paper was to describe the aesthetic and ecological roles of field boundaries and woodland patches in an agricultural landscape. Management will be analyzed here by calculating the change in social welfare (SW) that would ensue if the remaining open ditch margins in one case area of 100 ha in Nurmijärvi, southern Finland, were lost through further subsurface drainage. The results may be useful to establish the role of field boundaries and small woodland patches in the management of biodiversity in agricultural environments.

1.1. Aesthetic role of field boundaries and woodland patches

Marshall and Moonen (2002) assigned four functions to field boundaries, i.e. (1) agronomic (stock fencing, land ownership); (2) water protection (pollution and erosion control); (3) nature conservation (species refugia, corridors for movement, feeding and

breeding); and (4) recreation and rural development (walking, hunting, viewing the landscape). The aesthetic role of field boundaries can vary greatly in the course of the growing season. In addition, linear features such as field boundaries along waterways can be important in land use planning, in outlining a river landscape with growing trees and bushes (Rautamäki, 1990; MMM, 2001).

Hietala-Koivu et al. (1999) and Tahvanainen et al. (2002) showed that the interviewees preferred managed buffer strips to unmanaged strips, non-farmers preferring strips 5 m wide over those 3 m wide. Both the farmers and non-farmers, however, perceived the major impact of buffer strips as improving the quality of water courses.

Woodland patches are mainly semi-natural or uncultivated residual areas that provide local ecological and aesthetic benefits to an agricultural landscape (Forman and Godron, 1981). Woodland patches outline the broad scenery of a field area (Mikk and Mander, 1995; MMM, 2001) and may increase the patch density of an agricultural landscape, along with field boundaries, roads, and strips of vegetation beside waterways.

Erickson and De Young (1994) analysed the attitudes of 151 farmers in Washtenaw County, Michigan, USA, towards the management of windbreaks and woodland. They found that greater attention to woodland management was associated with an awareness of the benefits to be derived from trees and an aesthetic and intrinsic orientation towards the land. Erickson et al. (2002) also investigated the motivation of non-industrial private forest landowners in the mid-west of the USA towards retaining and managing their forest holdings and found that aesthetic appreciation was the strongest reason for owning and protecting woodland patches, followed by environmental protection. Preference studies in Finland have concentrated on larger forest areas, urban forests or afforested land (Tyrväinen and Tahvanainen, 1999; Tahvanainen et al., 2001; Tyrväinen et al., 2001).

1.2. Field boundaries and woodland patches as wildlife habitats

Little or no disturbance takes place in field boundaries that have a perennial vegetation, in contrast to the annual species characteristic of fields (Jobin et al.,

1997). According to Le Coeur et al. (1997) and Ma et al. (2002), adjacent fields may affect the boundary vegetation indirectly, e.g. through mechanical treatments, fertilizer misplacement or pesticide drift. Kleijn and Verbeek (2000) reported gradual changes in vegetation composition according to distance from a field, and they also found a close relationship between increased nutrient application to the crop and decreased species richness in the boundary vegetation. Ma et al. (2002) found boundary width to be an indicator of species richness and expected this to be related to environmental gradients arising from the degree of disturbance caused by the adjacent field.

The beneficial role of boundaries in terms of wildlife and environmental protection is well documented (Marshall and Moonen, 2002). Many invertebrates overwinter in field boundaries (Bayram and Luff, 1993; Pfiffner and Luka, 2000), birds nest and feed there (Tiainen and Pakkala, 2000). The plant species composition and structure of the boundaries are important factors for various animals (Bayram and Luff, 1993; Bäckman and Tiainen, 2002). Altogether 239 plant species were found in field boundary surveys in Finland 1995–1999 (Tarmi and Helenius, 2002).

The major variables for species diversity in landscape patches (Forman and Godron, 1981), are habitat diversity, disturbance, area, age, matrix heterogeneity, isolation, and boundary discreteness. The most common tree and shrub species in woodland patches of southwestern Finland are forest species such as *Betula pendula* Roth., *Picea abies* L., *Pinus sylvestris* L., *Sorbus aucuparia* L., *Salix* spp., *Juniperus communis* L., *Populus tremula* L. (Mikk and Mander, 1995). The role of woodland patches for invertebrates seems to vary according to species group, with the mobility of forest species being an important explanatory factor for their existence in woodland patches (Bedford and Usher, 1994; Fournier and Loreau, 2001).

Bedford and Usher (1994) found the richness of carabid beetle and spider species to be highest in the edge communities between woodlands and arable fields and species composition in such edge community more similar to that of the field than that of the forest.

Bird species breeding in forest islands require these to be of a certain critical size (Kurlavičius, 1995). The presence of mature hedgerows and small woods

was found to increase the density of the wood pigeon *Columba palumbus* L. nests in planted woodlands in England (Inglis et al., 1994), while species such as the fieldfare *Turdus pilaris* L., the greenfinch *Carduelis chloris* L., and the yellowhammer *Emberiza citrinella* L. (Pitkänen and Tiainen, 2001) have been observed to breed in woodland patches and feeding on fields in Finland. Whether a certain bird species is capable of nesting in a woodland patch is certainly dependent at least on the size and quality of the patch.

2. Material and methods

An area of 100 ha situated in Nurmijärvi (60°25′–60°26′N, 24°39′–24°40′E), southern Finland (Fig. 1) was analyzed. The soil types vary from clay soils to mud soils, and carex peat (Maanmittaushallitus, 1969), cereal production being typical of the area (Palva et al., 2001).

The land use classification which served as a basis for digitization by means of the ArcInfo (version 8.0.2) GIS (geographical information system) program employed a total of eleven categories (Hietala-Koivu, 1999). The material for the 100 ha was clipped out of digitized material comprising 2400 ha taken from three aerial photographs of scale 1:10,000 produced by the National Survey of Finland in 1954, 1973, and 1997 (Hietala-Koivu, 2002). The habitats recognized were >30 m², clumps of trees and bushes within farmland being defined as woodland patches when >2000 m², larger ones being classified as forests. Bare rocky patches within fields were classified as stone blocks. Field boundaries were either: ditch margins dividing parcels of arable land or field margins bordering non-arable land. Being line elements, wide ditches were buffered to form polygons and defined as being 1 m on both sides of the digitized line (i.e. a total width of 2 m) (Hietala-Koivu, 1999, 2002).

Changes at the class and landscape levels were assessed using the FRAGSTATS*ARC software (version 3.0, McGarigal and Marks, 1995). The indices chosen to describe class level changes in field boundaries and woodland patches between 1954, 1973, and 1997 were class areas (CA), number of patches (NP), and total edge lengths (TE). In addition, distances from the nearest woodland patches during the period

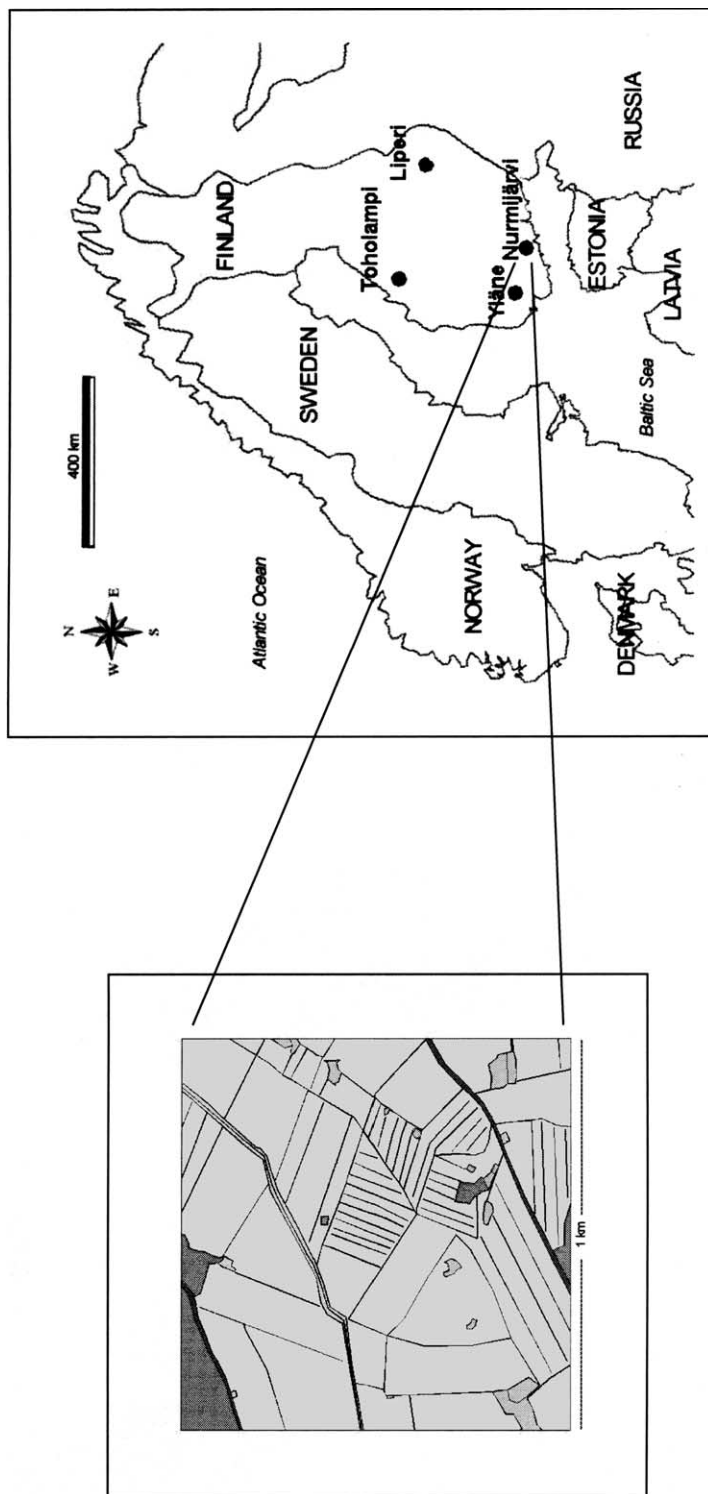


Fig. 1. Location of the case area of 100 ha in Nurmijärvi, in southern Finland.

concerned were calculated to assess trends in the isolation of such patches.

Overall landscape level diversity was assessed by calculating Shannon's diversity index (SHDI) and Shannon's evenness index (SHEI) (McGarigal and Marks, 1995; Hietala-Koivu, 1999, 2002). SHDI = 0 when the landscape contained only one patch, and the value increased with the number of patch types and/or as the proportional distribution of the area among patch types became more equal. However, the SHEI was also used to describe the distribution of land use types by area. This index expressed evenness as the observed level of diversity divided by the maximum possible diversity for a given patch richness and varied between 0 and 1 (McGarigal and Marks, 1995).

3. Results

From 1954 to 1997 (Table 1) the average area of the ditch margins decreased by 69% (from 5.8 to 1.8 ha) and their number by 88%, (from 323 to 40) in the study area. The area of field margins decreased slightly during the period concerned, from 0.7 to 0.5 ha, while their number increased temporarily from 38 to 49 in 1973. The agricultural landscape had become more homogeneous by 1997 (Fig. 2.) with a pronounced decrease of ditch margins (from 97,896 to 30,537 m),

Table 1
Changes in patches, shannon's diversity and evenness indices in case area of 100 ha in Nurmijärvi, southern Finland

Patch type changes	1954	1973	1997
Class area (ha)			
Ditch margins	5.8	3.5	1.8
Field margins	0.67	0.66	0.52
Woodlots	0.54	0.29	0.44
Number of patches (n)			
Ditch margins	323	149	40
Field margins	38	49	23
Woodlots	9	7	9
Total edge length (km)			
Ditch margins	98.9	58.0	30.5
Field margins	11.6	11.3	8.8
Woodlots	0.9	0.6	0.8
Distance between woodlots (m)	189	195	160
SHDI	0.85	0.73	0.62
SHEI	0.31	0.28	0.24

while the total for field margins decreased slightly between 1954 and 1973 (from 11,593 to 11,258 m), more markedly by 1997 (to 8841 m).

Average area, number, and total edge length of woodland patches within fields decreased from 1954 to 1973 (Table 1). The class area, number, and total edge length increased by 1997 (Table 1; Fig. 2). The shortest distance from one woodland patch to the next decreased generally during the period concerned with a substantial decline taking place in 1997. Both SHDI and SHEI decreased from 1954 to 1997.

4. Discussion of drainage

At the national level, an average of 500 m/ha of open ditches has been replaced with subsurface drains (Helenius et al., 1995). To assess the social costs of further subsurface drainage in the study area, the following analytical framework has been developed.

The production of a crop (e.g. barley) in the case area was expressed as $y = f(x)$, where y is the yield (kg/ha) and x the fertilizers used (kg/ha). This production function was assumed to be concave with a decreasing marginal return for fertilizer use. The effective cultivated area of arable land was higher for subsurface ($i = 1$) than for open ditch drainage ($i = 0$), but subsurface drainage also has higher technology cost $k_1 > k_0$ (including annual repayments of the investment and maintenance costs) than open ditch drainage. A farmer's problem is to choose the appropriate level of fertilizer use to maximize his profit (π_i) per hectare:

$$\pi_i = \max_{x_i} \{pf(x_i) - cx_i - k_i\}, \text{ for } i = 0, 1 \quad (1)$$

where p and c are the prices of the crop and the fertilizer, respectively. After profit maximization, the more profitable drainage technology is chosen.

The relevant question for society is whether subsurface drainage is desirable considering the effects on nutrient runoffs, landscape diversity, and species diversity in addition to profitability. When these effects are taken into account the social welfare (SW) function can be expressed as:

$$SW = \pi(s) - d_N(s) - d_P(s) + b_{LD}(s) + b_{SD}(s), \quad (2)$$

where s is the amount of cultivated area with subsurface drainage, π is private profitability, d_N is the social

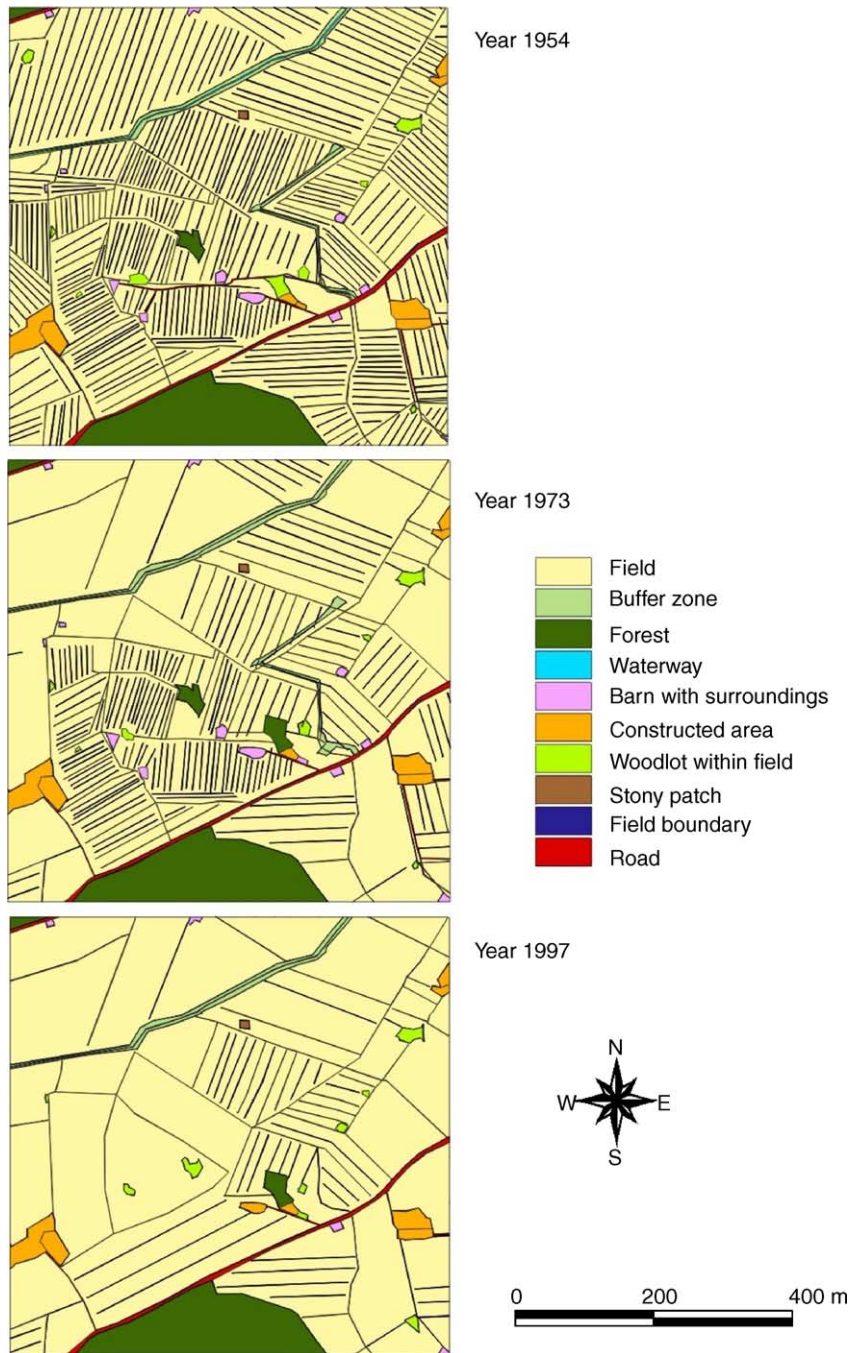


Fig. 2. Land use changes in the case area of 100 ha in Nurmijärvi, in southern Finland, between 1954, 1973, and 1997.

damage from nitrogen runoffs, d_p is the social damage from phosphorus runoffs, b_{LD} is the social benefit from landscape diversity, and b_{SD} is the social benefit from species diversity. From society's viewpoint, subsurface drainage should be increased to the point at which the social benefits are equal to the social costs. That is, until the net marginal benefit of additional hectare under subsurface drainage is zero, which is expressed as¹

$$\underbrace{\pi'(s) - d'_N(s) - d'_P(s)}_{(+)} + \underbrace{b'_{LD}(s) + b'_{SD}(s)}_{(-)} = 0 \quad (3)$$

Barley represented 30% of the crops in the study area (Palva et al., 2001). An assessment of the profitability of subsurface drainage by Haataja and Peltola (2001) showed that investment in subsurface drainage for barley cultivation was profitable, resulting in annual benefits of € 7.57 ha. Turtola and Paajanen (1995) analyzed the influence of improved subsurface drainage in terms of soil erosion, phosphorus losses, and nitrogen leaching in southwest Finland. As a result of improved subsurface drainage, runoff of particulate P decreased from 0.69 to 0.58 kg/ha, dissolved orthophosphate P from 0.12 to 0.09 kg/ha and nitrogen leaching increased from 7.0 to 14.0 kg/ha. The social benefits of reducing nitrogen and phosphorus runoffs were estimated to be € 1.60 kg of nitrogen and € 24.89 kg of phosphorus (Vehkasalo, 1999). The social benefits of landscape diversity and species diversity were estimated to be € 54.83 ha (Aakkula, 1999).

Using above parameter values the social desirability of further subsurface drainage in the case area can be assessed. The difference in social welfare between two drainage systems can be written as follows:

$$\Delta SW = \Delta \pi - 1.6 \Delta N_{\text{runoffs}} - 24.89 \Delta P_{\text{runoffs}} + 54.83 \Delta \text{Diversity}_{LD+SD}.$$

The replacement of the remaining open ditches by subsurface drainage would decrease social welfare by € 27.55 ha. This result mainly comes from a decrease

in diversity benefits and increase in nitrogen runoffs. As a consequence, from the society viewpoint further subsurface drainage should not be undertaken.

Due to uncertainty related to the social damage of nutrient runoffs and the social benefits of landscape diversity and species diversity a sensitivity analysis was conducted. It was searched for critical values of social damage and benefit estimates under which the optimal strategy would change (that is, to increase subsurface drainage in the area). This break-even approach (see, Pannell, 1997) revealed the fact that given the reasonable range of values for each damage and benefit estimate none of them would not change the optimal strategy alone. However, if all damage and benefit estimates are adjusted favourably for subsurface drainage then, e.g. the simultaneous combination of 70% decrease in nitrogen damage estimate, 70% increase in phosphorus damage estimate and 70% decrease in diversity benefit estimate would make further subsurface drainage socially desirable in the case area.

5. Conclusions

Changes occurring at the class and landscape levels point to a process of landscape homogenization in Nurmijärvi. Patch numbers, class areas, and total edge lengths of the field boundaries decreased markedly as a consequence of subsurface drainage during the period 1954–1997. The same trend was observed in woodland patches. The aesthetic and ecological values of field boundaries and small woodland patches within fields depend on their age, disturbance rate, and management (Forman and Godron, 1981).

A protection of the remaining ditch margins from clearance seems essential for preserving biodiversity in agricultural landscapes, but requires some financial support. The main result of the present study is that the few hectares of land that still have open ditches should not be subsurface drained.

Small woodland patches within fields and field boundaries have both an aesthetic and ecological role in the agricultural landscape. Critical factors for these roles are the age, disturbance rate, area and shape of the patches. The overall decline in landscape diversity during past decades was mainly due to the loss of open ditch margins on account of subsurface drainage. It is hence recommended that the remaining

¹ It is assumed here that by comparison to open ditch drainage, subsurface drainage increases farmer's profits, reduces nitrogen and phosphorus runoffs and decreases landscape diversity, and species diversity.

ditch parcels be retained, because the detrimental effects in terms of landscape diversity and species diversity would be greater than the benefits in terms of the reduced phosphorus runoffs and increased private profitability of barley cultivation.

Acknowledgements

The authors would like to thank Dr. Eila Turto, Dr. Juha Helenius and Mr. Antti Miettinen for valuable comments on the earlier versions of the manuscript, Ms. Tiia Järvenpää for assistance in calculating the distances between woodland patches and Mr. Malcolm Hicks for revising the language of the manuscript. Funding was provided by the Academy of Finland and the Ministry of Agriculture and Forestry under the Finnish Biodiversity Programme (FIBRE), via the project “Biodiversity Implications of Agricultural Policies: An Integrated Approach” (BIAPIA).

References

- Aakkula, J.J., 1999. Economic value of pro-environmental farming—A critical and decision-making oriented application of the contingent valuation method. *Agric. Econ. Res. Inst.*, Publ. 92. Helsinki, Finland.
- Agger, P., Brandt, J., 1988. Dynamics of small biotopes in Danish agricultural landscapes. *Landscape Ecol.* 1, 227–240.
- Bayram, A., Luff, M.L., 1993. Winter abundance and diversity of lycosids (Lycosidae, Araneae) and other spiders in grass tussocks in a field margin. *Pedobiologia* 37, 357–364.
- Bedford, S.E., Usher, M.B., 1994. Distribution of arthropod species across the margins of farm woodlands. *Agric. Ecosys. Environ.* 48, 295–305.
- Björklund, J., Limburg, K.E., Rydberg, T., 1999. Impact of production intensity on the ability of the agricultural landscape to generate ecosystem services: an example from Sweden. *Ecol. Econ.* 29, 269–291.
- Bäckman, J.-P., Tiainen, J., 2002. Habitat quality of field margins in a Finnish farmland area for bumblebees (Hymenoptera: Bombus and Psithyrus). *Agric. Ecosys. Environ.* 89, 53–68.
- Erickson, D.L., De Young, R., 1994. Management of farm woodlots and windbreaks: some psychological and landscape patterns. *J. Environ. Sys.* 22 (3), 233–247.
- Erickson, D.L., Ryan, R.L., De Young, R., 2002. Woodlots in the rural landscape: landowner motivations and management attitudes in a Michigan (USA) case study. *Landscape Urban Planning* 58, 101–112.
- Forman, R.T.T., Godron, M., 1981. Patches and structural components for a landscape ecology. *Bioscience* 31, 733–740.
- Fournier, E., Loreau, M., 2001. Respective roles of recent hedges and forest patch remnants in the maintenance of ground-beetle (Coleoptera: Carabidae) diversity in an agricultural landscape. *Landscape Ecol.* 16, 17–31.
- Haataja, K., Peltola, J., 2001. Salaojituksen kannattavuus Suomessa. MTT Economic Research, Working papers, 20.
- Hagelberg, E., 1998. Pienbiotoopit peltomaisemassa – tutkimus pienbiotooppien sijaintitekijöistä. Julkaisematon pro gradu-tutkielma. Helsingin yliopisto, Maantieteen laitos, (in Finnish), p. 89, +1app.
- Helenius, J., Tuomola, S., Nummi, P., 1995. Viljely-ympäristön muutosten vaikutus peltopyy ravintoon. (Summary: food availability for the grey partridge in relation to changes in the arable environment). *Suomen Riista* 41, 42–52.
- Hietala-Koivu, R., 1999. Agricultural landscape change: a case study in Yläne, southwest Finland. *Landscape Urban Planning* 46, 103–108.
- Hietala-Koivu, R., Tahvanainen, L., Nousiainen, I., Heikkilä, T., Alanen, A., Ihalainen, M., Tyrväinen, L., Helenius, J., 1999. Visuaalinen maisema maatalouden ympäristöohjelman vaikuttavuuden seurannassa. Maatalouden tutkimuskeskuksen julkaisuja: Sarja A 50, (in Finnish with English summary), p. 27.
- Hietala-Koivu, R., 2002. Landscape and modernizing agriculture: a case study of three areas in Finland in 1954–1998. *Agric. Ecosys. Environ.* 91 (1–3), 273–281.
- Ihse, M., 1995. Swedish agricultural landscape-patterns and changes during the last 50 years, studied by aerial photos. *Landscape Urban Planning* 31, 21–37.
- Inglis, I.R., Wright, E., Lill, J., 1994. The impact of hedges and farm woodlands on woodpigeon (*Columba palumbus*) nest densities. *Agric. Ecosys. Environ.* 48, 257–262.
- Jobin, B., Boutin, C., DesGranges, J.-L., 1997. Effects of agricultural practises on the flora of hedgerows and woodland edges in southern Quebec. *Can. J. Plant Sci.* 77, 293–299.
- Kleijn, D., Verbeek, M., 2000. Factors affecting the species composition of arable field boundary vegetation. *J. Appl. Ecol.* 37, 256–266.
- Kurlavičius, P., 1995. Birds of forest islands in southeast Baltic region. Institute of Ecology of the Lithuanian Academy of Sciences. Vilnius: Baltic ECO, 1995. ISBN 9986-443-07-5, p. 263.
- Le Coeur, D., Baudry, J., Burel, F., 1997. Field margins plant assemblages: variation partitioning between local and landscape factors. *Landscape Urban Planning* 37, 57–71.
- Le Coeur, D., Baudry, J., Burel, F., Thenail, C., 2002. Why and how we should study field boundary biodiversity in an agrarian landscape context. *Agric. Ecosys. Environ.* 89, 23–40.
- Linkola, M., 1981. Suomalainen kulttuurimaisema. In: Kinnunen, A., Sepänmaa, Y. (Eds.), *Ympäristöestetiikka*, Mäntän kirjapaino. pp. 119–149.
- Map: Maanmittaushallitus, 1969. National Survey of Finland. Maataloudellinen maaperäkartta Perttula 2041 12, Maaperäkartta 1:20 000.
- Ma, M., Tarmi, S., Helenius, J., 2002. Revisiting the species-area relationship in a semi-natural habitat: floral richness in agricultural buffer zones in Finland. *Agric. Ecosys. Environ.* 89, 137–148.

- Marshall, E.J.P., Mooney, A.C., 2002. Field margins in northern Europe: their functions and interactions with agriculture. *Agric. Ecosystems Environ.* 89, 5–21.
- McGarigal, K., Marks, B.J., 1995. FRAGSTATS: spatial pattern analysis program for quantifying landscape structure. U.S. Forest Service General Technical Report PNW 351.
- Mikk, M., Mander, Ü., 1995. Species diversity of forest islands in agricultural landscapes of southern Finland. *Landscape Urban Planning* 31, 153–169.
- MMM, 2001. Maisemanhoito, luonnon monimuotoisuus, perinnebiotoopit. Maatalouden ympäristötuen erityistuet 2000–2006. Ministry Agric. Forestry, (in Finnish), p. 19.
- MTTL, 2002. Suomen maatalous ja maaseutuelinkeinot 2002. Agrifood Research Finland. Economic Research (MTTL). Publications 101, (in Finnish), Vammala, p. 84.
- Palva, R., Rankinen, K., Granlund, K., Grönroos, J., Nikander, A., Rekolainen, S., 2001. Maatalouden ympäristötuen toimenpiteiden toteutuminen ja vaikutukset vesistökuormitukseen vuosina 1995–1999. MYTVAS-projektin loppuraportti. Suomen ympäristö 478. Suomen ympäristökeskus, (in Finnish with English summary), p. 92.
- Pannell, D., 1997. Sensitivity analysis of normative economic models: theoretical framework and practical strategies. *Agric. Econ.* 16, 139–152.
- Pfiffner, L., Luka, H., 2000. Overwintering of arthropods in soils of arable fields and adjacent semi-natural habitats. *Agric. Ecosys. Environ.* 78, 215–222.
- Pitkänen, M., Tiainen, J., 2001. Biodiversity in agricultural landscapes in Finland. *Birdlife Finland Conservation Series* (No. 3.), p. 93.
- Rautamäki, M., 1990. Maakunnallinen maisemaselvitys. Varsinais-Suomi. Varsinais-Suomen Seutukaavaliitto. Ympäristöministeriö. Ministry of Environ. Turku, p. 108.
- Ruuska, R., Helenius, J., 1996. GIS analysis of change in an agricultural landscape in Central Finland. *Agric. Food Sci Finland* 5, 567–576.
- Skånes, H., 1990. Changes in the rural landscape and the impact on flora. *Geografiska Annaler* 72A, 129–135.
- Soininen, A.M., 1975. Vanha maataloutemme. Maatalous ja maatalousväestö Suomessa perinnäisen maatalouden loppukaudella 1720-luvulta 1870-luvulle, Forssan Kirjapaino Oy. *J. Sci. Agric. Soc. Finland* 46, 309–316, 410–415.
- Tahvanainen, L., Tyrväinen, L., Ihalainen, M., Vuorela, N., Kolehmainen, O., 2001. *Landscape Urban Planning* 53, pp. 53–70.
- Tahvanainen, L., Ihalainen, M., Hietala-Koivu, R., Kolehmainen, O., Tyrväinen, L., Nousiainen, I., Helenius, J., 2002. Measures of the EU agri-environmental protection scheme (GAEPS) and their impacts on the visual acceptability of Finnish agricultural landscapes. *J. Environ. Manage.* 66, 213–227.
- Tarmi, S., Helenius, J., 2002. Maatalouden ympäristöohjelman mukaisten piennarten ja suojakaistojen toteutuminen sekä niiden kasviyhteisöjen monimuotoisuus. Helsingin yliopisto, Soveltavan biologian laitos, (in Finnish with English summary), Julkaisu No. 9, p. 35,+6 app.
- Tiainen, J., Pakkala, T., 2000. Population changes and monitoring of farmland birds in Finland. – *Linnut vuosikirja*, (Finnish with English summary). 1999. pp. 98–105.
- Turtola, E., Paajanen, A., 1995. Influence of improved sub surface drainage on phosphorus losses and nitrogen leaching from a heavy clay soil. *Agric. Water Manage.* 28, 295–310.
- Tyrväinen, L., Tahvanainen, L., 1999. Using computer graphics for assessing the aesthetic value of large-scale landscapes. *Scand. J. Forest Res.* 14, 281–288.
- Tyrväinen, L., Silvennoinen, H., Nousiainen, I., Tahvanainen, L., 2001. Rural tourism in Finland: tourists' expectation of landscape and environment. *Scand. J. Hospitality Tourism* 1, 133–149.
- Vehkasalo, V., 1999. Ympäristötuen yhteiskunnallinen kannattavuus (Abstract: Social profitability of the Finnish agri-environmental programme). In: Maatalouden ympäristöohjelma 1995–1999. n taloudellinen analyysi. Agricultural Economics Research Institute, Publications 90, Helsinki, Finland, pp. 42–77.
- YM, 1992. Arvokkaat maisema-alueet. Maisema-alue työryhmän mietintö I., (in Finnish with English abstract). Ministry Environ. Helsinki, p. 199.