

Field margins in northern Europe: their functions and interactions with agriculture

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Abstract

Most agricultural landscapes are a mosaic of farmers' fields, semi-natural habitats, human infrastructures (e.g. roads) and occasional natural habitats. Within such landscapes, linear semi-natural habitats often define the edges of agricultural fields. This paper reviews the role and interactions within and between the flora of these elements. In temperate, intensive agriculture, such field margin habitats, which historically had true agricultural functions, now are important refugia for biodiversity. As manmade habitats, field margins may also have important cultural roles as part of our landscape heritage, e.g. hedges in Britain. Whilst field margins are not usually specific habitat types, they contain a variety of plant communities in a variety of structures. These may range from aquatic elements to ruderal and woodland communities.

Studies demonstrate a variety of interactions between fields and their margins. Agricultural operations, such as fertiliser and pesticide application, have effects on the flora. Some margin flora may spread into crops, becoming field weeds. Margins also have a range of associated fauna, some of which may be pest species, while many are beneficial, either as crop pollinators or as pest predators. The biodiversity of the margin may be of particular importance for the maintenance of species at higher trophic levels, notably farmland birds, at the landscape scale. Margins contribute to the sustainability of production, by enhancing beneficial species within crops and reducing pesticide use. In northwestern Europe, a variety of methods to enhance diversity at field edges have been introduced, including sown grass and flower strips. The impact of these on weed flora and arthropods indicate mostly beneficial effects though conflicts exist, notably for the conservation of rare arable weed species. © 2002 Elsevier Science B.V. All rights reserved.

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1. Introduction

Field margins are a key feature of agricultural landscapes, present in some form at the edges of all agricultural fields (Marshall, 1988). In some landscapes, e.g. the bocage of northern France (INRA, 1976; Bazin and Schmutz, 1994; Burel and Baudry,

1999), field margins comprise the majority of the semi-natural habitats. In this paper, the role of field margins and their interactions with adjacent agriculture are reviewed with the objective of assessing their relative benefits for agriculture and the environment.

The definitions of field margins are varied and the etymology of the structures of field edges is equally diverse. Here, the term field margin is adapted from Greaves and Marshall (1987) and defined as the whole of the crop edge, any margin strip present and the semi-natural habitat associated with the boundary. The original definitions were based on the relative

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positions of the structural elements in the field margin and are repeated below. A functional definition can also identify a nature conservation strip that includes a margin strip and the crop edge managed for conservation (Marshall and Moonen, 1998). However, the areas at the edge of field blocks often form semi-natural habitats that are important refugia for flora and fauna.

1.1. The general structure of field margins

The principal components of an arable field margin are the boundary, any nature conservation or other strip and the crop edge. The margin strip is optional. The spatial layout is shown in Fig. 1.

Boundary. The boundary encompasses the barrier between fields or between two different types of land

use. Typical boundaries are a hedge, fence or wall, the hedge bank, if present, with its herbaceous vegetation, and any associated watercourse such as a stream, ditch or drain. Under some conditions, there may be no border between the crops, or simple post and wire fences dividing field areas.

The margin strip (see also Section 6). A margin strip is any strip established in the field or at the edge of the field, between the crop and the boundary. It may serve for access, wildlife and/or environmental objectives and may have agronomic, recreational or cultural functions. It includes grass strips, wildflower strips, strips sown to bird cover crops, unsown cultivated strips with naturally regenerated flora, sterile strips maintained by cultivation or herbicides, buffer strips and beetle banks. Beetle banks, however, are

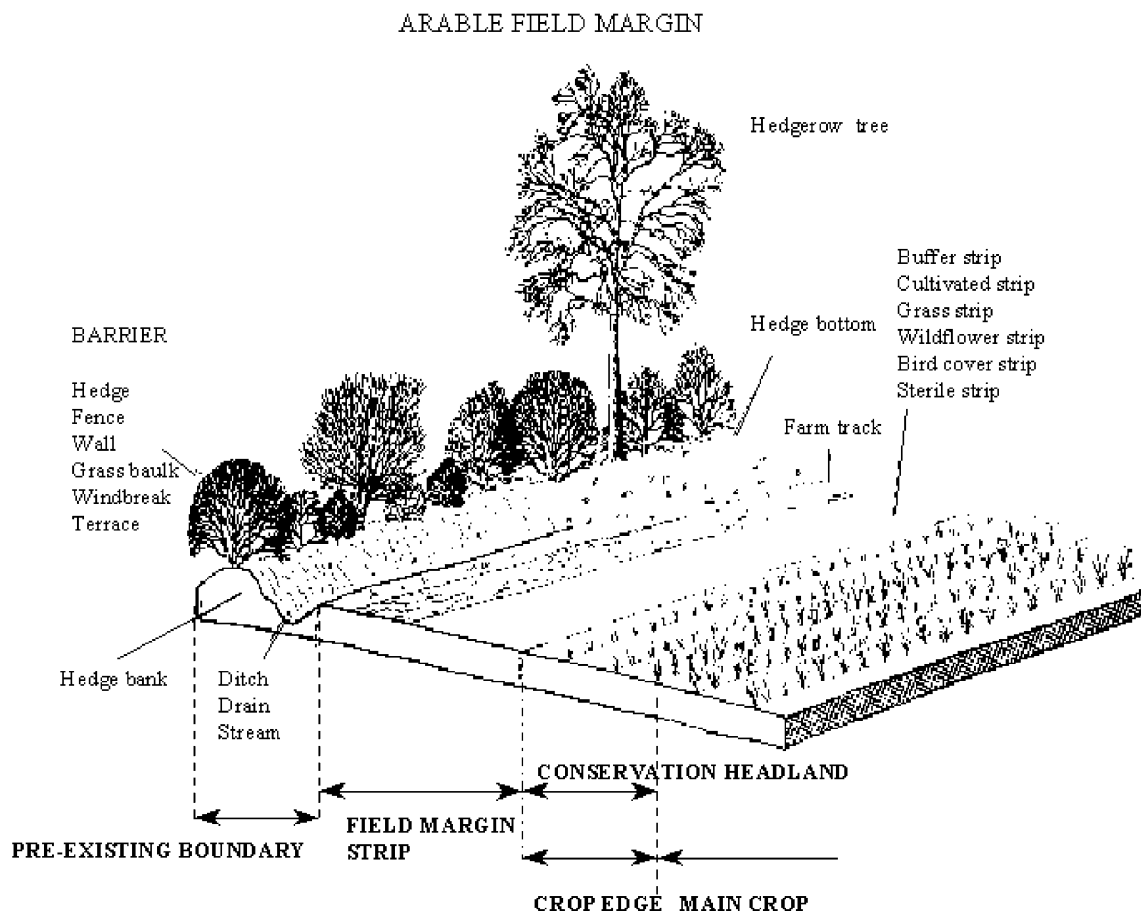


Fig. 1. The principal components of an arable field margin (after Greaves and Marshall, 1987).

situated across a field (Thomas et al., 1992) instead of between the pre-existing boundary and the crop.

The crop edge. The crop edge is defined as the outer few metres of the crop. The crop edge may be part of a nature conservation strip if it is a conservation headland or an unsprayed crop edge. Otherwise, it is a conventional crop edge.

The role and requirement of existing field margins in European farming systems have been reviewed by Marshall (1993, 1995) (Table 1). Field margins exist in the landscape because they have, or had in the past, real agricultural functions. Hedges and walls were maintained to keep farm stock in or out. In arable land, field margins delineate the field edge and land ownership. Local topography, geology, land ownership and farming enterprises influenced the form of field boundaries across Europe, giving a diversity of agricultural landscapes. Changes in agriculture have often resulted in changes in field boundaries. For example, land enclosures in England during the 18th and 19th centuries were accompanied by the planting of many hedges (Pollard et al., 1974). In modern times, agriculture has

Table 1

Roles, requirements and potential functions of semi-natural field margins in good agricultural practice (after Marshall, 1993)

Original roles and requirements	
1	To define the field edge
2	To be stock- or trespasser-proof, to keep animals in or out
3	To provide shelter for stock
4	To provide shelter for crops, particularly as windbreaks
5	To reduce soil erosion by wind or water
6	Not to compete with the crop for light, moisture or nutrients
7	Not to harbour weeds, pests and diseases
8	To harbour beneficial plants and animals
9	To act as a refuge or corridor for wildlife
10	To provide a source of fruits and wood
Current and potential functions of field margins	
A	Promotion of ecological stability in crops
B	Reducing pesticide use: exploiting pest predators and parasitoids
C	Enhancing crop pollinator populations
D	Reducing weed ingress and herbicide use
E	Buffering pesticide drift
F	Reducing fertiliser and other pollutant movement, especially in run-off
G	Reducing soil erosion
H	Promotion of biodiversity and farm wildlife conservation
I	Maintaining landscape diversity
J	Promotion of game species

Table 2

Major functions of field margins in agroecosystems

Function	Role
Agronomy	Land ownership, stock fencing, shelter, windbreak, weed and pest control, game and wood
Environment	Pollution control, eutrophication, pesticides, erosion, snow and water flow, and siltation
Nature conservation	Species refugia, biodiversity, habitat, feeding, breeding, corridor and movement
Recreation and rural development	Access, walking, driving, hunting, tourism, aesthetics, culture and heritage

seen major changes, with intensification of production, developments in machinery, crop protection and the need for larger field sizes. Land re-allotment programmes, in which ownership has been rationalised, have also been implemented in many countries. These developments have been accompanied by changes in field boundaries, often the removal of such features. However, a series of subsidiary roles for field margins have been identified, reflecting agricultural, environmental, conservation, recreational and cultural or historical interests. Further, new approaches to creating and managing field margins have shown the importance of these functions. Udo de Haes (1995) discussed the four different interests involved in field margin management, as defined by de Snoo (1995) (Table 2).

1.2. Agronomic functions

Field margins have as their prime agricultural roles, stock fencing and delimiting field areas or ownership. In addition, margins provide shelter for stock in adverse weather, both with shade in summer and shelter from snow and wind in winter. Margins can play an important role as windbreaks to protect adjacent crops. Studies on wind behaviour show the shelter effects of hedges (Marshall, 1967; Helps, 1994). Field margins provide habitat for a range of insects. Many of these are of agronomic benefit to adjacent arable crops (Wratten, 1988) though pest species also occur. Many polyphagous beetle species use margins as over-wintering habitat, from which they emerge into the crop. They are also good places to locate beehives (Carr and Bell, 1991).

1.3. Environmental functions

Field margins may act as buffers to the movement of pollutants to adjacent terrestrial and aquatic habitats. This may be by drift retention (e.g. Davis et al., 1994; de Snoo and de Wit, 1998; Tsiouris and Marshall, 1998) or by preventing the movement of surface water flow and particulate movement (e.g. Cooper et al., 1995; de Jong and Kowalchuk, 1995; Lowrance et al., 1997; Sovell et al., 2000). Margins may also influence the flow of nutrients and water within agricultural landscapes (Pinay et al., 1993; Burel, 1996).

1.4. Recreational functions

As traditional features in some landscapes, field margins may have heritage values. For example, many old hedges dating back nearly 1000 years to the Saxon era in Britain delimit the boundaries of church parishes (Pollard et al., 1974). More recently, hedges planted during land enclosures were also used as jumps for horses during fox hunting. The typical hedge landscapes of Normandy, Brittany and England encourage tourism and give a sense of place to residents and visitors alike.

Field margins can be used as footpaths and bridleways, providing access in the countryside, leaving the cultivated area undisturbed. Flower strips around fields near main roads have improved the aesthetic value of the landscape; people will stop and take photographs. Field margins can also enhance gamebird populations by providing nesting cover and food resources and can thus contribute to farm income in hunting areas.

1.5. Wildlife functions

Studies of the changes in land use in the UK, under the UK Countryside Survey, have included botanical assessments of field flora and the flora of linear landscape features including hedges, verges and watercourses. In intensively managed lowland landscapes, linear features contain the greatest botanical diversity (Barr et al., 1993). Thus field margins are refuges for many species. In addition to the flora, field margins may also support a diverse fauna, including invertebrates (Sotherton, 1985; Morris and Webb, 1987; Wratten, 1988; Duelli et al., 1991; Lagerlöf et al., 1992), mammals (Pollard and Relton, 1970;

Boone and Tinklin, 1988; Fitzgibbon, 1997; Verboom and Huitema, 1997) and birds (O'Connor, 1987; Lack, 1992; Vickery and Fuller, 1998). The role of field margins for gamebirds, notably partridge (*Perdix* spp.), are well documented (Potts, 1986; Rands and Sotherton, 1987).

As linear features, field margins are also thought to act as corridors for the movement of fauna and possibly flora. Evidence for this has been shown for carabid beetles of forest and woodland in Brittany (Burel, 1989). Bats also utilise margins to fly along, as part of their feeding behaviour (Verboom and Huitema, 1997). Field margins are also known to be important over-wintering habitat for many insects that move into adjacent arable crops (Sotherton, 1984; Wratten, 1988; Thomas et al., 1994). However, it has also been shown that field margins can be barriers to the movement of such species between fields (Mauremooto et al., 1995; Thomas et al., 2001). Field margins may also act as sources for some crop pests (van Emden, 1965; Frank, 1998a).

2. The field edge ecotone

The classical definition of an ecotone is a region of marked ecological change, often between different environments, reflecting a transition zone between two different habitats and disjunct species distributions (Forman, 1995). The plant communities of the ecotone can reflect mixtures of the adjacent habitats, but often the ecotone also supports characteristic species not present in the adjacent habitats. Typical ecotones are those at the edge of watercourses, the seashore and woodland edges. The application of the term ecotone to the edges of agricultural fields is comparatively recent (Kovar, 1992), reflecting studies on the distribution of flora at arable field edges (Marshall, 1989; Fritz and Merriam, 1994; Joenje and Kleijn, 1994). Under arable farming, when soils are regularly cultivated, the field margin may be regarded as an ecotone. There is usually a disjunct distribution of the flora, with ruderal species predominating in the crop area and a different community, at least under northern European Atlantic climate conditions, within the relatively less disturbed boundary. Within the field margin ecotone, a mixture of species is often present resulting in higher diversity than either the arable field or the boundary (Marshall,

1989). The margin flora and the arable weed flora at 5 and 50 m into fields have been studied on a farm in Essex, UK (Marshall and Arnold, 1995). Results indicated no relationship between the plant communities. Within permanent grassland, it might be argued that there is less difference between the flora of the field and the boundary. Nevertheless, there are often marked differences in management within grass fields, associated with sowing short-term leys, fertiliser use, cutting for silage and grazing, which result in a different flora to that in the margin (Marshall and Hopkins, 1990).

3. Plant communities in field margins

As field margins often comprise a variety of structures, including watercourses, banks, woodland edges, etc. a variety of plant communities can occur within them. There are almost no characteristic field margin plant species in Britain though a range of communities may be present. The communities can include segetal or ruderal plants, typical of arable land or disturbed ground. In addition, grassland communities, tall herb communities, shrub, woodland and aquatic communities may be present. In Britain, only one shrub species, *Pyrus cordata* (Plymouth pear) is found only in field margins, certain hedges in southwest England (Hooper, 1970).

Phytosociological surveys of British field margins identify four scrub or underscrub communities, each associated with hedge species such as *Crataegus monogyna*, *Prunus spinosa* and *Rubus fruticosus* (Rodwell, 1995). The plant species present may represent sub-optimal communities of a variety of other habitat structures. However, extensive surveys across Britain (Barr et al., 1993) identify linear semi-natural features in lowland agricultural landscapes as containing the most diversity of plant species. Thus field margins, streambanks and verges are refugia for plant species in intensively managed land and a key to the conservation of plant diversity (Bunce et al., 1994). It is likely that this pattern is repeated across Europe (Van Strien, 1991; Melman and Van Strien, 1993; Burel and Baudry, 1995; Burel et al., 1998) and North America (Forman and Baudry, 1984; Freemark and Boutin, 1995; Jobin et al., 1997; Boutin and Jobin, 1998).

4. Impacts of agriculture on field margin flora

The close proximity of the field boundary to farm operations renders them susceptible to disturbance. In arable land, the application of inorganic and organic fertiliser can result in the addition of plant nutrients to non-target areas such as field margins (Rew et al., 1992; Tsiouris and Marshall, 1998). Data

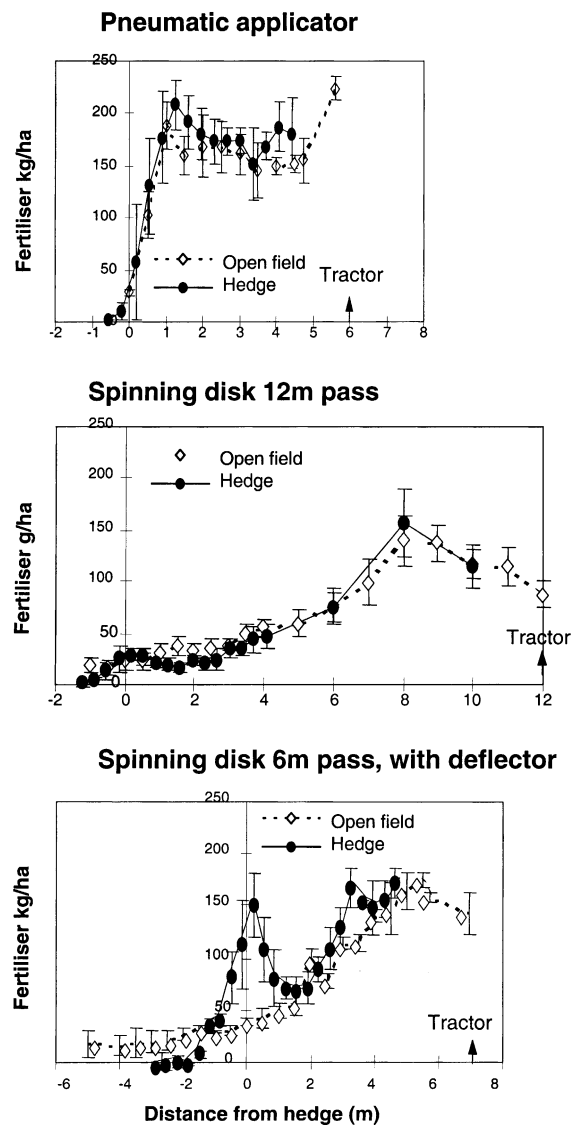


Fig. 2. Patterns of granular fertiliser deposition from a pneumatic and spinning disk applicators in open-field conditions and against a hedge (after Tsiouris and Marshall, 1998).

on inorganic fertiliser displacement indicates that spinning disk machinery, rather than pneumatic or liquid injection methods, can spread granular fertiliser significant distances into field margins. The presence of a structure such as a hedge can result in concentration of fertiliser granules at the field edge, giving application rates as high as field concentrations (Fig. 2).

The addition of nitrogen and phosphorous to field margins is likely to result in dominance by responsive competitive-ruderal species (*sensu* Grime, 1979) and the loss of species diversity (Marrs, 1993). The drift of other agrochemicals, particularly herbicides, may also affect field margin flora (Marshall, 1987). Drift does occur (Longley et al., 1997; de Snoo and de Wit, 1998) though data on the impacts on flora are limited (Marrs et al., 1991; Marrs and Frost, 1997). Studies of the flora of field margins where different herbicide regimes were imposed on the adjacent arable fields have not revealed significant changes in the boundary flora (Marshall, 1992). However, experimental studies on field margin communities affected by fertiliser and

herbicide have shown significant impact of fertiliser on the flora and some effect of herbicide (Fig. 3), dependent on the active ingredient (Kleijn and Snoeijs, 1997). The effect of soil cultivation and disturbance from hedge cutting are also thought to affect the flora of the field edge (Bond, 1987).

At the field and landscape scale, a number of studies have investigated the effect of farming on the flora of field edges. In the bocage of northern France, farming and landscape structure interact to influence both the woody and herbaceous flora of boundaries (Le Coeur et al., 1997; Thenail et al., 1997; Burel et al., 1998; Baudry et al., 2000), reflecting the impact of agricultural management. Studies of the flora in linear landscape features in the UK as part of the National Countryside Survey indicate that while linear features are important for botanical diversity (Barr et al., 1993), there have been significant declines over time. The increase of nitrophilous plant species indicates eutrophication is occurring, probably from a variety of sources, including agriculture and the atmosphere. Studies also

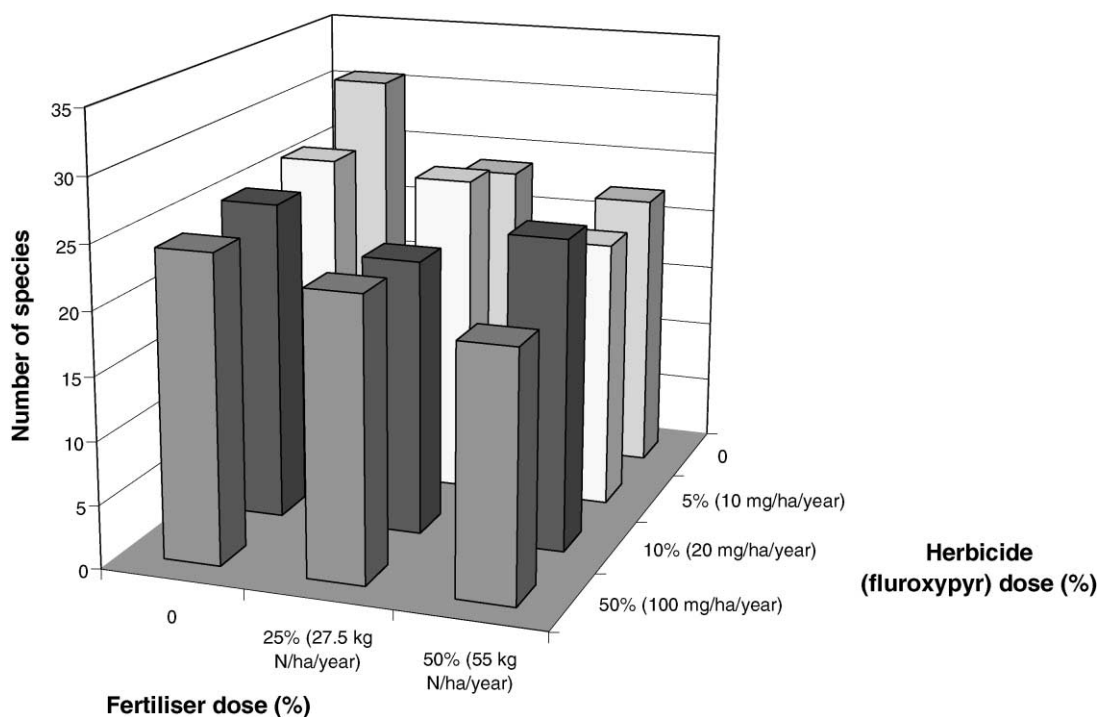


Fig. 3. The effects of 3 years of fertiliser and herbicide application (as % of standard dose) on species richness (no. of species per square metre) of a mixture of grassland species sown on a fallow arable field (after Kleijn and Snoeijs, 1997).

indicate that as adjacent field productivity increases, the role of linear features as refugia for plant diversity also increases in importance (Smart et al., unpublished).

5. Impacts of margin plants on adjacent agriculture

The flora of field edges can have both direct and indirect effects on adjacent agriculture. Direct effects are mediated through weed spread into the crop and by microclimatological and competition effects. Crop yields are typically less at the field edge than the middle (Boatman, 1992; Cook and Ingle, 1997; Sparkes et al., 1998). These effects may be due to competition for light, moisture or nutrients by the flora of the field boundary. The structure of the margin may also affect the distribution of pest and beneficial insects at the field edge (Lewis, 1969). However, the boundary may protect the adjacent crops, acting as a wind-break or snow barrier (Marshall, 1967; Helps, 1994). Studies on the location of plants at arable field edges (Marshall, 1989; Wilson and Aebischer, 1995) reveal that plant species show four distribution patterns: (1) limited to the non-crop area, (2) some ability to spread from margins, (3) typically limited to the crop area or (4) have highest densities in crop edges or headlands. In temperate northeastern Europe, the number of species typical of the margin that also invade the crop edge (type 2) are limited in number. More often, the weed flora of the arable crop is largely unrelated to that in the margin (Marshall and Arnold, 1995). Those species that spread into the crop include annuals, such as *Anisantha sterilis* and *Galium aparine*, perennials, such as *Elytrigia repens*, and biennials, such as *Heracleum sphondylium*. Further, the disturbance of the field margin and the removal of perennial species can encourage populations of the annual species capable of colonising the field. Weed ingress may be managed by recreating or maintaining a perennial flora in the field margin and reducing disturbance (Marshall and Smith, 1987; Moonen and Marshall, 2001).

Indirect effects of the margin on adjacent farming are mediated through plants via other groups. Certain pest species are associated with plant species in field margins. For example, black bean aphids use the shrub *Euonymus europaeus* as their primary host

(vanEmden, 1965). There is also evidence of mollusc species spreading into crops from margins and causing crop damage (Frank, 1998a). Whilst there are such examples of adverse effects of field margins on adjacent agriculture, there are also many examples of beneficial invertebrate species associated with field margins. Polyphagous predators have been shown to be associated with margins (Sotherton, 1984, 1985; Wratten, 1988; Booij and Noorlander, 1992). A number of beetle species and spiders are associated with field margins (Huusela-Veistola, 1998; Thomas and Marshall, 1999) and can have significant impacts on aphid populations. As well as predators, such areas can contain plants that support populations of pollinating insects which are of value to legume and other crops (Fussell and Corbet, 1992; Lagerlöf et al., 1992; Corbet, 1995). Observations on the beneficial effects of pest predators led to the development of “beetle banks” as reservoir habitats for over-wintering species (Thomas et al., 1991). A proportion of these species are associated with particular plant species, while others are influenced by the vegetation structure of the margin.

6. Impacts of introduced field margin strips

In Europe, a variety of methods of managing the field edge have been researched and introduced (Marshall and Moonen, 1998) including sown grass and flower strips. These modifications to traditional management have had a variety of objectives, including enhancing biological pest control, enhancing gamebird populations, weed control, environmental protection, wildlife conservation and enhancing diversity. Broadly, there have been: (a) methods to reduce weed ingress involving the use of herbicides or cultivation to create a cordon sanitaire, (b) methods that manipulate the management of the crop edge and (c) methods to create new vegetation structures as margin strips and buffers. Most techniques have more than one objective.

Modifications to the management of the pre-existing boundary, particularly hedges, whilst relevant, are not considered here. Nevertheless, ongoing research (e.g. Maudsley et al., 2000) indicates that management can have profound effects on the ecology of boundaries. Techniques of creating and managing margin strips are considered further.

Table 3
Types of modified field margin strips

Type	Description	References
Sown grass strip	Sown strip at the field edge	Marshall and Smith, 1987; Huusela-Veistola, 1998
Sown grass and wild flower strip	Sown strip at the field edge	Marshall and Nowakowski, 1991; Smith et al., 1993; Lys et al., 1994; West and Marshall, 1996; Kleijn et al., 1998
Sterile strip	Cordon sanitaire round the field edge created with herbicide or cultivation	Bond, 1987
Uncropped wildlife strip (arable flower margin)	Cultivated strip, but not sown with a crop	Critchley, 1994
Set-aside margin	Typically 20 m wide strip of natural regeneration, qualifying for set-aside payments	MAFF, 1988
Sown wildlife mixtures (strips or blocks)	Blocks of seed and flower-producing plants; also game cover strips such as kale	Game Conservancy, 1994
Conservation headland	Reduced herbicide and pesticide use in the crop edge	Rands, 1985; Sotherton et al., 1985; Rands and Sotherton, 1987; Chiverton, 1993
Beetle bank	Sown grass strip across large fields, typically on a raised bank created by ploughing	Thomas et al., 1991, 1992

6.1. Types of margin strips

Margin strips can be divided into two groups, i.e. permanent and temporary strips (Table 3). The type of strip that is created can have major impacts on its possible functions for wildlife and environmental protection, as well as for the way the strip fits into existing farming practice. Permanent strips are created by natural regeneration of the flora or are sown to perennial grass and/or wildflower mixtures and can include beetle banks across fields. Temporary strips include the uncropped but cultivated strips (uncropped wildlife strips), unsprayed crop edges (conservation headlands) and strips sown to bird cover crops or flowers to encourage pollinating insects or other beneficial insects. Permanent strips are especially important for species that do not disperse easily in the landscape, notably most plant species. Buffer strips will usually be permanent, protecting watercourses from pollution by agrochemicals. For the farmer, permanent strips may require extra work, because the strips cannot be treated as a crop within the field. Nevertheless, permanent strips may facilitate access or be sited to control weeds. Management of temporary strips, on the other hand, can be integrated in the normal crop management, because, on most occasions, the conservation strip is part of the crop. However, they will

only be beneficial for those species that are adapted to regularly cultivated crop areas or have the ability to move freely in the landscape. Such species may not depend on the nature conservation strip, but can use the pre-existing boundary and other landscape elements at different times of the year. Temporary strips can also play an important role in the conservation of rare or threatened arable weed species.

6.2. Agronomic impacts of introduced margin strips

Few studies on the weeds associated with grass strips have been made. However, unpublished work on comparisons of sown strips with sterile strips and cropping to the boundary (Nowakowski and Marshall, 1998) indicates that grass and wildflower strips can prevent spread of *A. sterilis* to some extent. Further, due to the movement of the edge of cultivation, sterile strips can increase *A. sterilis* populations in the field margin. Marshall (1990) demonstrated that sown perennial grasses significantly reduced the growth and spread of rhizomes of *E. repens*, a perennial weed of field edges. Thus grass strips could reduced ingress of this weed. Recent studies of different sown mixtures for creating margin strips in ESAs have shown that a variety of weeds, including *H. sphondylium*, *Urtica dioica*, *A. sterilis* and *Cirsium arvense*, are signifi-

cantly reduced by sowing grass or grass and flower mixes (West et al., 1997; Smith et al., 1999). These studies and others indicate that where a field margin contains less desirable plant species at the outset, these are likely to increase where natural regeneration is used to create extended margins. Sowing will reduce these species but not eliminate them (Marshall and Moonen, 1997).

Significant reductions in aphid populations have been recorded up to 5 m into an adjacent cereal crop from grass + flower strips in Germany (Marshall, 1997). Flower strips can also enhance numbers of predatory hoverflies (Harwood et al., 1992; Hickman and Wratten, 1996). Other beneficial insects are those which pollinate crops, notably bees and bumblebees. These species utilise flower resources which can be created or enhanced by extended margin strips (Lagerlöf et al., 1992) though care is required in selecting seed mixtures (Carreck and Williams, 1997).

The presence of margin strips may facilitate access to crops for weed, pest and disease inspection. Strips may also allow the management of the boundary, notably hedge cutting, without damage to adjacent crops. Strips may also allow machinery turning and reduce compaction within the crop.

Extended margins may not always provide agronomic benefits. There are unconfirmed reports of increased rabbit damage adjacent to extended margins. In Switzerland, mollusc grazing in oilseed rape can be increased adjacent to flower strips (Frank, 1998a).

6.3. *Environmental impacts of introduced margin strips*

Margin strips can influence the environmental impacts of agricultural operations, particularly fertiliser and pesticide applications and off-target effects. This may be achieved by interception, collection and modification of agrochemicals. The introduction of margins may result in farming operations taking place at greater distance from pre-existing semi-natural habitat and thus giving them some protection. Buffer strips can be used to reduce surface movement of water and entrained sediment into watercourses and some leaching of nutrients and agrochemicals. Increased infiltration at the field edge may reduce erosion and allow greater opportunity for nutrient transformation before reaching off-field areas.

Buffers can be either grass strips or forested areas. Structural diversity in the buffer strip, with trees, shrubs and a grass margin, is reported to be most effective (Verchot et al., 1997; Haycock and Pinay, 1993).

6.3.1. *Interception of drift and misplaced fertiliser*

de Snoo and de Wit (1998) and de Snoo (1999) demonstrated that the creation of a 3 m wide buffer strip (an unsprayed crop edge or conservation headland) reduced pesticide drift into the adjacent ditch by 95% at wind speeds of 4.5 m/s; with 6 m wide buffer strips, no drift could be measured in the ditch. Marrs et al. (1989) found that the maximum safe distance at which no lethal effects from herbicides were found was 6 m from a tractor-mounted sprayer, but for most herbicides 2 m wide strips were sufficient. At that distance, plants can be damaged, but they recover towards the end of the growing season. However, 5–10 m wide buffer strips were recommended around nature reserves. Introduced grass margins should therefore offer some protection to pre-existing habitat.

The presence of a hedge may reduce pesticide drift to adjacent areas by collection though deposition on the lea side of hedges is observed (Davis et al., 1994). The concentration effect of a hedge on fertiliser granule deposition is also marked (Fig. 2; Tsiouris and Marshall, 1998). The effect of different vegetation structures on spray drift interception is currently being examined (M. Nowakowski, pers. comm.).

6.3.2. *Reduction of dissolved soil nutrients*

Mander et al. (1997) found that forested buffer strips in Estonia are effective in reducing N and P input in streams. Younger stands were more efficient than older stands and width was an important factor in the design of the buffer strip. Verchot et al. (1997) found a marked decrease in nitrate concentrations at the edge of a field with a grassy filter strip and a larger effect at the edge of a field with a forested filter zone. Winter nitrate retention in a grass and a poplar vegetated buffer strip in the south of England has been measured. The poplar strip was found to be more efficient in NO₃ retention than the grass strip. It is suggested that although the vegetation does not have an active role in nitrate retention in winter, the vegetation supplies the soil microbial biomass with carbon, necessary for denitrification (Haycock and Pinay, 1993).

Vegetated filter strips in North Carolina greatly reduced runoff of chemical loads into the watercourses with up to 50% of P and NH_4 was filtered out (Daniels and Gilliam, 1996). A multi-species riparian buffer strip system with four tree species, shrubs and a switchgrass strip placed along a stream in Iowa reduced nitrate–nitrogen concentrations considerably. In the buffer strip, levels never exceeded 2 mg/l whereas they were 12 mg/l in the adjacent arable fields. The system helped to control soil erosion, trapped and transformed N and P pollution, stabilised the stream-bank, provided wildlife habitat, produced biomass for on-farm use, contains quality hardwood for the future and enhanced the aesthetics of the landscape (Schultz et al., 1995).

Grass cover increases infiltration rate, which may allow nitrogen transformations to occur before reaching watercourses or groundwater. Experimental tilted beds with clay loam and a switchgrass sward gave 64% infiltration rather than runoff. This figure was reduced to 26% for bare clay loam beds. Sandy loam beds with switchgrass gave 17% infiltration within the stand and bare sandy loam only 8% (Mersie and Seybold, 1997).

6.3.3. Reductions in sediment transport

Sediment transport can result in the movement of phosphorous and pesticides to non-target habitat, as well as causing sediment build-up in watercourses. In Finland, grass buffer strips were found to reduce the amounts of total solids, phosphorus and nitrogen in water by 23, 6 and 47%, respectively. The buffer strips were effective in autumn, but not in spring (Uusikamppa and Ylaranta, 1992). van Dijk et al. (1996) also found that grass strips could play a role in soil erosion control. Outflow sediment concentrations depended on inflow concentration of sediment and width of the grass strip. Reductions of sediment discharge varied between 50 and 60, 60 and 90, and 90 and 99% for strips of 1, 4–5 and 10 m width, respectively. Old grass strips were more effective than younger grass strips, probably due to differences in grass density. In France, Patty et al. (1997) showed that grassed buffer strips of 6, 12 and 18 m wide reduced suspended solids by 87–100%, loss of atrazine and its metabolites by 44–100% and more than 95% of isoproturon and diflufenican. Sowing the crop perpendicular to the slope seemed to be beneficial in reducing pesticide content in runoff.

The effectiveness of vegetated buffer strips not only depends on their hydrologic and hydraulic characteristics, but also on their width and placement within the landscape (Tim et al., 1995). Pearce et al. (1997) demonstrated in a laboratory experiment that length and width of the vegetated buffer strip is more important for filtering sediment than height of the vegetation.

6.4. Wildlife impacts of introduced margin strips

Buyts (1995) compared the effects of four types of nature conservation strips on the vegetation, mammals, breeding birds and insects, and compared their compatibility with existing farming practices. The strips were natural regeneration, regeneration strips with volunteer cereals in combination with sowing of wildflowers, sown grass–clover and sown leguminous strips. The grass–clover mixture gave the lowest plant species diversity, but in some strips rare arable weeds appeared. Deer and hares were particularly attracted to the leguminous strips. The strips were not very important for breeding birds, but most species were found in the natural regeneration and the leguminous strips and partridges fed in some strips. Butterfly abundance and species richness was highest in the leguminous strips and lowest in the grass–clover strips. Hoverfly (Syrphidae) numbers were related to the presence of mayweed (*Matricaria*) species.

Comparison of the vegetation development of margins strips left to revegetate naturally or sown with a simple grass mixture indicated that colonisation by the adjacent flora was slow. A grass mixture may be useful from a weed control viewpoint, but species richness was typically low on such plots (Kleijn et al., 1998). Inclusion of perennial flowers in seed mixtures results in greater plant species richness (Marshall and Moonen, 1997) and associated invertebrate diversity (Thomas and Marshall, 1999). Over-wintering habitat for invertebrates is provided by such strips (Thomas et al., 1994).

de Snoo (1995) showed that the cover and the species richness of crop weeds in unsprayed crop edges increased compared with sprayed crop edges. In sugar beet, cover increased from 10 to 44% and species richness from 6 to 24 species; in potatoes, cover increased from 4 to 11% and species richness from 8 to 17 species and in winter cereals, cover

increased from 2 to 32% and species richness from 6 to 17 species. Most *Papaver* species, *Anagallis arvensis* and *Fumaria officinalis* are only found in the unsprayed crop edges and not elsewhere in the field. Insect densities increased by a factor of 3–4 in the unsprayed crop edges and species richness increased by a factor of 1.4. Although aphid densities are higher in the unsprayed crop edges than in the sprayed crop edges, they did not spread into the rest of the field. Butterfly species richness also increased in the unsprayed edges, and there was a positive spin-off for diversity in the ditch bank. Carabid activity was higher by a factor of 1.3 in the unsprayed crop edges rather than in the sprayed crop edges. The number of carabids also increased. Unsprayed winter cereal edges had a positive effect on blue-headed wagtail (*Motacilla flava flava*).

6.4.1. The boundary

Margin strips can protect wildlife in the pre-existing boundary. Hegarty and Cooper (1994) showed in Ireland that hedges with a boundary strip or uncultivated and unsprayed headland often have higher species richness than other hedges. Investigations by Longley et al. (1997) and Longley and Sotherton (1997) into the reduction of the volume of spray drift reaching the boundary show that 6 m wide buffer strips significantly reduce the spray drift into the boundary, the exact reduction depending on wind conditions and crop. There was evidence that the mature arable crop would absorb some of the spray drift in situations without a buffer strip. Mortality rates of butterfly larvae fed on grasses from the boundary with a buffer strip were lower than those on grasses from a boundary without a buffer.

Buffer zones may also be needed to protect seedlings of non-target plants in field boundaries from herbicide spray drift. A multi-species experiment showed a wide sensitivity of species to spray drift. Seedlings of some plants were affected at greater distances than established plants, either by greater capture of spray drift or by greater sensitivity. Thus, on sites where vegetation regeneration is largely dependent on seedling establishment, buffer zones up to 20 m wide may be needed (Marrs et al., 1993).

A comparison of the hedge-bottom vegetation of two neighbouring farms in Wiltshire, one with 2–20 m wide sown grass strips and the other with 0.5 m wide sterile strips, showed that sown grass strips had a pos-

itive influence on species richness. The abundance of *A. sterilis* in the hedge-bottom was also significantly reduced where grass strips were present (Moonen and Marshall, 2001). The mechanism is believed to be the protection from disturbance afforded by the introduced grass margins.

6.4.2. Landscape

Nature conservation strips, as new habitat, can enhance the diversity of elements in the landscape. Like any other type of field margin habitat, they may act as a corridor for the dispersal of species through the landscape. The purpose of a corridor should be to facilitate recolonisation of a habitat after local extinction, to serve as routes for migrating animals or to link connected patches of small habitats to provide sufficient territory for mobile animals to maintain a population. Few studies have shown the corridor function of nature conservation strips though this role is clear for hedgerows and forest beetles (Burel, 1989; Charrier et al., 1997). Dover (1994) demonstrated flight patterns of butterflies along field margins, while Hopkins and Feber (1997) indicate that butterflies are associated with the field margin rather than the crop in arable land. de Snoo (1995) states that the establishment of unsprayed strips without any connection to pre-existing landscape elements such as ditchbanks is of little use to butterflies. Certain bat species, e.g. pipistrelle (*Pipistrellus pipistrellus*), continuously feed while flying. They only fly above habitats that supply sufficient food, among which are many types of field margins. In addition, they will not usually cross gaps of more than 30 m within these linear habitats. These data are confirmed by studies in the Netherlands by Verboom and Huitema (1997).

7. Discussion

In intensively managed agricultural landscapes semi-natural habitats survive as remnants, most often as linear features, of which field margins are usually the commonest structures. Whilst boundaries originally had and still have agricultural functions, their importance for environmental and conservation functions is becoming of greater significance. Their close proximity to agricultural operations renders them susceptible to disturbance, particularly from pesticide

drift and eutrophication from fertiliser misplacement. The effects of fertiliser may be of greatest significance for the flora (Marrs, 1993; Kleijn and Snoeijs, 1997), but insecticide drift may adversely affect the fauna (Davis et al., 1994). At the landscape scale, structure, location, land use and management can affect the composition of field margins (Le Coeur et al., 1997). Such features may be sources of weeds, pests and disease, but data indicate that weed problems are limited to a small number of species and field margins may be of greatest importance in providing habitat for beneficial species within agriculture. In warmer Mediterranean conditions, the flora may behave very differently to the moist Atlantic areas, where competitive exclusion by perennial species reduces annual weeds. However, there is little published information on this. The role of climate on the composition of the margin flora across Europe is worthy of further study.

A range of initiatives has resulted in the creation of new field margin features in northern Europe, notably conservation headlands and margin strips. Support mechanisms exist to encourage farmers to create new habitat, e.g. the UK Countryside Stewardship Scheme (MAFF, 1998) and the Dutch Ecological Mainframe. The functions of these strips are often for wildlife conservation in farmland, aimed at Biodiversity Action Plan species or habitats (Anon., 1994), but agronomic reasons for their creation also exist, e.g. to control annual hedgerow weeds such as *A. sterilis*. The use of buffer strips in riparian situations to limit pollution has also promoted margin strips. Whilst further data on the impact of introduced margin strips on different taxa are required, current data demonstrate beneficial effects of botanical diversity, particularly wild flowers, on invertebrate diversity (Thomas and Marshall, 1999), Syrphidae (MacLeod, 1999; Frank, 1999) and bees (Fussell and Corbet, 1992). Other taxa may respond to vegetation structural diversity, e.g. Araneae (Huusela-Veistola, 1998). Whilst many studies demonstrate the enhancement of populations of pest predators or parasitoids, few studies clearly demonstrate significant impacts on pest populations (e.g. Kromp, 1999).

Some potential conflicts exist in creating new habitat as field margin strips. The creation of new habitats is unlikely to be as important for wildlife as the retention of existing margins, particularly where these form linkages in the landscape (Grashof-Bokdam,

1997). It is also argued that the need to maintain existing corridors should not depend on absolute proof of their value. The requirement for careful targeting of new margin strips is illustrated with situations where rare annual arable species are known to occur. These species require regular soil disturbance to create germination opportunities and often survive only in the margins of intensively managed fields (Wilson, 1994). Sowing a perennial margin strip in such situations will remove safe sites for germination and increase competition, resulting in poor survival. However, new margins can be established where colonisation from the seedbank or from adjacent areas will allow diverse communities to develop. From an agricultural viewpoint, flower margins may enhance populations of certain gastropod species (Frank, 1998a) resulting in crop damage in oilseed rape, but not winter wheat. However, control measures using molluscicides can be implemented at the crop edge (Frank, 1998b).

This paper summarises some of the benefits and possible conflicts of interest associated with field margins. A number of areas are identified where further information is required:

1. Roles of field margins for different taxa and interactions between different species:
Little information is available for Amphibia, Reptilia, Gastropoda and Heteroptera or on species and trophic interactions in margins.
2. Role of margins in the landscape:
No information is available on the quantity, quality and configuration of field margins in the landscape to optimise species and community conservation. The corridor function of margins has not been quantified for the majority of species. The effects of landscape complexity on “ecological stability” in crops, pest species and biological control are also largely unquantified.
3. The effects of climate on margin plant communities:
The composition of the margin flora across Europe may vary markedly, affecting function and species interactions, as well as management requirements.
4. The management of field margins:
There are well-defined management options for certain objectives, particularly enhancement of plant diversity and gamebird populations, but for most other taxonomic groups no specific

management options have been developed. Some refinement of management options and seed mixtures, taking into account possible conflicts, soil restrictions and needs for recreational access, are required. The effects of vegetation composition on buffer function also need to be quantified.

5. The interactions between agriculture and the margins:

Better quantification of the effects of field margin strips on crop performance through their influence of pest predators, parasites and pollinating insects is needed. There is also a need to understand the relationships between margins and modifications to crop management at the field edge, e.g. machinery use, soil compaction, double cultivations, etc.

8. Conclusions

Agricultural habitats are a mosaic of cropped and uncropped areas. Field margins play an important role in the biological diversity of farmland, affecting and being affected by adjacent crop land. Whilst there may be some conflicts between these habitats, notably for crop protection, there are clearly opportunities to derive crop protection benefits and conservation benefits from appropriately managed field margins. Further, the view that cropped habitats are simplified ecosystems should no longer be espoused. Complex interactions between cropped and non-crop areas are important for many taxa. Studies on carabid beetles, e.g. by Thomas et al. (2001), illustrate that some species utilise the crop, others the margins and yet others utilise both habitats at different times of year. Clear understanding of these interactions may allow the design of field and margin arrangements that utilise biodiversity within the crop and conserve farmland wildlife at the landscape scale.

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