SESSION 4A

WEEDS, BIODIVERSITY AND ENDANGERED SPECIES

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Papers	4A-1 to 4A-4

The diversity of arable plants – past, present and some futures

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ABSTRACT

There is much current concern about declines in the biodiversity associated with changes in the diversity of arable plants. Sources of data on the current status and trends in the flora of arable fields are reviewed. Forthcoming national data sources are reviewed, and a proposal for a synoptic arable plant survey is presented. There have been reductions in and in the range of some species, reductions in species diversity at the field level, and shifts from broad-leaved species to assemblages dominated by grasses. It is suggested that present conservation measures may be enough to ensure the survival of scarce species, but that the decline in conservation value of arable fields in general will continue, unless there is an increased awareness that weed management and arable plant conservation are not incompatible.

INTRODUCTION

There is substantial public and policy concern over the declines in arable plants in Great Britain. This concern partly reflects worries about arable plant species that are now nationally rare (Stewart *et al.*, 1994), and partly worries about the declines of more common species that are regarded as being important food sources for animal groups (Campbell *et al.*, 1997; Potts, 1997). These concerns have already led to a series of policy initiatives. The cereal field margin is now one of the priority habitat types under the Biodiversity Action Plan (Anon, 1995), with an action "to maintain, improve and restore by management the biodiversity of some 15,000 ha of cereal field margins on appropriate soil types in the UK by 2010." The pilot Arable Stewardship scheme has been introduced in England specifically to conserve the flora and fauna of arable systems, and to contribute towards meeting this target (MAFF, 1998), and the issue of the loss of arable biodiversity is at the heart of the current farm-scale trials of genetically-modified herbicide tolerant crops (Firbank *et al.*, 1999).

The purpose of this paper is to try to characterise overall patterns of changing arable plant assemblages with particular reference to Great Britain, giving particular attention to the nature and limitations of the data as they exist. I will concentrate on the fields themselves, and field margins will only be considered in passing. I will also look ahead to new data sources that are currently in preparation, and (somewhat rashly) suggest how Britain's arable plant assemblages may well change in the future.

SOURCES OF INFORMATION ABOUT CHANGES IN STATUS OF ARABLE PLANTS

Historical records

The appearance of the arable ecosystem can be traced through archaeological evidence and pollen records, while a measure of the composition of arable weed communities can be obtained from analyses of middens (Jones, 1998). Local florae and herbaria provide evidence of presence of different species, but not of absence. However, there are cases when they do provide at least anecdotal evidence of changes in occurrence over time. Similarly, other written accounts can be used to infer the status of arable plants. For example, Shakespeare's reference to the corncockle suggests it was regarded as a pernicious weed (Firbank, 1988). All such records are prone to a variety of biases.

Traditional farming systems

Most farming systems have been so highly modified that they give few insights into the communities of a century or more ago, and this includes the majority of organic farms. However, there are a few exceptions, and their study gives a valuable assessment of the state of weed assemblages before industrialisation (e.g. Svensson & Wigren, 1986).

Records of weed seeds in grain samples

The first systematic survey of weeds that I am aware of was the survey of cereal grain for weed seeds conducted by the Official Seed Testing Station (OSTS) at Cambridge (Anon, 1918). This survey is biased towards those species with a similar seed size to grain, but is unbiased in relation to apparency to humans. Thus changes in the rank order of weed seeds gives a measure of actual changes in the flora (changes in absolute numbers are less useful as they are more dependent on the seed cleaning efficiency). Sadly, few data were actually published, and the Centre had a policy of retaining only these summary records.

Vegetation survey and mapping

The Botanical Society of the British Isles has been co-ordinated three major reviews of all higher plants, including arable species. The first was a call for species records in 1954 that resulted in the Atlas of the British Flora, and had a good, but uneven coverage (Perring & Walters, 1983). The second was an update of records of scarce plants undertaken in 1991-92 (Stewart *et al.*, 1994), and the third a structured survey of species presence in a regular subsample of tetrads (squares 2 km x 2 km) in 1988-89 (Rich & Woodruff, 1995; Rich & Woodruff, 1996). These surveys provide the best data about distribution at the tetrad scale, and while the 1988 survey provided an incomplete coverage, species distributions have been generated using a smoothing process incorporating data on soil type (Firbank *et al.*, 1998). They give no information on changing abundance or frequency within the tetrads.

The ITE Countryside Surveys of 1978 and 1990 included surveys of vegetation within permanent plots in 1 km squares across the whole countryside of Great Britain, selected at random and stratified by the ITE Land Classification that includes climate, topography, geology etc. Species presence and cover were recorded in main plots, 200 m^2 in area (Barr *et al.*, 1993), and other plot types not relevant here. Some of these plots included arable fields. The Countryside Surveys therefore give information on changes in frequency within fields, and they are particularly sensitive to changes among the more widespread and frequent species. The data are collected over a whole summer, although the *order* of survey is as consistent as possible between surveys. Therefore, the within season variation is greater than it might be given a survey within a smaller period. Also, some of the differences between the years may have been due to characteristics of the seasons, rather than indicating a long-term trend.

There have been surprisingly few comprehensive, national surveys of arable plants. Whitehead & Wright (1989) undertook surveys of species presence in winter cereals in 1988 for comparison with previous surveys in 1968 and 1973, and Chancellor (1977) reported a national survey of 40 arable weed species at the tetrad scale. Most surveys have dealt with a small number of species or a small range of sites. These include long-term repeated monitoring of a small number of sites (perhaps the extreme example is Chancellor (1985), who monitored one field for 20 years). They also include surveys structured to establish the causes of differences among contemporary arable plant communities. The surveys of crops come to mind (e.g. Wilson, 1994), but the surveys of set-aside land should not be neglected, as they give information about the regeneration capacity of arable land. The most relevant such survey that has been published is the 1996-8 evaluation of set-aside. This included vegetation survey of around 200 set-aside fields, half of which were rotational (Fowbert & Critchley, 1998).

Experimental research

Long term experiments have a particularly important role in considering changes in the arable flora. The longest running is the Broadbalk experiment at Rothamsted, but there are others, frequently considering changes in weed florae in relation to different cropping systems (e.g. the results of Integrated Farming projects such as LIFE and SCARAB), and occasionally considering the ecological strategy and dynamics of the plant species themselves (McCloskey *et al.*, 1996).

New information becoming available

Much information about the status of arable plants is fragmentary. However, there are important new sources of data in the pipeline that will help clarify recent trends and current status.

The field work for Countryside Survey 2000 is now complete, and the results will be published late in the year 2000. They will include the resurvey of the permanent plots described above, and will also include new plot types. One of these is the arable field margin plot, designed to detect infrequent species. This consists of preparing a species list for a plot 100 m long by 1 m wide running along the inside edge of cultivated land, and it has been used for all arable fields with a main plot located within them.

Work is also proceeding on an update of the Atlas of the British Flora, the Atlas 2000. This involves collating existing records, supplemented by four years of fieldwork, to produce maps at the 10 km square scale (Pearman & Preston, 1996). There is also work on linking more local biodiversity databases through the National Biodiversity Network, and there are plans for a national survey of rare weeds in 2000. Results from the surveys of land under the Arable Stewardship scheme may well also be informative.

The need for a survey of arable plants

Valuable as these exercises will be, they do not address the precise requirements for a comprehensive, national monitoring programme tailored for arable plants. I would suggest that these requirements include:

Information about crop management, and inputs
Current national surveys are not linked directly to management practices
Surveys in autumn and spring, and of seedbanks
The ephemeral nature of arable plants requires more than one survey per year
Frequent surveys
The arable habitat is prone to marked shifts between years because of weather and cropping fashions. It is therefore important to have surveys of a frequency of at most 5 years
Appropriate stratification
The Countryside Survey stratifies by land class; perhaps an arable plant survey should be stratified by other factors, such as farm type and soil type.

CHANGES IN THE ARABLE PLANT FLORA

The information may be incomplete, but the overall story of the development of our arable flora seems clear enough. The cereal system was developed in the Middle East, firstly by the accidental, and then more purposeful, domestication of large-seed grasses. The species that lived in association with these grasses formed the basis of the arable ecosystem, although other weed species were picked up as agriculture moved across western Europe. The species composition of these systems was probably more or less complete after Roman times except for introductions from the New World (notably *Matricaria discoidea (= M. matricarioides)*, but changes in abundances continued as a result of changes in land management practice, and, no doubt, climate change (Jones, 1998). It seems that the rate of change have accelerated dramatically in the last century. These changes were characterised by some species becoming increasingly localised and scarce, reduced species diversity at the field scale, and shifts from florae dominated by broad-leaved plants to ones dominated by grasses.

Localisation of some arable species

Many arable plant species remain widely distributed, according to the most recent available data. However, some species that constitute our scarce arable flora (Stewart *et al.*, 1994) have become much reduced in recent years (others were never very common). Some species once widespread, including *Agrostemma githago* are now considered extinct (Firbank, 1988), and others, such as *Centaurea cyanus*, are now restricted to a very few sites, and are named within the UK Biodiversity Action Plan (Anon, 1995). The distribution of these scarce species is not random. They tend to be found on land that has been arable for a long time (Wilson, 1990), and many (but not all) species now considered scarce have become localised on the lighter soils in south-east England (Stewart *et al.*, 1994).

There remains a suspicion that some scarce arable species may be more widespread than currently thought. For example, Kay & Gregory (1998) reported quite an impressive list of 20 less frequent arable plants in a survey of seven pairs of organic and non-organic farms in Oxfordshire (10 found only on organic farms, and 3 only on non-organic ones). Much depends upon the nature of the survey technique; as species become less abundant, they are increasingly likely to be missed by quadrat-based monitoring, and also some species can persist in the seedbank, allowing sites to be occupied intermittently. Such results are consistent with an overall picture of many species existing as a small number of highly fragmented populations.

Reduced species diversity at the field level

Analysis of Countryside Survey quadrats in arable fields in the eastern, arable lowlands of Britain visited in both 1978 and 1990 show declines in species number per plot, but not in the western, pastural lowlands (Table 1). A similar geographic contrast was also seen in the set-aside surveys of 1996 and 1997: a mean of 2.6 non-crop species per $0.25m^2$ quadrat was recorded in rotational set-aside in the arable counties of eastern England, as opposed to 3.8 species per quadrat in the west and north of the country ($P < 0.01$) (Fowbert & Critchley, 1998).

Other data also show a loss of diversity. In Denmark, non-crop species per $0.1\ m^2$ plot in winter wheat fell from 5.8 to 2.1 between 1967-70 and 1987-89 (Andreasen *et al.*, 1996). Historical sources are consistent with diversity losses, but they are difficult to interpret quantitatively.

Table 1. Changes in species richness in fixed plots dominated by arable plants between 1978 and 1990 in the arable lowlands and pastural lowlands of Great Britain (Bunce *et al.*, 1999).

Landscape type	*No. plots*	*Species no. per plot*		*% change*	*P*
		1978	*1990*		
Arable lowlands	124	6.69	5.08	-24	< 0.01
Pastural lowlands	64	7.55	8.05	7	n.s.

Reduced cover of non-crop plants

The impression from historical and literary sources is that there has been a decline in the weediness of fields, in other words, that the cover of non-crop plants has declined. However, I have found no concrete evidence for this change at the national level. No significant decline in cover was recorded by the Countryside Surveys, for example (Bunce *et al.*, 1999). Cover values are admittedly difficult to compare, because they are sensitive to time during the season and weather conditions.

Shifts from broad-leaved weeds to grasses

Literary and other historical sources paint pictures of cereal fields full of colour, with poppies, corn marigolds, corncockles and other broadleaved plants, very different from the monochrome greens of many fields today. These impressions are reinforced by the flora of traditional arable systems, and by the list of more frequent species in the OSTS records early in the 1900s (Anon, 1921). The Countryside Survey data showed declines between 1978 and 1990 of crop and crop edge plants typified by *Stelleria media*, *Polygonum aviculare* and *Veronica arvensis* and, notably, *Matricaria discoidea*, but also including grasses such as *Poa annua*. In contrast, there were significant increases in the cover of *Agrostis stolonifera* and *Lolium perenne* (Bunce *et al.*, 1999). Overall changes in rank order of weed occurrence reflect these changes, and remind us that some broad-leaved species, such as *Stellaria media*, remain widespread (Table 2).

Table 2. Rank order of weed species presence within main plots in arable fields from the Countryside Surveys of 1978 and 1990 in the lowlands of Great Britain. All species ranked 10 and above in any survey are included.

	Arable lowlands		*Pastural lowlands*	
	1978	*1990*	*1978*	*1990*
Stellaria media	1	2	1	3
Matricaria discoidea	2	9	4	10
Poa annua	3	1	3	1
Polygonum aviculare	4	3	2	2
Elytrigia repens	5	4	8	8.5
Persicaria maculosa	6	23	13	18
Chenopodium album/polyspermum	7	5	6.5	4
Convolvulus arvensis	8	9	>25	>25
Myosotis spp.	9	22	17	>25
Veronica persica	10	12	5	18
Capsella bursa-pastoris	13.5	6	20	13
Senecio vulgaris	13.5	9	>25	18
Lolium perenne	15	12	6.5	5
Galium aparine	16	15	>25	6.5
Viola arvensis	20.5	7	24	6.5
Lamium purpureum	20.5	12.5	9	14.5

The relationships between species attributes and persistence under changing farm management practices

Arable fields can be regarded as separate parcels of habitat, separated from one another by barriers that include hedgerows, woodlands, roads etc. For species that can only thrive within and at the edge of the field, persistence requires that the colonisation rate into unoccupied patches is at least the same as the extinction rate (e.g. Levins, 1969). Assume, for the sake or argument, that initially all fields had a fairly similar, species-rich arable flora. The persistence of species to the present therefore has depended upon their ability to survive within individual fields and their ability to disperse into fields from which they have been lost.

Persistence within the field depends upon susceptibility to herbicides, to timing of cultivation, to being outcompeted under high nutrient regimes, etc. Dispersal ability across agricultural landscapes depends upon the actual mechanism of seed dispersal, clearly, but also on the degree of habitat specialisation. Species that can persist in a wide range of soil conditions, in fields and in field margins (such as *Elytrigia repens*) are clearly more able to colonise new sites than those restricted to cultivated land of particular soil types and weather conditions. In general terms, the species that have declined the most tend to be broad-leaved arable specialists with limited powers to disperse and with short-lived seed banks. They are easily pushed to extinction within a site, and are unlikely to colonise from field boundaries or from other sites. They survive in pockets of land that have been largely continuous arable and not subject to intensive use of herbicides and continuous winter cropping – such pockets are likely to be found on long-established organic land. Species with longer-lived seedbanks are buffered from the effects of unfavourable crop management, but even they cannot persist indefinitely. Once a species is removed from a landscape, it can take many years for them to recolonise, if ever. The declines in diversity in those areas of England subject to intensive agricultural practices on a large spatial scale may be hard to reverse.

CHANGES IN CONSERVATION QUALITY OF WEED ASSEMBLAGES

Do these declines matter? Are they a sign of successful agriculture, of little consequence to non-agricultural interests? I would suggest that there are two, quite separate, conservation issues involved. The first relates to the presence of scarce plant species, the second to the overall quality of the wider countryside, for wildlife and for people. I would argue that many of the scarce arable species have restricted ecological roles, little public resonance (perhaps the major exception being *Centaurea cyanus*), and are at the edges of their ranges in Britain. Therefore, as a species group, they are not of the highest priority for conservation, and perhaps the targets of the UK cereal field margin Biodiversity Action Plan are adequate. I would welcome some local re-introductions as part of projects combining cultural and biodiversity conservation; it would be interesting to see more "traditional" cereal fields being created as part of Countryside Stewardship schemes.

The second issue is the decline of the more common broad-leaved plant species. I argue that this change affects many people in terms of the attractiveness of the landscape. It also poses a threat to numbers of animal groups, notably farmland birds. An analysis of the Countryside Survey data shows that, of the food plants for birds listed by Campbell *et al.* (1997), more decreases were detected than increases, especially for seed-eating birds in the arable lowland landscape (Table 3). The decline of the Polygonacea is a particular concern. Farmland birds can only thrive given large areas of suitable food resource and habitat, far larger than encompassed by the Cereal Field Margin Habitat Action Plan (Firbank, 1998) or by the pilot agreements of the Arable Stewardship area. There is much advice, and many methods available for conserving arable wildlife, and many examples of success (e.g. Anon, 1997). However, it is far from clear that the positive, but localised, effects of such conservation measures will outweigh a continued decline elsewhere.

Table 3. Changes in frequency of food plants between 1978 – 90 of selected declining farmland birds (abridged from Bunce *et al.*, 1999).

	Bird population % change	No. significant changes in food plants Arable lowlands		pastural lowlands	
		+	-	+	-
Tree sparrow	-89	0	4	0	3
Grey partridge	-82	1	6	0	5
Linnet	-52	0	5	2	5

Possible future trends

It is unrealistic to assume that agriculture will allow a return to the very weedy fields of the last century. The commercial pressures on intensive agriculture will be to keep fields weed-free, even on organic and low-input systems, where weed management can pose a serious problem. Under a business-as-usual scenario, I suggest that the scarce plants will be maintained through existing and planned conservation measures, but the loss of arable plant diversity will continue in the wider countryside, becoming more acute as buried seed reserves are exhausted (see Orson, this volume). Fields in western Britain will become more like those in the east, and those in the east will lose even more of their conservation value. The losses of farmland birds may well accelerate at the national scale. While organic farming will not encourage a continued switch to grass-dominated communities, farmers will still try to achieve good weed control. In the longer run, climate change may well favour those species that are currently scarce (possibly to economically damaging levels), as conditions in south and east Britain become warmer and drier. However, none of these factors in themselves is enough to halt the decline in arable biodiversity.

What is needed is an appreciation that weeds and arable plants are not necessarily the same things. If plants can be tolerated within and around the crop without prejudicing the financial return, then they should not be regarded as weeds. Crops should be managed to maintain the diversity of arable plants; perhaps in low-yielding parts of the fields (not necessarily the crop edges), perhaps by using new combinations of crops, herbicides and rotations, perhaps involving re-introductions. Rotational set-aside can be used to provide opportunities for species to replenish their seed reserves – possibly using selective herbicides to prevent seed return from grass weeds. Policies should be introduced that encourage such actions, for example through cross-compliance whereby such areas are required for IACS support.

CONCLUSIONS

The trends in the conservation value of arable fields up until 1990 have been almost totally negative. Data will shortly be available that will show whether those trends have continued in the last decade, or whether the increased emphasis on conservation has started to have an effect. Whatever the results, new information will be required if we are to produce policies and practices that will ensure the continued survival of our arable ecosystems through the years ahead. But more than that – we need a change of perception by all farmers that weed management and the promotion of biodiversity are not incompatible.

ACKNOWLEDGEMENTS

I thank Bob Naylor, Philip Wilson, Simon Smart and Peter Lutman for their comments on this paper, and Simon Smart for the analysis of rank order of abundances.

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Soil seed bank diversity under integrated and conventional farming systems

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ABSTRACT

Soil seed bank diversity was investigated under conventional and integrated farming systems at several sites studied in the LINK IFS project. Seed banks were sampled in the baseline year and after the final year of the five-course rotation in a number of split fields and various diversity indices were calculated. Generally, total seed density increased on integrated plots but was contained under conventional management. There were some indications of increased diversity on integrated plots at two sites. A greater number of differences was recorded between position in the field, where greater diversity was recorded in the 'margin' than 'field' samples. Integrated management, which included some spring cropping, resulted in greater importance of spring germinating species in the seed bank at two sites. Greater diversity would be expected in the vegetation of arable land where more varied agronomic practices create a greater variety of niches. The relatively small differences between the conventional and integrated management may not have been great enough to record marked differences in the diversity statistics used here.

INTRODUCTION

Agricultural production has intensified enormously over the last few decades. The introduction of pesticides, simplification of rotations, increase in nitrogen inputs and removal of many semi-natural habitats such as hedges have all contributed to a decline in biodiversity of species at a range of trophic levels (Sotherton, 1998). The weed flora represents both a component of biodiversity itself and a potential food source for other organisms. Seed banks represent the potential weed flora of an arable ecosystem; most weed species common on arable land form persistent seed banks and in any one year only a small proportion of individuals germinate and emerge. Seed banks therefore form a significant component of botanical biodiversity on arable land. Because many species have long term persistence, seed banks reflect the cumulative effects of past management over many years. Studies of the seed bank therefore represent a more comprehensive assessment of botanical biodiversity than individual weed counts.

The LINK IFS project was a collaborative study which ran between 1992 and 1997 at six sites across the UK differing in soil type, climatic conditions and agronomic practices (Wall, 1992). The project compared conventional systems, applying inputs to overcome constraints on production but avoiding risk, with integrated systems which also aimed to maximise profitability but where non-chemical management was considered first, with agrochemical inputs where necessary (Holland *et al.*, 1994). Integrated management was designed to have environmental benefits and included a range of husbandry practices including reduced tillage, mechanical weeding, lower pesticide inputs and manipulation of sowing date (Ogilvy *et al.*, 1995).

MATERIALS AND METHODS

Site details

Data for three of the LINK IFS sites, with different soil types, are presented here: ADAS Boxworth (Cambridgeshire, clay), ADAS High Mowthorpe (North Yorkshire, silty clay loam over chalk) and Lower Hope Farms (Herefordshire, silty clay loam). Conventional management represented local conventional practice at each site. Herbicide and nitrogen inputs were lower on integrated than conventional treatments when averaged across all years and phases of the rotation (Table 1). However, at Boxworth grass weed herbicides were applied to integrated treatments at similar levels to the conventional system because control of aggressive weeds such as *Alopecurus myosuroides* and *Anisantha sterilis* was considered a priority. The frequency of non-inversion tillage and spring cropping were both higher on integrated plots (Table 1). Fields were split or quartered (minimum plot size = 2.5 ha) with eight replicates (seven at Lower Hope) of each treatment in a five-course rotation. For further details of management systems see Ogilvy *et al.* (1995).

Table 1. Herbicide and nitrogen inputs and frequency of non-inversion tillage and spring cropping for each treatment, averaged across all phases of the rotation (1992-1997).

	Herbicide pu* ha^{-1}		Nitrogen kg ha^{-1}		Non-inversion (%)		Spring crops† (%)	
	Conv	Int	Conv	Int	Conv	Int	Conv	Int
Boxworth	1.67	1.45	147	112	28	56	0	13
High Mowthorpe	1.16	1.01	162	116	25	35	0	20
Lower Hope	1.03	0.47	153	122	5	28	0	20

* pu = pesticide units. For an explanation of units see Coutts & Prew (1996).

† not including potatoes which were included in both rotations at High Mowthorpe and Lower Hope.

Soil seed bank sampling

Soil samples were taken for seed bank analysis during the spring in the baseline year of the study (1993) and again after the end of the rotation (1998). Approximately 20 soil cores, 2.5 cm diameter and 20 cm deep, were collected from 1 m^2 quadrats at 4 m (margin) and 40 m (field) from the field margin. Cores were split into two depths for processing, but here results for both have been combined. Cores were bulked together, thoroughly mixed by hand and three subsamples, each representing 20% of the total weight of soil, were analysed by an extraction method. This involved wet sieving to reduce the bulk of material (smallest mesh size of 300 μm) followed by flotation of organic matter using a saturated solution of calcium chloride. Seeds were then picked out by hand, identified and tested for viability by squeezing between forceps (Ball & Miller, 1989).

Data analysis

Data for the three subsamples were combined and various diversity indices were calculated for each quadrat: Shannon's H, Margalef's D, Simpson's D and number of species per quadrat. Several indices were calculated because no single index can fully describe diversity. These indices all include species richness and abundance in their calculations: Shannon's H is biased towards species richness, whereas Simpson's index increases with greater equitability

(Clements *et al.*, 1994). Data for each site in baseline and final years were analysed using analysis of variance with a split plot design (factor 1 = system; factor 2 = position within field). Mean values for treatments were analysed where fields were quartered with replicate treatments adjacent to each other.

RESULTS

Mean total seed density was higher at High Mowthorpe and Lower Hope than at Boxworth (Table 2). This may be a function of soil type - seed densities are generally lower on heavy clay soils. Also, seed banks were sampled during the spring when many of the grasses with short-term persistence which dominate the weed flora at Boxworth may have germinated. Small increases in total seed density were recorded in both treatments at Boxworth, whereas at other sites seed bank densities were controlled under conventional systems, but increased under integrated management. Similar total numbers of species were identified at each site, although at Boxworth more species were recorded which could not be identified. Generally, a high proportion of species recorded at each site were recovered from both treatments in each year (Table 2). The total number of species recorded did not change under either treatment except at High Mowthorpe where the number of species increased under the integrated rotation.

Table 2. Total seed density and mean species counts in each system in baseline and final years

	Conventional		Integrated		
	1993	1998	1993	1998	
Total seed density m^{-2}					Mean
Boxworth	3 067	5719	3 958	6 823	4 892
High Mowthorpe	11 670	7 182	16 125	34 807	17 446
Lower Hope	21 571	16 780	6 293	30 505	18 787
Total no. of species					Total
Boxworth	24 (3)	25 (2)	23 (4)	24 (2)	35 (11)
High Mowthorpe	19 (2)	20 (2)	19 (2)	27 (2)	32 (4)
Lower Hope	21 (2)	21 (4)	16 (1)	21 (3)	28 (5)

Figures in parentheses represent additional species which were not identified.

Mean diversity values were relatively low for all indices, perhaps reflecting the relatively small size of soil samples analysed. There were no significant differences in diversity indices calculated between farming system or position in the field in the baseline year of sampling (data not shown), although there was considerable variability between fields. Analysis of final year samples showed significantly greater diversity in integrated than conventional systems as defined by Margalef's index at High Mowthorpe and Lower Hope and number of species per quadrat at one site (Table 3). At Lower Hope there was a significant interaction between system and position in the field for species number. Diversity was higher in the margin than in the field for all indices calculated at two sites.

Table 3. Diversity indices for final year samples for each treatment and sampling position.

	Conventional		Integrated		Treat	df	Posn	df
	Margin	Field	Margin	Field	SEM	(resid)	SEM	(resid)
Boxworth								
Shannon's H	1.30	0.95	1.21	0.76	ns		0.096*	13
Margalef's D	0.59	0.40	0.57	0.39	ns		0.057*	13
Simpson's D	3.62	2.26	2.91	2.23	ns		0.307*	13
No. of spp.	5.75	4.37	5.87	3.87	ns		0.543*	13
High Mowthorpe								
Shannon's H	0.90	0.98	1.26	1.12	ns		ns	
Margalef's D	0.41	0.45	0.78	0.65	0.049**	5	ns	
Simpson's D	2.55	2.69	2.62	2.53	ns		ns	
No. of spp.	4.50	4.67	8.75	7.58	0.558**	5	ns	
Lower Hope								
Shannon's H	1.33	0.99	1.42	1.03	ns		0.089*	10
Margalef's D	0.57	0.56	0.89	0.64	0.049*	5	0.039*	10
Simpson's D	3.49	2.26	3.14	2.74	ns		0.232*	10
No. of spp.	6.25	6.17	10.00	7.33	Interaction SEM = 0.513* 10 df			

* = $p<0.05$; ** = $p<0.01$

Under conventional management, similar species dominated the seed bank in the baseline and final years. Spring germinating species such as *Atriplex patula* and *Chenopodium album* increased in importance in integrated plots at Boxworth and Lower Hope between baseline and final years (Table 4). However, all plots at Lower Hope were dominated by *Poa annua* which accounted for a mean of 75% of the total seed bank across all treatments and sampling dates. At High Mowthorpe, increases in seed bank density under integrated management could largely be attributed to increases in *Papaver rhoeas* and *P. annua*.

DISCUSSION

Many components of the integrated system might be expected to affect seed bank composition. The relatively small number of differences between the management systems recorded in this study may have been a result of the relatively small differences in management between the two systems or variability between fields. The use of more selective and better targeted herbicides might result in increased species number by allowing control of agronomically important weeds, whilst maintaining populations of less economically significant species. However, Mayor & Dessaint (1998) found variable effects of chemical, integrated and mechanical control on soil seed bank diversity, although the effects of herbicide and soil disturbance were combined in this study. Derksen *et al.* (1995) also reported little influence of herbicides on weed diversity under different tillage systems.

Table 4. Most common species in the seed bank in 1998, with percentage of total seed bank for the final year (with 1993 values in parentheses) at Boxworth and Lower Hope.

Conventional Species	1998		Integrated Species	1998	
Boxworth					
Stellaria media	51	(16)	*Atriplex patula*	53	(21)
Sonchus asper	9	(5)	*Fallopia convolvulus*	9	(8)
Veronica persica	9	(<0.1)	*Chenopodium album*	5	(<0.1)
Capsella bursa-pastoris	7	(<0.1)	*Capsella bursa-pastoris*	5	(<0.1)
Aethusa cynapium	5	(28)	*Alopecurus myosuroides*	5	(<0.1)
Lower Hope					
Poa annua	59	(79)	*Poa annua*	56	(52)
Stellaria media	10	(6)	*Chenopodium album*	18	(<0.1)
Unid. 1	7	(4)	*Atriplex patula*	6	(<0.1)
Matricaria matricarioides	6	(<0.1)	*Stellaria media*	5	(8)
Atriplex patula	5	(3)	*Ranunculus* sp.	2	(5)

In contrast to natural ecosystems, there is evidence that lower weed diversity is a product of increasing disturbance in agroecosystems (Cardina *et al.*, 1991). Reduced ploughing frequency in integrated plots might therefore contribute to greater diversity compared to conventional systems. However, Cardina *et al.* (1991) compared ploughing with a no-tillage system, whereas under this IFS study, there were only small differences in ploughing frequency under conventional and integrated management.

Hald (1999) reported a marked difference in the weed flora under winter and spring sown cereals. The increase in importance of spring germinating species under the integrated system at two sites, suggests that the inclusion of spring cropping within the rotation might have had the most profound effect on the species composition of the seed bank. Although spring cropping was only included as an alternative to winter crops at one phase in the rotation (and only in the first three years of the study at Boxworth), many species favoured by spring soil disturbance, such *as C. album* and *A. patula*, form very persistent seed banks. A single year's seeding of such species could therefore influence the seed bank markedly.

Significant differences in calculated indices between field and margin suggest that integrated management had a greater effect on seed bank diversity in the field margin than in the field itself at Lower Hope. Greater diversity would be expected in seed banks at the edge of the field, where propagules could be derived from species inhabiting the semi-natural field boundary, but which are not a component of an arable flora because they are not adapted to a ruderal strategy. However, the absence of any significant differences between field and margin seed banks in the baseline year suggest that these differences may not be great under conventional management. More detailed analysis of these data and those for the other LINK IFS sites may determine the factors contributing to the changes observed here.

Integrated systems are potentially beneficial for weed and seed bank diversity because they provid a greater variety of niches as a result of fewer herbicide inputs, lower levels of soil disturbance, more varied rotations and a wider range of drilling dates. The fact that few significant differences were identified in this study was probably a result of the relatively small differences in management practices under the two systems, particularly in comparison with other studies. It was difficult to maintain significant differences in management through the life of the project because falling market prices in recent years have meant that farmers have been forced to reduce variable costs. Despite this, there were indications that integrated management was beneficial for other groups. Spring germinating species such as *A. patula* and *F. convolvulus* belong to families which are known to occur frequently in the diets of farmland birds, many of which are in decline (Campbell & Cooke, 1997). However, the introduction of spring cropping resulted in huge increases in the seed bank in some fields. The challenge for the future will be to balance wildlife benefit with agronomic sustainability.

ACKNOWLEDGEMENTS

Financial support from the Ministry of Agriculture, Fisheries and Food (MAFF) is gratefully acknowledged. Thanks to many colleagues involved with the IFS project for their contribution to this work.

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Germination of seeds from two non-target species subjected to sublethal herbicide dosages

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ABSTRACT

To investigate the effects on the quality (visual), dry weight, germination and viability of the seeds of non-target plants exposed to sublethal herbicide dosage, seedlings of *Thlaspi arvense* L. and *Sinapis arvensis* L. in spring barley were subjected to five different dosages of the herbicide isoproturon (1/1, 1/2, 1/4, 1/8 and 1/16 of normally recommended dosage) in two seasons and the seeds collected. *T. arvense* seeds from unsprayed controls had a high germination rate (81-93 %), but the proportion of seeds germinating was highest at low dosage. Compared with control, the proportion of germinated seeds was reduced at highest herbicide dosage while the proportion of ungerminated, living seeds and of dead seeds was increased. The proportion of germinated seeds of *S. arvensis* seeds from unsprayed controls was lower (58-69 %) than in *T. arvense*. *S. arvensis* seeds responded to low herbicide dosage with a decreased proportion of ungerminated, but living seeds. The changes in germination of seeds from plants subjected to sublethal dosages are discussed in relation to side-effects on non-target vegetation, persistent seed-bank and toxicological testing of herbicides.

INTRODUCTION

During the last two decades, the density and biodiversity of weeds in arable fields have decreased in Denmark in the established vegetation (Andreasen *et al.*, 1989) as well as in the seed bank (Jensen & Kjellsson, 1992). Many non-pest arthropods present in arable fields, especially in cereals, are important to birds (Sotherton, 1991), and most non-pest herbivorous arthropods are associated with wild species of Brassicaceae, Asteraceae and *Polygonum* spp. (Hald *et al.*, 1994). In the interest of both floristic and faunistic conservation, it is important to maintain a high biodiversity of weed (wild plant) species in cereal fields (Potts, 1986; Wilson, 1989; Hald *et al.*, 1994). Therefore, it is important to balance the intensity of weed control in cereal fields in such a way that the biodiversity of weeds is not further reduced. One weed control strategy is to regard weed species that are beneficial to wildlife as non-target species (i.e. wild plants) and to choose herbicide treatments that select among broad-leaved weed species as recommended by Moreby & Southway (1999). This strategy will leave most of the non-target weed population surviving, but subjected to a sublethal dose (Hald, 1993 & 1997). The herbicide isoproturon was chosen as an appropriate selective herbicide expected to reduce the number and/or biomass of target weed species in the spring barley while leaving other weed species unaffected, especially non-target Brassicacea species. The question is: if non-target weed species are subjected to sublethal herbicide dosages in cereal fields, will they provide sufficient numbers of viable seeds for the seed bank to ensure long-term survival in the field ?

A reduced seed production capacity of plants which have been subjected to sublethal doses of herbicides has been reported among annual broad-leaved weed species which are common in cereal fields (Hume & Shirriff, 1989; Rasmussen, 1993; Hald, 1993 & 1997; Andersson, 1994). Sublethal, low dosage of herbicides have been reported to stimulate growth in plants (Streibig, 1988; Marrs *et al.* 1991; Kjær, 1994). Further, sublethal dosages of herbicides applied to the parent plant may affect the course of germination in seeds and change the rate of input to the persistent seed bank. Some studies on seed dormancy and viability have been carried out on more damaging weed species as *Avena fatua* L. (Peters 1990) and *Galium spurium* L. (Andersson 1996), but few studies have addressed these issues in non-target species. Furthermore, few studies have examined the effect of herbicide doses on the parent plants whilst they were in the seedling stage (Hume & Shirriff, 1989; Andersson 1996), i.e. the stage of the annual weeds at the time when spring cereals are usually sprayed. In a pot trial with *Chenopodium album* L. seedlings, Hume & Shirriff (1989) found germination of seeds to increase with parental herbicide dose. Andersson (1996) in a pot trial with plant material of three broad-leaved species of low genetic variation at five growth stages and two herbicides at four dosages, found varying effects on seed germination among species, including the seedling stage.

Hald (1993 & 1997) quantified the growth and production of flowers, capsules and seeds per surviving plant of two Brassicaceae species, *Thlaspi arvense* L. and *Sinapis arvensis* L. in a field experiment using the balanced weed control strategy in spring barley. This paper reports the quality (visual), seed dry weight, germination and viability of seeds produced by parent plants subjected to sublethal dosages of isoproturon at the seedling stage in a field experiment carried out in spring barley and discusses the implications.

MATERIALS AND METHODS

The dose experiment with *T. arvense* and *S. arvensis* parent plants was carried out in 1993 in the same field as used by Hald (1993 & 1997): a sandy clay soil. The entire experiment was repeated in 1996 in another field with similar soil. The field experiment was carried out in four blocks, each containing five herbicide treatment plots and one untreated control plot of 25 metres' length each. Plots were located randomly within each block. The treatments were 1/1, 1/2, 1/4, 1/8 and 1/16 of the normally recommended dosage of isoproturon (1 kg a.i. ha^{-1} applied as 50% w/w isoproturon, Rhône-Poulenc). The target was 20 experimental seedlings in each plot. Thus seeds from a number of different unsprayed populations were sown at 20 sites in each plot on the same day as the crop was sown. Before spraying, 20 seedlings were marked. *S. arvensis* was not sown in the 1/1 dosage plots, as the mortality of this species is high at this dosage (Hald, 1997). In 1996 each of the two species were sown at 30 sites per plot. Both species have long-term persistent seed banks (Thompson *et al.*, 1997). Herbicide spraying was carried out at the 1-2 true leaf stage of the weed seedlings. To measure exposure, the spray was sampled in each plot on glass slides (in total 56.3 cm^2) placed 15 cm above the soil surface. After five minutes the slides were preserved in methanol, cooled, and stored at -18 °C until measured by HPLC using electro-chemical detection. The observed mean exposure dosage was 1/20 at the lowest dosage level each year and 15 and 17 times this dosage in the highest dosage level in 1993 and 1996 respectively. Thus both years the observed exposure range was about 20% lower than the target dosage.

All capsules of the marked plants ripening before the first night with frost were harvested, dried at 28 °C ± 1°C for 14 days, and kept in a dark room under constant conditions (20°C and 22%RH) until the germination trials were set up. The seeds were sorted into healthy or empty, immature or seeds partly-eaten by insects. To analyse herbicide effects on distribution of seed weight, all healthy seeds from two random blocks in 1993 were weighed individually. In 1996, all healthy seeds were simply pooled within plots and weighed to analyse effect on mean 1000-seed weight. Before germination all seeds from a plot were pooled for each species, treated with a 0.2 % KNO_3 solution and kept in the dark for 14 days at 5°C to obtain good germination of viable seeds. In total 16 samples, each of 25 seeds, were used per plot, or as many samples of 25 seeds as possible. The seeds were germinated at 20°C in 8h light and 16h dark in a completely randomised design, seedlings classified as healthy or abnormal, and removed. The seeds which had not germinated after 35 days were tested for viability with 2,3,5-triphenyl-tetrazolium-chloride, and classified as dead or alive. In 1993, germination was only tested on healthy seeds. In 1996, the number of seeds was low, and therefore the germination of both healthy and unhealthy seeds was tested.

Response in attributes of seeds to dosage were analysed using variance analysis followed by comparison of control with treated plots and of highest dosage plots with the other treatments and control. GLM and the TUKEY option or ANOVA (SAS, 1988) was used (α= 0.05). The analysed response attributes were: proportion of healthy seedlings (G), of living seeds (L), of dead seeds (D), and of germinated seeds with abnormal seedlings (AB). The Shapiro-Wilk W-statistic and P(W) for normality of distribution of dry weight of healthy single seeds was calculated for each treatment (SAS proc UNIVARIATE). Some of the data required transformation to obtain constant variance: $\log_{10}$(weight of seed) and arsine$(\text{proportion})^{1/2}$. The extremely dry weather in the summer of 1996 reduced plant growth in both herbicide treated and control plots; especially of *T. arvense*. This resulted in fewer samples in 1996 and some of the samples were pooled within treatment. Therefore, most emphasis has been put on the results from 1993. Results from 1996 were used mainly as a check against the conclusions drawn from the 1993 results.

RESULTS

The proportion of germinated seeds (G) of control plants was higher in *T. arvense* (81-93 %) than in *S. arvensis* (58-69 %), and in both species the proportion of germinated seeds with abnormal seedlings (AB) was low (Table 1). The portion of ungerminated seeds in control was low in *T. arvense* but high in *S. arvensis* where it consisted of more living (L) than dead (D) seeds. These findings were consistent between years. Compared to the unsprayed control, the proportion of germinated seeds (G) was increased at the lowest herbicide dose (1/16) in both species. The proportion of germinated seeds in *T. arvense* was less than control at the highest dose (1/1). In *S. arvensis* the proportion of germinated seeds at higher doses remained at the high level found at 1/16 dose. In *S. arvensis* the proportion of germinated seeds at highest dose (1/2) was higher than in control. The increased proportion of germinated seeds at 1/16 dose in *T. arvense* resulted from a reduced proportion of dead seeds (D), and in *S. arvensis* from a reduced proportion of ungerminated, living seeds (L). The reduced proportion of germinated seeds at 1/1 dose in *T. arvense* resulted from an increased proportion of both ungerminated, living seeds (L) and of dead seeds (D). In *S. arvensis* the high proportion of germinated seeds at the highest dose resulted from a lower proportion of dead seeds (D). The greatest range of change in germination within the dose range 1/16 to 1/1 (1/2) was 21 percentage points.

Because fewer seeds were produced in the dry year of 1996 (Table 1), there were fewer results from germination trials and significant effects were difficult to establish. However,

Table 1 Means (backtransformed proportions) of germination of healthy seeds of *T. arvense* and *S. arvensis* in 1993 and 1996. The number of samples of 25 seeds available is noted. In italics: seeds were pooled from replicates within treatment and are not included in the comparison of means.

T. arvense	Class	Year	df	Control	1/16	1/8	1/4	1/2	1/1
Germinated	G	1993	241	0.81a	0.91	0.83a	0.83a	0.89	0.70b
seeds		1996	15	*0.93*	*0.96*	*0.97*	*0.94*	*0.80*	*0.88*
	AB	1993	241	0.02ab	0	0	0.01ab	0	0.01ab
		1996	15	*0.01*	*0.01*	*0.02*	*0.06*	*0.08*	*0*
Un-germinated	L	1993	241	0.04a	0.07a	0.07a	0.03a	0.01	0.14b
seeds		1996	15	*0*	*0.01*	*0*	*0*	*0*	*0*
	D	1993	241	0.03a	0.01	0.05a	0.05a	0.07ab	0.10b
		1996	15	*0.05*	*0.01*	*0.01*	*0*	*0.12*	*0.12*
Number of samples		1993/1996		51/7	33/4	44/6	47/2	33/1	55/1
S. arvensis									
Germinated	G	1993	206	0.58a	0.65b	0.67b	0.59ab	0.66b	
seeds		1996	98	0.69a	0.69a	0.60b	*0.47*	.	
	AB	1993	206	0.02a	0.03a	0.03a	0.02ab	0.01b	
		1996	98	0.01a	0.04b	0.03b	*0.07*	.	
Un-germinated	L	1993	206	0.19ab	0.12	0.13	0.24ab	0.24ab	
seeds		1996	98	0.17ab	0.09	0.15ab	*0.05*	.	
	D	1993	206	0.13a	0.15a	0.13a	0.10ab	0.07b	
		1996	98	0.11a	0.14ab	0.19b	*0.37*	.	
Number of samples		1993/1996		57/64	40/23	54/23	43/6	30/0	

df: error df of comparison. a: does not differ from control. b: does not differ from the highest dosage.

the 1996 results mostly confirmed the results from 1993 or at worst, did not contradict them. Thus in *T. arvense* the proportion of germinated seeds compared with control was increased at 1/16 dosage and reduced at 1/1 dosage. In the case of S. *arvensis* the reduced proportion of ungerminated, living seeds at 1/16 dosage was a consistent result.

In both years, the proportion of unhealthy seeds was higher in *S. arvensis* (11-23%) than in *T. arvense* (4-10%), but the proportion was not related significantly to herbicide dosage in either species (not shown). In both species the distributions of dry weight of healthy seeds were skewed to right and deviated from normal in both control and herbicide treated plants [$P(W)<0.05$, except in *S. arvensis* at 1/2 dosage $P(W)=0.068$]. The mean 1000-seed weight of healthy *T. arvense* and *S. arvensis* seeds was 1.40 g and 2.78 g in 1993 and 1.1 g and 2.2 g in 1996, and did not differ among treatments in either of the species (ANOVA; *T. arvense* $P=0.27$, $n=12$ plots; *S. arvensis* $P=0.24$, $n=22$ plots). In both species the proportion of unhealthy seeds that were dead (>62% in *T. arvense*, >59% in *S. arvensis*) was high, as was the total proportion of dead seeds and seeds with abnormal seedling (>67% in *T. arvense*; >97% in *S. arvensis*). None of these proportions differed significantly among treatments (not shown).

DISCUSSION

The 1996 data, although from a very extreme year and a different locality, either confirmed the 1993 results for *T. arvense* or did not contradict them. In *S. arvensis*, which had higher mortality in response to isoproturon than *T. arvense* (Hald, 1997), only the effect on proportion of ungerminated but living seeds was consistent in the two years. Further, in both species the proportions of seeds within the different fate groups at control were consistent between years. Thus most of the results obtained in 1993 in a field experiment in competition with a spring barley crop and with genetically varied plant materials were reproduced in 1996. The results therefore suggest that herbicide may affect germination not only at high dosage, but most consistently at low dosage. Thus in both species, the germination of healthy seeds was stimulated when parent plants had been subjected to the lowest dosage. However, the fate of the ungerminated seeds was different in the two species: in *T. arvense*, the proportion of seeds that died was reduced, whereas in *S. arvensis*, the proportion that remained alive was reduced. Seeds from *T. arvense* plants which recieved a high dose of isoproturon showed germination to be inhibited. The effects on *S. arvensis* seeds to high dosage differed between years or the attribute was not affected at all compared to control, as demonstrated by the proportion of un-germinated, but living seeds. The size of the changes in response to dosage were smaller than those found by Hume & Shirriff (1989), who found an increase in germination of 40 percentage points at highest dosage compared to control using a different species and herbicide.

Both the stimulation of germination at the lowest herbicide dosage (i.e. reducing dormancy) as found in both species and the inhibition of germination (i.e. increasing of dormancy) at the higher dosages in T. *arvense*, may affect the input rate to the persistent seed bank. However, dosages effective in controlling the target weed species were 1/2 dosage or higher (Hald, 1993 & 1997). Thus, if isoproturon is to be used in a selective balanced strategy for weed control, only the effects on germination found at half dosage or higher are relevant for the flora in the field. However, in fields in rotation, the large reduction (to one half or more) at 1/2 dosage in number of seeds produced per surviving plant compared with control plants of the two species (Hald 1993 & 1997) is still of much greater importance for the size of the seed bank and of the future population. The changes in dormancy of seeds were not reflected in the mean dry weight of seeds or in the distribution of seed weight - variables of importance for dormancy (Thompson *et al.*, 1997). Andersson (1996) also did not find any effect on 1000-seed weight of the application of herbicide to the seedlings of *T. arvense*. However, herbicide applied at later growth stages reduced 1000-seed weight of *T. arvense* and other species (Andersson 1996).

Stimulation of growth of parent plants at sublethal, low herbicide dosage has been found by others (Streibig, 1988; Marrs *et al.* 1991; Kjær, 1994), so the germination increase of 7-10 percentage points at low dosage found in *S. arvensis* and *T. arvense* may be more universal. Treatment with herbicide doses as low as 1/16 would rarely occur in normal farming practice. However, wild plants in field boundary biotopes and neighbouring natural areas may recieve low doses through wind drift of herbicide during spraying (Marrs *et al.* 1993) and as wet deposition and may thus produce seeds with stimulated germination ability, i.e. the seed input to the persistent seed bank the year these species are subjected to sublethal effects is reduced. Common wild plant species from semi-natural communities, such as pastures, have a low frequency in persistent seed bank compared to arable species (Hodgson & Grime 1990), so the implication of such a potential reduction is unknown, but should be studied. The effect on germination of low doses to parent plant is also relevant in toxicological testing of herbicides.

ACKNOWLEDGEMENT

Thanks to L Michaelsen, the Ministry of Food, Agriculture and Fisheries' Department of

Seeds, for the germination tests; N H Spliid, the Department of Environmental Chemistry for HPCL analyses; G Cracknell, C Topping and R E L Naylor for improving the English.

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Space for endangered plants in arable landscapes

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ABSTRACT

The management of arable farmland has undergone a revolution during the second half of the 20th century, and these changes have had many consequences for the botanical diversity of farmland habitats. These habitats include not only the regularly cultivated arable fields, but also less frequently disturbed areas, field boundaries and trackways. Many species of these habitats are now endangered throughout northern Europe, and are becoming the focus of conservation concern.

INTRODUCTION

The arable landscape north-western Europe has undergone a transformation during the second half of the 20th century. Changes in the management of arable land have involved the widespread use of herbicides, other agrochemicals and artificial fertilisers, mechanisation of nearly all farming operations, the development of highly nitrogen-responsive crop varieties and efficient field drainage. These factors have affected not only arable land itself, but also all of those habitats associated with it and have resulted in the large-scale removal of hedgerows and other boundary features (Chapman & Sheail, 1994), the simplification of crop rotations and loss of crop diversity, loss of permanent and semi-permanent grasslands (Stoate, 1996), loss of seasonally inundated areas and the surfacing and increased use of tracks. Change of land use from arable to intensive pasture has now become a cause for concern in areas marginal to arable farming, and mixed farming has now disappeared from much of Britain

The overall processes of agricultural intensification have led to reductions in farmland habitat quality and diversity. As a result, many once widespread plant species have become rare. Of the 62 vascular plant species listed on the Priority List of the UK Biodiversity Action Plan (BAP) (Anon, 1998), 14 are found exclusively in farmland habitats or have a large proportion of their British populations on farmland. The UK BAP also lists 159 species "of conservation concern", and 24 of these are predominantly farmland species (Tables 1 & 2). The conservation of the arable farmland habitat mosaic is therefore of great importance for the maintenance of Britain's floristic diversity.

FARMLAND HABITATS OF IMPORTANCE FOR ENDANGERED PLANTS

The majority of arable farmland consists of regularly cultivated land, but several other habitat types are present even in the most impoverished agricultural landscape. These include field boundaries, land temporarily out of cultivation (in field boundaries, as fallow or as set-aside), seasonally wet areas, ponds, ditches, tracks and ley grasslands. All of these habitats have a characteristic suite of associated plant species.

Arable fields

Plant communities of arable fields have changed greatly in recent years with the adoption of new techniques of arable farming. The declines of many species once characteristic of arable fields have been catastrophic and have occurred throughout Europe (Holzner, 1977; Wilson, 1990). Species which have short-lived seed-banks were among the first to decline, and these included the characteristic weeds of flax which are now virtually extinct in Europe (Kornas, 1988). Of the 62 species of priority conservation concern in the UK BAP, 12 are arable species (Table 1). Nineteen arable species are "nationally rare" (Wigginton, 1999), while a further 14 are "nationally scarce" (Stewart et al, 1994).

Many uncommon arable plant species have very specific requirements, and diversity of management is necessary for the maximisation of the botanical diversity of arable fields. *Ranunculus arvensis* for instance occurs almost exclusively in fields where winter-sown cereals are the main crop. *Galeopsis angustifolia* however requires spring cereals with stubble left uncultivated after harvest. The Scilly bulb-fields are a very specialised arable habitat and associated endangered plants include *Silene gallica, Briza minor* and *Fumaria occidentale*.

Seasonally inundated areas

Low-lying areas and hollows in arable fields frequently hold water during the winter. Wet conditions can also prevent the establishment of crop cover, thereby favouring the growth of non-crop species. The very rare *Lythrum hyssopifolia* occurs in two arable sites, and *Myosurus minimus* is a characteristic species which has become much rarer in recent years. Suitable habitats for these species can also be found on the compacted soil of tracks and gateways.

Irregularly cultivated land

Several species are typical of irregularly-cultivated margins of arable fields where vegetation develops slowly on nutrient-poor soils, and where open sites for the establishment of seedlings can persist for several years following cultivation. Field boundary removal and more efficient ploughing have caused such habitats to become rare. On chalky soils in the south-east of Britain there are still sites for species including *Ajuga chamaepitys, Filago pyramidata* and *Teucrium botrys*. In the south-west, occasionally cultivated land can support populations of *Lotus angustissimus* and *L. subbiflorus,* while on sandy soils in the Breckland, similar habitats have populations of *Veronica verna, V. praecox* and *Silene conica*. The farming landscape before the 1940s would probably have contained many fields where cultivation had lapsed temporarily, and in the early stages of secondary succession these would have been ideal habitat for these species. The introduction of set-aside in the early 1990s created opportunities for some uncommon species including *Ajuga chamaepitys* and *Gastridium ventricosum*.

Tracks and tracksides

The majority of our modern roads were created from what were formerly partially vegetated tracks. These often consisted of a considerable width of land, some of which would have been

Table 1. Arable plant species of conservation concern in Britain.

	Conservation status[1]	BAP listing [2]
Adonis annua	RDB	C
Agrostemma githago	RDB	
Anthemis arvensis	Unknown	
Anthoxanthum aristatum	RDB Extinct	
Apera interrupta	NS	
Apera spica-venti	NS	
Arnoseris minima	RDB Extinct	
Briza minor	NS	
Bromus arvensis	Unknown	
Bromus interruptus	RDB Extinct, Endemic	P
Bromus secalinus	Unknown	
Bupleurum rotundifolium	RDB Extinct	
Caucalis platycarpos	RDB Extinct	
Centaurea cyanus	RDB	P
Consolida ambigua	Unknown	
Echium plantagineum	RDB	
Euphorbia platyphyllos	NS	C
Filago lutescens	RDB	P
Filago pyramidata	RDB	P
Fumaria densiflora	NS	
Fumaria parviflora	NS	
Fumaria occidentalis	RDB Endemic	P
Fumaria purpurea	NS Endemic	P
Fumaria reuteri	RDB	C
Fumaria vaillantii	NS	
Galeopsis angustifolia	NS	P
Galeopsis segetum	RDB Extinct	
Galium spurium	RDB	
Galium tricornutum	RDB	P
Lithospermum arvense		C
Lythrum hyssopifolia	RDB	
Ranunculus arvensis	NS	C
Scandix pecten-veneris	NS	P
Silene gallica	NS	P
Torilis arvensis	NS	P
Valerianella dentata		C
Valerianella rimosa	RDB	P
Veronica triphyllos	RDB	C
Vicia parviflora	NS	

[1] RDB, Red Data Book <15 10km squares; NS, Nationally Scarce Species <100 10km squares.
[2] P, UK BAP Priority List; C, UK BAP species of conservation concern.

habitats including arable field margins under the terms of the UK BAP (Anon, 1995), and the Countryside Stewardship Scheme has been the primary means of delivering these objectives. The efficacy of these schemes for endangered plant species is however incompletely known, and they have been handicapped by lack of knowledge of the distribution of some species and limited funding. Pilot schemes aimed specifically at arable land were launched in 1998 and it is to be hoped that the measures introduced in these Arable Stewardship pilot areas will be applied to the rest of the country in due course. It should be emphasised however that schemes aimed specifically at arable land will not be effective at conserving associated farmland habitats, and that other measures are necessary.

The inclusion of farmland habitats and species in national and local Biodiversity Action Plans is a crucial step towards achieving their effective conservation. Such plans are particularly important as they seek to gain acceptance and commitment from all relevant organisations and individuals including farmers and the agricultural industries. The action plan process can act as an important incentive to research, survey and the implementation of conservation measures.

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