



## SEED BANKS IN ABANDONED ARABLE LAND ON CHALK: IMPLICATIONS FOR HABITAT RESTORATION

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## ABSTRACT

Seed banks of ex-arable land on chalk were studied under glasshouse and field conditions. The depth distribution of viable seeds implies that annual weeds associated with arable cultivation survive longer in the soil than perennial forbs and grasses. Emergence of seedlings in the field is dominated by annual weed species characteristic of arable cultivation. The UK Set-Aside scheme does not allow effective management to reduce soil fertility or to control plant growth and seeding. Without such management, land taken out of arable cultivation on chalk soils will become vegetated with an undesirable mixture of weed species, leaving a low probability of restoring species-rich chalk grassland vegetation.

## INTRODUCTION

Ratcliffe (1984) stated that "allowing that many areas not actually under cultivation have shown substantial change in floristic composition, it seems likely that no more than 20% of the total area of chalk grassland existing in 1939 survives with its former floristic richness." Losses have been particularly marked in the south-east of England. Blackwood & Tubbs (1970) estimated that less than 4% of the chalk on the South Downs still supported pasture. Between 1966 and 1980 a further quarter of this remnant was lost (Anon, 1984), much to arable cultivation. This dramatic decline in the area of species-rich grassland has understandably resulted in the remaining fragments becoming important for conserving the many plant and animal species dependent on this habitat. Given the financial incentives now being offered to take land out of cultivation under the Set-Aside and Environmentally Sensitive Area schemes, the question arises whether such land could be restored to support the flora and fauna of the old chalk grassland pastures.

Former arable "improved" grassland presents a management challenge. The aim of conservationists is to try to restore species-rich chalk grassland vegetation, similar to that which preceded cultivation, rather than to settle for a typical "weedy" post-cultivation flora. Encouragingly, much species-rich, apparently permanent chalk pasture which appears to have escaped cultivation, has in fact been cultivated at some time in the past (Wells *et al.*, 1976). However, although these formerly cultivated areas contain some plant species characteristic of old chalk grassland, they differ considerably in composition from nearby pastures where there is no evidence of former cultivation. Although species-rich grasslands can develop spontaneously on chalk soils after cultivation, it has been estimated that over 100 years is needed, even under the most favourable conditions, for the vegetation to resemble old chalk grassland (Mitchley, 1988).

In the past, cultivated areas were less extensive than nowadays and many areas of chalk grassland still existed, acting as important sources of propagules. In addition, the agricultural practices of the past were usually based on low input/low output systems where the arable land was not heavily fertilized, and grazing, particularly by sheep, was more common. Therefore, there would be less tendency for sites to become dominated by aggressive species and more opportunity for slower-growing chalk grassland species to invade. Now, however, eutrophication is one of the major difficulties in re-establishing species of permanent grassland on former arable sites (Marrs, 1985). Also, remaining areas of long-established chalk grassland are now so small and isolated that, in many cases, there is no source of propagules of chalk grassland species nearby.

Secondary succession on calcareous substrates after the cessation of agriculture is a poorly understood subject; until recently, few arable sites on such soils had been abandoned. Most of the earlier studies of grasslands arising from ex-arable sites on calcareous soils described cases where intensive use of agrochemicals was not widespread, and high residual soil fertility was not such a problem as it is now. However, three recent studies (Graham, 1983; Gibson *et al.*, 1987; Booth, 1988) consider situations where modern artificial fertilizers were used before reversion to pasture. The major source of the vegetation which arises after cessation of cultivation is the bank of viable seeds on and in the soil. Root and rhizome fragments may also make a small contribution to the vegetation following the last cultivation. In this paper, we present results from two studies of seed banks in valley bottoms on chalk sites taken out of arable cultivation. The results are used to assess the chances of re-establishing chalk grassland vegetation within the framework of the UK Set-Aside scheme.

## METHODS

Three experiments were conducted to estimate the potential of the seed bank to contribute to vegetation cover. Firstly, a glasshouse investigation was undertaken to provide an assessment of the germinable seed bank, by incubating soil samples under conditions designed to promote the germination of as many seeds as possible. While this type of assessment is valuable for comparisons, it reveals little about the likely course of vegetation development in the field after disturbances such as ploughing. In the field many seeds do not germinate because crucial cues to break dormancy are not experienced. To distinguish between the germinable seed bank determined under glasshouse conditions, and the seedlings which would emerge from the soil in the field, germination was recorded on permanently exposed, but undisturbed soil. To assess the contribution of the seed bank to recruitment as early secondary succession progressed, germination was also recorded beneath a canopy of vegetation developing after a disturbance similar to ploughing.

### The study site

The ex-arable sites chosen for these studies appear particularly suitable for the re-establishment of chalk grassland. They are valley bottoms within a National Nature Reserve and almost totally surrounded by

hillslopes bearing ancient, species-rich chalk grassland vegetation which might act as a source of propagules of permanent grassland species. Cultivation ceased on the sites in 1975. The studies reported here were conducted between 1981 and 1988.

#### Glasshouse determination of the seed bank

The term seed bank is used to denote seeds and fruits at and beneath the soil surface which are capable of germination (Sagar & Mortimer, 1976). The method of germinating seeds under glasshouse conditions in this study is adapted from Thompson & Grime (1979). While allowing accurate assessment of the transient component of the seed bank (mostly large seeds at the soil surface which are capable of immediate germination), it does not accurately census the persistent component, which may remain viable for several years.

Cores of soil 12 cm deep were collected at monthly intervals from March 1981 until October 1982 (Graham, 1983). The cores were divided into three horizons corresponding to depths of 0-4, 4-8, 8-12 cm, air-dried and passed through a sieve to remove stones and vegetation. Soil from each depth was spread in a 2 cm deep layer over sand in seed trays, and placed in a glasshouse under a 16/8 h light/dark regime with a mean temperature of 25°C. Sub-irrigation kept the trays moist. Every week, germinated seedlings were counted, identified and removed, and the soil was turned to promote further germination. Most samples were monitored for 36 days, since negligible germination occurred after this time.

#### Analysis of germination from the seed bank under field conditions

A field plot of 3 x 13 m was fenced to keep out vertebrate herbivores. Within this plot the soil was thoroughly dug in May 1981 to a depth of 15cm, and all vegetation removed. Following this disturbance, the effects of which were analogous to ploughing, no further disturbance took place. Germination of seedlings was then assessed monthly from June 1981 until November 1982. In eight 25 x 50 cm quadrats, seedlings were identified and counted at monthly intervals and allowed to continue growing. Thus, germination was monitored in these quadrats beneath a developing canopy of vegetation. In another eight similar quadrats, seedling numbers and identities were recorded at monthly intervals for the same period, and the seedlings were then removed. Thus, in these quadrats germination was monitored from a permanently exposed soil surface.

In all the results reported below, data on germination of seedlings are summed over the period of investigation.

### RESULTS

#### Germination from different soil strata under glasshouse conditions

The majority of species recorded in the glasshouse study germinated mainly from the 0-4 cm soil stratum. However, several annual species exhibited either approximately equal germination from all soil strata, or more abundant germination from the deeper strata. These included Stellaria media, which germinates successfully from considerable depth (Fryer & Makepeace, 1977), Polygonum aviculare and P. convolvulus.

When the commonly recorded species were grouped into the categories of grasses, annual forbs and perennial forbs, analysis of variance showed that mean percentage germination, calculated both on untransformed and arcsine-transformed data, differed significantly for all categories of species in all three soil strata. Also, mean percentage germination fell significantly for annual forbs (Fig. 1). Of five grass species for which sufficient data were available for analysis, four were perennial (*Holcus lanatus*, *Lolium perenne*, *Phleum pratense*, *Agrostis stolonifera*), and one annual (*Poa annua*). *P. annua* showed a germination pattern with depth which resembled that of the other perennial grasses (Fig. 1c), with germination concentrated in the upper soil stratum, rather than evenly distributed down the profile as in the annual forbs.

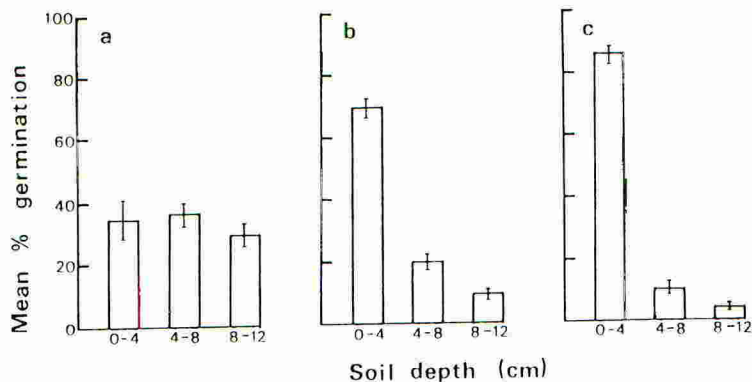


Fig. 1. Mean ( $\pm$  S.E.) percentage of seeds of (a) annual forbs, (b) perennial forbs, (c) grasses, germinating from successive soil depths over the study. For annual forbs, number of species ( $n$ ) = 10; for perennial forbs,  $n$  = 8; for grasses,  $n$  = 5. (From Graham & Hutchings 1988a)

Insufficient data were available in this study for biennials to be included in the analysis. However, their mean values for percentage germination from the three soil strata were very similar to those for perennial forbs. A later study (Booth, 1988) confirmed that there were no significant differences between the mean germination percentages of biennial and perennial forb species in each soil stratum. The study by Graham was carried out 6-7 years after arable cultivation ceased, while that of Booth was undertaken in a different valley bottom, 9-10 years after cultivation. The results of these studies match closely, the only difference being a small (but significant) fall in percentage of annual forbs germinating as depth increased in the study by Booth. This was not observed in the earlier study.

#### Comparative analysis of germination under glasshouse and field conditions

More species of annual, biennial and perennial forbs germinated in the glasshouse than in the field, and more species from each of these categories germinated from the exposed soil surfaces than from those with recovering vegetation (Table 1), suggesting that the leaf canopy inhibited germination and possibly also prevented seeds from reaching the soil surface. Whereas there was little variation in the numbers of species germinating from the soil samples in the glasshouse, regardless of the date on which they were collected (Graham & Hutchings, 1988a), few species germinated between summer 1981 and the following spring in either of the field studies (Graham & Hutchings, 1988b).

TABLE 1. Numbers of annual, biennial and perennial forb species appearing in the different experimental treatments between November 1981 and October 1982. (from Graham & Hutchings, 1988b).

	Glasshouse conditions	Exposed quadrats	Recovering vegetation quadrats
Annual forbs	21	15	10
Biennial forbs	4	3	1
Perennial forbs	16	10	7
Total forbs	41	28	18

Table 2 shows the numbers of seedlings in different categories which germinated over a comparable period (November 1981 to October 1982) in the field and from the monthly soil samples. The smallest reduction in germination in the field compared to the glasshouse, was for the grasses, particularly on the exposed soil; this was due to a flush of germination in the autumn following their dispersal (Graham & Hutchings, 1988b). For all other categories of seedling, germination from the exposed soil under field conditions was only 7%, or less, of that observed in the glasshouse, and germination under the developing vegetation canopy was 4% or less. The greatest difference between the glasshouse and field experiments was in the numbers of perennial forbs germinating.

TABLE 2. Number of seedlings appearing  $m^{-2}$  in different germination trials November 1981–October 1982. Figures in parentheses are germination levels expressed as a percentage of those in the glasshouse. (from Graham & Hutchings, 1988b).

	Glasshouse conditions	Exposed quadrats	Recovering vegetation quadrats
Annual forbs	23700(100%)	1620(6.8%)	787(3.3%)
Biennial forbs	1990(100%)	60(3.0%)	31(1.6%)
Perennial forbs	20200(100%)	744(3.7%)	150(0.7%)
Total forbs	45890(100%)	2424(5.3%)	968(2.1%)
Grasses	2280(100%)	690(30.3%)	128(5.6%)
Total seedlings	48170(100%)	3114(6.5%)	1096(2.3%)

Table 3 shows the most commonly recorded species in each set of germination conditions in rank order of abundance. The five most abundant species under glasshouse conditions were all recorded over ten times as often in this experiment as they were under field conditions. Statistical analysis showed no similarity between the abundance rankings of species germinating in the field and from soil in the glasshouse. Several major differences in emergence ranking can be seen; in particular, Veronica persica and Kickxia elatine were higher in rank order of abundance in the glasshouse than in the field, whereas Medicago lupulina was higher in rank order under both sets of field conditions than it was in the glasshouse. This analysis

highlights the danger of predicting the vegetation which might arise under field conditions from analyses of seed banks made in the glasshouse; both the abundance of seedlings and the rank abundance of the species germinating will differ strongly in the field. However, the abundance ranking of germinated seedlings under the two sets of field conditions was significantly correlated (Spearman's rank correlation  $r_s = 0.58$ ,  $P \leq 0.05$ ).

TABLE 3. Mean seedling emergence  $m^{-2}$  from November 1981–October 1982 of the fourteen most common species appearing in the glasshouse, and their emergence in the field. (from Graham & Hutchings, 1988b).

Species	Glasshouse conditions		Exposed quadrats		Recovering vegetation quadrats	
	Number of seeds	Abundance rank	Number of seeds	Abundance rank	Number of seeds	Abundance rank
<i>Ranunculus repens</i>	10100	1	516	1	30	8
<i>Veronica persica</i>	5660	2	45	9	11	10
<i>Anagallis arvensis</i>	5600	3	342	4	504	1
<i>Kickxia elatine</i>	4080	4	8	13	2	13
<i>Hypericum perforatum</i>	3400	5	119	7	61	3
<i>Euphorbia exigua</i>	1820	6=	345	3	40	5
<i>Sonchus asper</i>	1820	6=	149	6	88	2
<i>Cirsium vulgare</i>	1800	8	32	10	31	7
<i>Crepis capillaris</i>	1580	9	51	8	45	4
<i>Cerastium holosteoides</i>	1430	10	19	12	17	9
<i>Reseda lutea</i>	456	11	29	11	3	12
<i>Plantago lanceolata</i>	391	12	2	14	1	14
<i>Polygonum aviculare</i>	324	13	189	5	6	11
<i>Medicago lupulina</i>	217	14	454	2	33	6

## DISCUSSION

Several authors have reported lower germination from soil seed banks under field conditions compared with that observed when soil samples are brought into the glasshouse (Roberts & Ricketts, 1979). Bearing in mind that the seed bank size was not completely ascertained by the methods used in this study, it is clear that most seeds remain dormant while they are in soil, at least until disturbance brings them to the surface. Of the forbs, germination of annual species was least reduced by field conditions, and germination of perennials was most reduced (Table 2).

For most perennial herbs, seed output each year is usually far lower than that of annuals, although over the course of their lives there may be little difference in total fecundity (Grime, 1979). In general, seeds of perennials do not remain viable in the soil for as long as those of annuals. Thus, there are few major perennial weeds of arable cultivation which rely mainly on seed recruitment (Fryer & Makepeace, 1977). If it is assumed that annual incorporation rates during the years of cultivation and

the loss of viability through time are constants, the results in Fig. 1 imply that there are marked differences in the rates at which viability is lost in the soil by different categories of species (Roberts & Feast, 1973). They indicate that seeds of many annual species have extremely long life spans; despite no introduction of seeds into the lower strata of the soil by ploughing for 6-7 years prior to this study, there was no significant difference in the mean proportions of the seeds of annual species which germinated from the top 4cm and the 8-12cm stratum. The viability of seeds of perennial species declines far faster, as shown by the significant fall in mean proportional germination down the soil profile. Seeds of grass species lose viability even faster.

Seeds of many grass species can germinate immediately on dispersal from the parent plant, and few grass species exhibit prolonged dormancy or retain viability in the soil for long periods (Grime *et al.*, 1981). Most cultivated grasses do not form large seed banks; these are only found in a few indigenous grass species with small seeds (e.g. *Agrostis* spp., *Holcus mollis*). The decrease in number of seeds and species of perennial forbs and grasses down the soil profile, as revealed in the glasshouse study (Graham & Hutchings, 1988a) is probably characteristic of the seed banks of old arable fields; it may be that the steepness of this decrease is indicative of the length of time since the soil was last cultivated. All of the species with even germination down the soil profile were annual species of arable cultivation, many of which are known to have large, persistent seed banks. The species which showed maximum germination from the deeper soil strata were without exception weed species. Taken together, these species accounted for the great majority of seedlings germinating under field conditions (Tables 3 and 4).

TABLE 4. Representation of species characteristic of chalk grassland vegetation in the seedlings appearing in different germination trials. (from Graham & Hutchings, 1988b).

	Glasshouse conditions	Exposed quadrats	Recovering vegetation quadrats
Number of species characteristic of chalk grassland	12	10	9
Number of grass species characteristic of chalk grassland	2	1	1
Percentage of species germinating which were characteristic of chalk grassland	24.5	26.3	28.1
Percentage of all seedlings germinating ( $m^{-2}$ ) which were characteristic of chalk grassland species	11.4	15.4	9.1

#### Restoration of chalk grassland vegetation via propagules from the seed bank

In all three investigations of the seed bank, the germination of species which can be regarded as typical components of chalk grassland



vegetation was low (Table 4). Only 12 of the 49 species which germinated in the glasshouse are regular constituents of chalk grassland vegetation, and all 12 are minority components of this vegetation type (see Table 12.1 in Grubb, 1986). Ten of these species are perennials and the other two (*Medicago lupulina* and *Senecio jacobaea*) often behave as perennials in closed grassland. In the field quadrats with permanently exposed soil, 13 of the 38 species which germinated were characteristic of chalk grassland vegetation; on the quadrats with recovering vegetation the corresponding figures were nine species out of 22. The lists of species characteristic of chalk grassland were similar in all three cases. Virtually all the species concerned were perennials with small seed banks and germination behaviour which was unresponsive to soil disturbance. Under all conditions of germination, these species accounted for a small proportion of all the germinating seedlings (Table 4). Whereas the seed bank revealed in all three investigations consisted predominantly of annual weeds of arable cultivation and these formed most of the vegetation developing under field conditions, chalk grassland vegetation consists almost entirely of perennial species, mostly with long life spans.

The results of these studies suggest that, rather than restoration of species-rich, perennial-dominated vegetation resembling chalk grassland, the immediate prospect for many abandoned arable fields on chalk soils will be occupation by the weed species associated with arable cultivation. These are opportunist germinators after site abandonment or disturbance, fast growing, competitive, and highly fecund, shedding large numbers of seeds back into the site in the first year after abandonment. In contrast, the perennials characteristic of chalk grassland vegetation have either small persistent seed banks or only transient seed banks and therefore must rely on dispersal to reach the site. In most cases the dispersal abilities of these species are poor (Booth, 1988), so that by the time they arrive the site will already have been occupied. Their growth is slow, even when soil fertility is high. The prospect that they will soon dominate "improved" ex-arable sites is therefore remote. It should be remembered that these pessimistic prognostications are based on results obtained in sites which might be regarded as highly favourable for the re-establishment of chalk grassland vegetation.

Although rapid restoration of vegetation resembling chalk grassland clearly appears to be unlikely on most ex-arable sites, a closer approach to this vegetation type might be possible if residual soil fertility is reduced, and the vegetation is kept shorter, by mowing or grazing, especially in the early part of the growing season. Gibson *et al.* (1987) have shown that even a short period of spring grazing produces more diverse vegetation than ungrazed grassland, and encourages faster establishment of permanent grassland species. Although the present regulations of Set-Aside allow mowing, the scale of the financial incentives of the scheme make it unlikely that farmers will elect to mow more than once a year; in addition, the scheme precludes removal of cuttings, which will do nothing to alleviate the problem of high residual soil fertility and will probably allow some seeds of the weedy post-cultivation vegetation to be dispersed on site. Grazing of farm livestock is not permitted, making the prospects for establishing those species and types of vegetation which are desirable to the conservationist very bleak indeed. Rather than providing opportunities for restoring habitat types which have been severely depleted by agricultural expansion, the current schemes for setting land aside from arable cultivation, are likely to promote, at least initially, exactly the types of vegetation which the farmers involved will deplore the most.

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## COLONIZATION OF GRASSLAND UNDER EXTENSIFICATION BY HEDGEROW SPECIES

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## ABSTRACT

Colonization of grassland under extensification (low stocking rate) was investigated in Normandy, France, in 11 1-4 ha contiguous meadows. *Rubus* is a dominant species in ungrazed patches. Those patches provide habitats for other hedgerow species. Species composition of patches is largely dependent on the species pool of surrounding hedgerows. Species differ in their ability to colonize new patches. A fine scale study of a meadow shows that persistence of sward species under ungrazed patches also differ.

## INTRODUCTION

World food market conditions, new EEC regulations (milk quotas, set-aside programs), changing farming structure under new social conditions (aging farmers, pressure of environmentalists) provide challenging questions on how to manage our land and for what purposes? Terms such as "set aside", "extensification", "land abandonment" are now widespread among agriculturists as well as among ecologists. These terms imply more or less controlled changes in agricultural systems at field, farm and micro-regional levels with possible benefits for ecological conservation (new non agricultural habitats, possibility to control erosion, nutrient leaching, etc) and also possible negative effects on production capability (spread of weeds or pest species). If these new questions on the interactions between agriculture and environment deserve attention (Park, 1988), the understanding of ongoing processes requires a rather complex approach (Golley & Golley, 1988; Brossier, in press) using aspects of ecology technology and economics.

In this paper I will focus on extensification in grassland in hedgerow network landscapes, in central Normandy, France. What is extensification?; it is a fuzzy concept, maybe a cliché? As pointed out by Tirel (1987) the word can be applied to a large variety of input/output ratios in agriculture. Here our interest is in land use extensification, a low input/output ratio when land surface area is considered. In farming systems where grassland is dominant, this means no fertilizer, a low stocking rate on a yearly basis, a low labour input for grassland management often on large farms. That is to say, the emerging agricultural systems will be different from the ones that were existing prior the general increase of inputs of the last decades. Ways to design and to manage such systems have to be found, should they be primarily for agricultural purposes or for conservation purposes (Thalen et al., 1987).

Regarding the effects of extensification on meadows, researchers have mostly focused on grassland species composition (Hopkins & Wainwright, 1989; Baudry et al., 1988; Losvik, 1988; Vivier & Baudry, 1988). Studies on the invasion of grassland by woody, semi-woody or thorny species, that can be the starting point of a succession toward some kind of woodland, are few and primarily done for conservation purposes (Buttenschoen, 1988; Thalen et

al, 1987). Buttenschon, in Denmark, focused on the establishment of woody species in grassland, but did not consider Rubus, a dominant pioneer in our area. The study shows a difference between pioneer wind dispersed species that can only establish themselves under non-grazing regimes and species of more mature stages (e.g. Quercus) less sensitive to grazing. The purpose of Thalen's work is to propose a model of vegetation dynamic under extensification.

From an ecological point of view, grassland in the temperate zone is a pioneer stage where succession is stopped by heavy human or human induced disturbance (cutting, grazing, spraying). As extensification is meant to reduce these types of disturbances, this may allow successional processes to take place and, ultimately, lead to a conversion of grassland into scrub or woodland. This will decrease the amount of fodder available to cattle, but also may create opportunities for species of non-agricultural land to expand their habitat.

#### MATERIAL AND METHODS

##### The study area

The area where the investigations were made (le Pays d'Auge) is predominantly covered by grassland, grazed by cattle. Meadows are 1-6 ha and are surrounded by hedgerows, where elm was once dominant, along with ash and hawthorn. Dairy production is the main enterprise but meat production, as a by-product is also important. Milk quotas and physical constraints have led to changes in land use: ploughing on the one side, extensive grazing on the other, even within a farm. In fact stocking rate has never been high (<1.5 cattle unit per ha and often barely above 1). Increase in farm size (from 23.6 ha in 1970 to 27 ha in 1980), decrease of the number of total working units led to land management problems. Formerly farmers had time to do the cleaning of their meadows by hand, they had time to manage their hedgerows, even if some did not. Nowadays, only mechanical work is done, either cutting or spraying hedgerows, brambles or bracken fern. Even this is not always done, especially when farmers only have the parcel for one year (they purchase the grass, not renting the land). Presently the instant stocking rates are low, grassland vegetation goes out of control and ungrazed patches are spreading. These are invaded by bramble (Rubus fruticosus) and/or bracken (Pteridium aquilinum) that are often abundant in surrounding hedgerows. Invading patches can be from 1 to 20 meters wide and can also spread from hedgerows.

##### Sampling

To study the colonization of grassland by hedgerow species we sample hedgerows and bramble/bracken patches, hereinafter designated as patches, in 11 contiguous meadows. They were partly on the slope of a hill, partly on the top of it (plateau). Hedgerows are connected to woods that can serve as a source of species (Baudry, 1988; Burel & Baudry, in press). A total of 39 hedgerows and 51 patches were sampled. Not all the patches of every meadow were sampled because they were too numerous. Presence of species in any sampled plot was recorded. Plots were 30 m long in hedgerows and 4-5 m<sup>2</sup> in patches. Field work was done in June 1987 and June 1989. In addition one particularly heterogeneous and derelict meadow was sampled in June 1988. In 21 plots of all types of vegetation, including normally grazed patches, we estimated the contribution of each species to the total above-ground biomass. This was done to assess not only the invasion by hedgerow species, but also the decline of grassland species.

## Data analysis

Both data sets were analyzed using correspondence analysis (CA), a multivariate method developed by Benzecri (1973, 1984). This yields a gradient of samples whose proximity indicates resemblance and also a gradient of species, where the proximity means high co-occurrence. For details on data analysis in plant ecology, see Legendre & Legendre (1984, 1987), Orlovi (1988) and Kent & Ballard (1988). But, as the purpose of each study was different, the analysis were carried out with different approaches.

### The 11 meadows study

Only species present in more than 10% of the samples were retained. The CA was performed on the matrix hedgerows v. species, so hedgerow species formed the background of the factorial space. To compare hedgerow and patch species compositions, the aggregated samples of hedgerows and patches of each meadow were mapped in the factorial space as supplementary elements. Doing so the species that are in patches but not in hedgerows do not affect the ordination. As the number of hedgerows and patches sampled in the meadows differed we consider only presence or absence of species in the aggregate, instead of the total number of patches where it was present in a meadow. Individual patches were also mapped as supplementary elements.

### The heterogeneous meadow study

All the recorded species present in at least 5% of the plot were used. Some plots were almost mono-specific (2 composed almost only of bracken, one of *Brachypodium pinnatum* and one of *Rosa canina*). These were only used as supplementary elements in the CA of plots v. species.

## RESULTS

### Colonization of ungrazed patches by hedgerow species

#### Gradient of hedgerow species composition

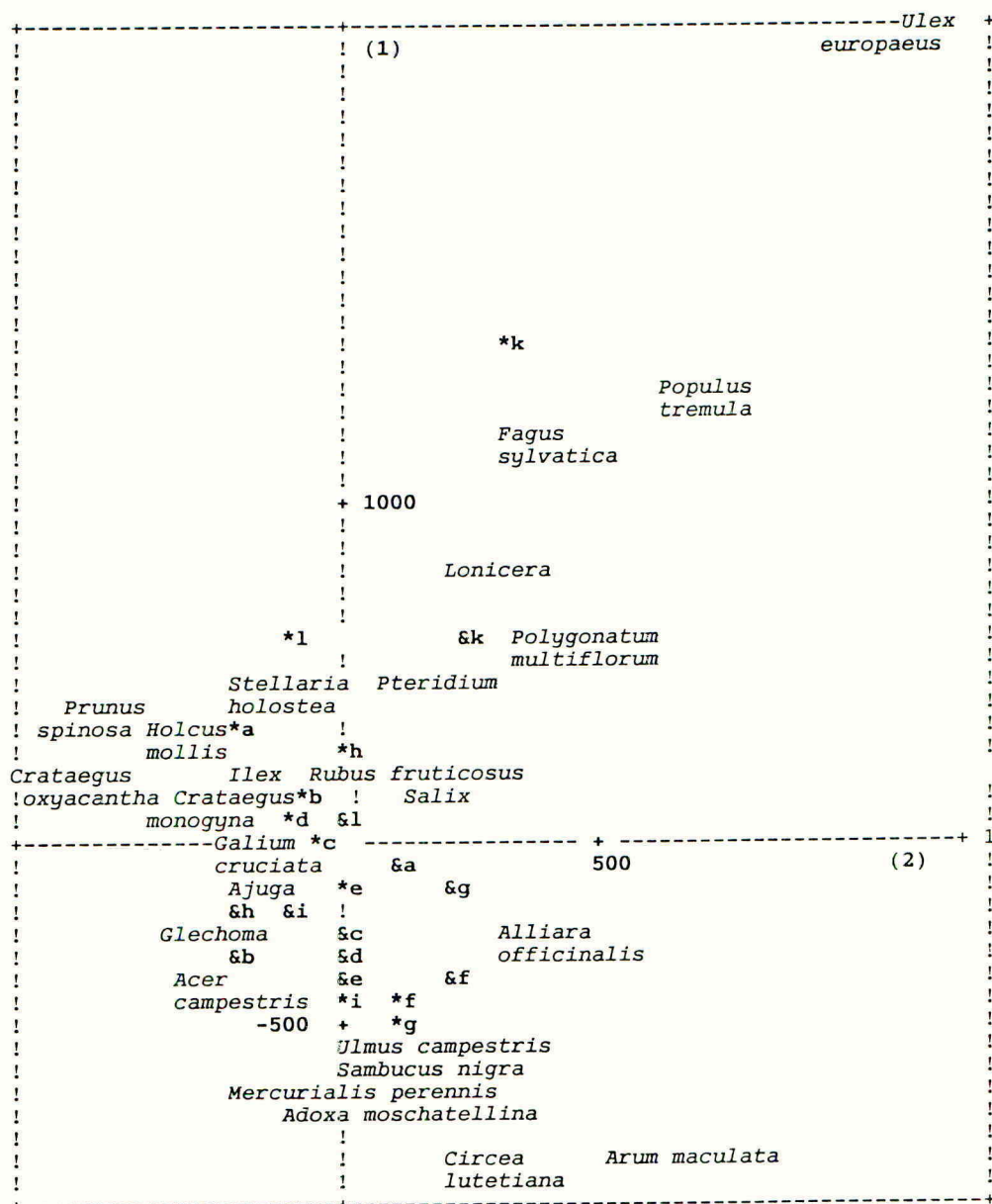
The first axis (13.3 % of the variance) opposed species such as *Ulex europaeus*, *Fagus sylvatica*, *Populus tremula*, *Pteridium aquilinum* and *Lonicera peryclimenum* on the positive part to *Circea lutetiana*, *Adoxa moschatellina*, *Mercurialis perennis* and *Ulmus campestris* in the negative part (Fig.1). It is a contrast with species characteristic of the leached soils of the plateau (top the hill) to species of nutrient rich soils on the slopes. It should be noted that the low eigenvalue (0.178) indicates that the gradient is not steep.

Differentiation along the second axis (8.9 % of the variance) is less clear. On the plateau there is a contrast between *Ulex*, *Populus* on the one side and *Crataegus monogyna*, *Prunus spinosa* on the other side. As they can all be considered as early successional species, this may indicate different pathways of succession. On the slope, *Arum maculata* and *Alliaria officinalis* may indicate a high nitrogen content.

#### Resemblance between patches and hedgerows

Fig.1 shows the place of the aggregate sample on the ordination and Fig.2 the relationships between the scores of the aggregate patches and hedgerows on the first axis for each meadow. They are highly correlated ( $r=0.88$ ,  $p<0.001$ ) indicating that patch species composition is highly dependent on the surrounding hedgerows. The general pattern is that patches tend to have a higher score on the first axis, the underlying process may

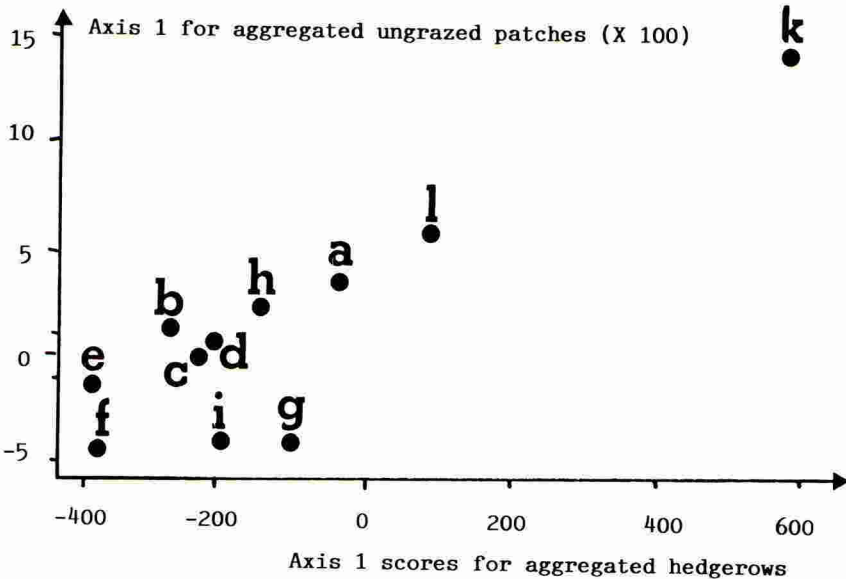
Fig. 1 First (1) and second (2) ordination axes of the correspondance analysis performed on the species composition of single hedgerows. Only the species contributing to the inertia of the axes are shown. Aggregated samples of hedgerows (&) and patches (\*) are mapped as supplementary elements. Letters refer to meadows.



be that species of rich mesic woodland cannot colonize patches easily. We will examine the behaviour of the different species below.

Though the relationship is statistically significant, Fig. 2 shows that 3 patches deserve more attention (patches "g", "i" and "f"). In meadow "g" only one patch was sampled. It was situated on a wet, rich soil, while upper hedgerows are on the plateau. So the patch score is lower on the first axis, because it provides habitat for rich soil species. Meadow "i" is also physically heterogeneous and has tree dominated patches inhabited by species of mesic rich soils. Hedgerows of meadow "f" are at the bottom of axis one. Its patches are also wet and wooded and close to hedgerows, so there are few differences in species composition between the two. Habitat conditions play a role in the process of colonization in addition to nearby species pool. When patches are looked at individually, it appears that wooded ones are close to woodlots, toward the bottom of axis one.

Fig.2: Relationships between ungrazed patches and hedgerows (aggregated at field scale) on the first axis of CA



#### A closer look at species

To assess the colonization ability of species we compute a ratio  $R$  of the the number of times a species is present in both hedgerows and patches in a meadow as a proportion of its occurrence in hedgerows. This confirms the assumption that species at the bottom of axis 1 (especially under -500, see fig. 1) have a lower colonization ability than species with a higher score (Fig. 3).  $R$  is independent of the species frequency in hedgerows, indicating that a species may live under hedgerow conditions or had time to colonize them but may be rare under patch conditions or had not enough time to get into them. This is consistent with the fact that woody patches (hedgerow conditions) have more hedgerow species than others. Species frequency in patches is related to colonization ability (Table 1).

Table 1 gives the frequency of species in aggregated hedgerow and patche samples and species ability to colonize patches. Some species (e.g. Alliaria officinalis, Taxus baccata, Crataegus oxyacantha, Ilex aquifolium, Caerophyllum temulum) were never found in patches, while others (Rosa

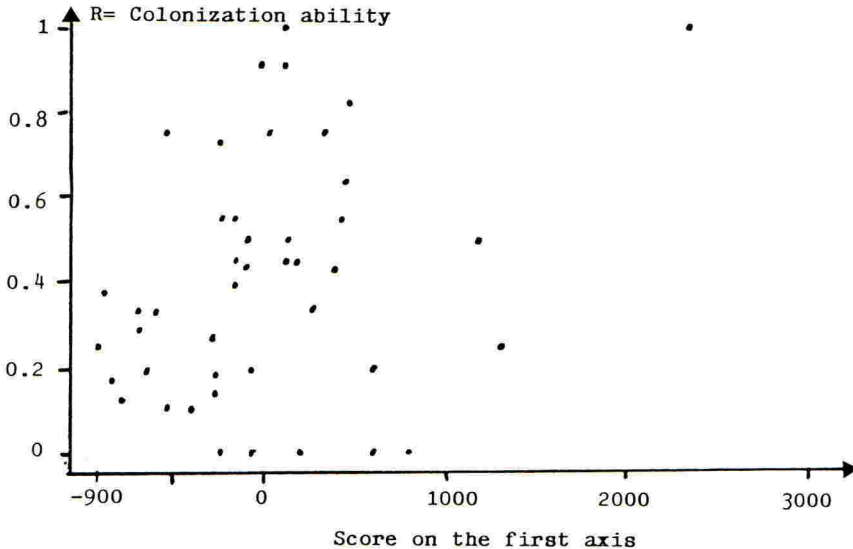
Table 1: List of species (frequency >10%) in the landscape study with their scores on axes 1 and 2 of CA, with number of their occurrences in the aggregated samples of hedgerows and patches and R a measure of their patch colonization ability.

N° occurrence of species	CA scores				R
	Axis 1	Axis 2	hedgerow	patch	
<i>Alliaria officinalis</i>	-227	552	10	0	0
<i>Taxus baccata</i>	-57	15	7	0	0
<i>Crataegus oxyacantha</i>	200	-765	7	0	0
<i>Ilex aquifolium</i>	203	-210	11	0	0
<i>Caeratophyllum temula</i>	606	234	5	0	0
<i>Lonicera periclymenum</i>	805	329	5	1	0
<i>Euphorbia sylvatica</i>	-527	206	9	1	.11
<i>Acer campestre</i>	-380	-369	9	1	.11
<i>Adoxa moschatellina</i>	-759	-49	8	1	.13
<i>Cornus sanguinea</i>	-261	-503	7	1	.14
<i>Arum maculatum</i>	-825	827	6	2	.17
<i>Geum urbanum</i>	-261	73	11	2	.18
<i>Ulmus campestre</i>	-629	129	10	2	.20
<i>Ajuga reptans</i>	-60	-266	5	6	.20
<i>Polygonatum multiflorum</i>	613	580	10	2	.20
<i>Ficaria verna</i>	-896	751	4	1	.25
<i>Populus tremula</i>	1300	1139	4	1	.25
<i>Hedera helix</i>	-280	69	11	3	.27
<i>Mercurialis perennis</i>	-673	-266	7	3	.29
<i>Athyrium filix-femina</i>	-680	966	9	3	.33
<i>Sambucus nigra</i>	-591	16	6	3	.33
<i>Primula acaulis</i>	286	933	3	1	.33
<i>Circea lutetiana</i>	-862	429	8	4	.38
<i>Viola sp</i>	-151	360	10	4	.40
<i>Prunus spinosa</i>	389	-728	7	3	.43
<i>Tamus communis</i>	-93	88	9	4	.44
<i>Fraxinus exelcior</i>	-135	-344	11	5	.45
<i>Crataegus monogina</i>	127	-226	11	5	.45
<i>Corylus avellana</i>	151	-42	11	5	.45
<i>Prunus avium</i>	189	-379	11	5	.45
<i>Veronica chamaedris</i>	-78	21	10	6	.50
<i>Salix atrocineria</i>	142	113	8	6	.50
<i>Fagus sylvatica</i>	1183	463	2	2	.50
<i>Geranium robertianum</i>	-212	222	11	6	.55
<i>Stachys sylvatica</i>	-158	37	11	6	.55
<i>Quercus pedunculata</i>	433	-241	11	6	.55
<i>Stellaria holostea</i>	466	-300	8	6	.63
<i>Glechoma hederacea</i>	-234	-21	11	8	.73
<i>Fragaria vesca</i>	-537	169	4	6	.75
<i>Galium cruciata</i>	36	-150	8	8	.75
<i>Holcus mollis</i>	331	-81	4	3	.75
<i>Pteridium aquilinum</i>	473	9	11	9	.82
<i>Galium aparine</i>	-11	-45	11	10	.91
<i>Rosa arvensis</i>	118	-202	11	10	.91
<i>Rubus fruticosus</i>	115	-102	11	11	1
<i>Ulex europaeus</i>	2330	1766	1	2	1



canina, Galium aparine, Galium cruciata, Glechoma hederacea) are frequent, not to speak of Rubus and Pteridium which are abundant.

Fig.3: Relationship between the colonization ability of species and their score on the first axis

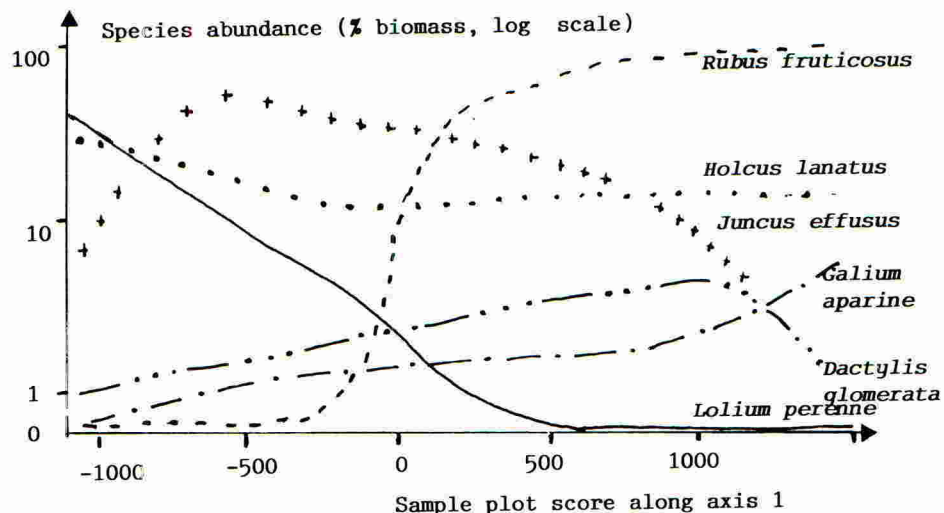


#### Colonization of ungrazed patches and persistence of grassland species

This fine scale study shows a very high contrast between the different plots: high eigenvalues for the first three factors of the CA (0.68, 0.61, 0.59). On a plan of axes 1 and 3 two main gradients are apparent: on axis 1 an opposition between ungrazed patches and meadow vegetation, that splits into mesic and wet vegetation along axis 3. This gives 3 types of vegetation, dominated by Rubus and/or Pteridium, the second by Juncus sp and the third by Lolium perenne, Holcus lanatus, Trifolium repens. But these species do not have the same distribution along axis 1. Lolium perenne is concentrated at the negative end, Pteridium at the positive one, while Rubus is present almost everywhere on the positive part. Cynosurus is on the negative part, but other common, if not abundant, grasses such as Anthoxanthum odoratum, Dactylis glomerata or even Holcus lanatus stay along the gradient. Holcus mollis is only present when Rubus and/or Pteridium are abundant. In these conditions legumes almost disappear. So if dominant species do not overlap in space, which is clearly seen in the meadows, many other species are more equally distributed (Fig.4).

Among the hedgerow species labeled "good colonizer" at landscape level (11 meadows), apart from Rubus, Pteridium, and Holcus mollis, only Galium aparine is somewhat abundant, though Galium cruciata is present. On the other hand Geum urbanum was found more frequently than at landscape level. Therefore, generalizing results from one level to another should be made with caution.

Fig. 4: Variation of the abundance of some species along a gradient of abandonment in a single meadow



#### CONCLUSION

These investigations of grassland under extensive grazing in Normandy allow provisional conclusions on the colonization of meadows by hedgerow species.

-In all the cases but one studied, colonization starts by one of two aggressive species, *Rubus fruticosus* or *Pteridium aquilinum*. They have different biologies, the first is bird or mammal dispersed, while the other can be wind dispersed, though it reproduces mainly vegetatively, as does *Rubus* once established. *Pteridium* is much more difficult to control either by cutting or spraying than *Rubus*. Cattle trampling can also affect their vitality. Not only do the two species coexist in the same meadow but often in the same patch.

-Other hedgerow species can establish themselves in *Rubus* or *Pteridium* patches, but they are never abundant and can only thrive at the edge of bramble patches. As *Rubus* spreads, other plants die and have to reproduce to maintain a population. Habitat stability seems to occur when trees grow and shade the *Rubus*. This is probably a slow process, except in the wettest spots, as it is not uncommon to see bramble climbing over apple trees.

-Colonization of ungrazed patches by hedgerow species appear to be driven by three factors: i) species pool in hedgerows, even within a landscape less than 1 km wide, patch composition is very much a function of surrounding species composition. ii) species behaviour, some species are good colonizers other are not; in both groups wind and bird dispersed species occur. iii) local physical conditions - presence of trees increases the probability of establishment

-Persistence of grassland species under the edge of ungrazed patches can be seen along a gradient from no persistence (*Lolium*) to good persistence (*Dactylis*). Intra-species genetic diversity of the latter should be addressed (unpublish work by Fily shows important genetic

differences under various grazing conditions within the species *Dactylis*).

-Patterns of colonization are scale dependent: results of a study of many patches in a single meadow are not necessarily consistent with those of a study of aggregated patches in several meadows.

-If extensification of grazing is, first of all, a matter of agricultural practices, the way to relate them to ecological patterns is unclear. In a single meadow, the decision level for a farmer, several gradients of species composition can be found. If the dates of grazing, the instant and the annual stocking rates play a role, vegetation dynamics are certainly also affected by the behaviour of a herd in an heterogeneous environment. Once unpalatable species begin to invade a meadow they create spots undisturbed by cattle, encouraging spread. In the meantime patches of good sward still exist even if they shrink and may suffer from over trampling and over grazing.

-Extensification and its ecological consequences pose the problem of sward maintenance under good climatic conditions and with nearby sources of aggressive species. From an agricultural point of view, uncontrolled extensification diminishes the productive area. From a conservation standpoint if it does provide opportunities for non agricultural species to expand, the benefit goes mainly to species such as *Rubus* and *Pteridium* that are far from being endangered.

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## THE EFFECTS OF INSECT HERBIVORES ON WEED COMMUNITIES

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## ABSTRACT

Changes in land use, resulting in marginal land coming out of intensive agricultural production, highlight the need for a greater understanding of the dynamics of vegetation colonisation and management. Manipulative, long-term field experiments, involving the judicious use of insecticides, demonstrate that insect herbivory has an important impact on such plant communities. Whereas a reduction in foliar herbivory enhances the growth of perennial grasses, that of below-ground herbivory produces a high forb species richness and maintains a balance between forbs and grasses. The implications of these findings in the management of farmed land are discussed.

## INTRODUCTION

Current and recent changes in the Common Agricultural Policy are causing land to be taken out of intensive arable cultivation. Although a variety of uses have been suggested for such land, all proposals require an understanding of the dynamics of colonisation by plants and the associated fauna. Within an arable system, set-aside or otherwise abandoned land will be colonised first by a range of annual plant species, followed closely by the establishment of perennial grasses and forbs (non-graminaceous species). Such ruderal plant communities can generally be referred to as weed communities (even though only relatively few species will be the pernicious weeds associated with agricultural practice).

The management of set-aside or abandoned land is at the forefront of current research. One aim is to produce a sward rich in perennial forbs, but devoid of pernicious weeds, which will have high amenity, landscape and conservation value. This can be achieved by seed sowing (e.g. Wells, 1987) or defoliating by grazing (e.g. Gibson *et al.*, 1987b) or cutting (e.g. Bakker, 1989). However, other potentially more subtle, and thus previously overlooked, factors may also be important. Recent work, mainly at Silwood Park, has demonstrated that the impact of insect herbivory, so clearly seen in the crop situation, can be an important determinant in the dynamics of plant communities. This paper aims to demonstrate, through the results of long-term manipulative field experiments, the effects of insect herbivory on the establishment and development of weed communities. Such communities are an important stage in the development of more permanent semi-natural habitats and therefore play a significant role in successful habitat restoration/recreation.

## MATERIALS AND METHODS

The experimental sites

There were two experimental sites, both on ex-arable land. One was on acidic, sandy soil at Silwood Park, Berkshire and had previously been under a rotation of winter wheat, field beans and Brussels sprouts. Here, the experiment began on vegetation establishing from bare ground (see Brown & Gange, 1989). The other experimental site, at Wytham, Oxfordshire was on shallow soil overlying Jurassic corallian limestone and had been under cereal cultivation since 1960, being regularly cultivated from then until 1981, when a crop of winter wheat was sown but not harvested. Thus, the colonising weed community was four years old when the experiment started in 1985. Each site was fenced to exclude rabbits and, at the Wytham site, deer were also excluded. Mollusc grazing was controlled by the application of slug pellets (see Brown & Gange, 1989). Two experiments are described. The first had two treatments: control (with natural levels of insect herbivory) and foliar insecticide-treated (to reduce levels of above-ground herbivory). The second, which is in its fourth year at the Silwood site but has only recently begun at the Wytham site, had four treatments: soil insecticide-treated (to reduce levels of below-ground herbivory) and foliar and soil insecticide-treated (to provide a complete reduction in herbivory), in addition to the two treatments included in the first experiment. In the first experiment, there were ten spaced replicates (3m x 3m plots) of each treatment within a randomised design and in the second, five replicates of each of the four treatments.

The foliar insecticide was Dimethoate-40 (Portman Agrochemicals Limited) which was applied at the standard agricultural rate of 0.336 kg a.i. ha<sup>-1</sup> (equivalent to 75ml per plot) (Martin & Worthing, 1976) at 2-3 weekly intervals in the summer and monthly during the winter. Control plots were sprayed with an equal volume of water. Dursban 5G, containing 5% chlorpyrifos w/w (Dow Agriculture), was used as the soil insecticide and was applied at the recommended agricultural rate (18 g per plot) at monthly intervals. The main advantages of this compound are: non-toxicity to small mammals and birds (Clements & Bale, 1988), no known nematocidal effect and "little or no detectable effect (at the recommended agricultural rates) on overall populations of fungi, bacteria or algae" (Anon., 1985). In addition, the work of Clements *et al.* (1986) indicates that in granular form Dursban 5G has only a minimal effect on earthworms. Both insecticides were tested for direct effects on the vegetation, using the procedure described in Brown *et al.*, (1987).

Sampling

The vegetation was monitored by point quadrat pins, using five 38 cm linear frames of ten pins randomly placed in each plot. All touches of living plant material were recorded to species. Five samples were taken during each growing season over a three-year period and provide information on the effects of insect herbivory on:

- (i) the number of plant species (species richness)
- (ii) the total number of touches of vegetation, which provides a measure of cover abundance.
- (iii) the total number of touches (i.e. cover abundance) of plant species belonging to different life-history groupings (e.g. annual forbs and grasses, perennial forbs and grasses (see Gibson *et al.* (1987) for details).

The above-ground macro-invertebrates were sampled by "D Vac" suction. In each control plot, three samples were taken (giving a sampling area of 0.293 m<sup>2</sup>). One sample was taken from each insecticide-treated plot to confirm the efficacy of the treatment. The apparatus was held in position for 0.5 min and the sampling area then searched by hand for large invertebrates resistant to suction. The below-ground insect herbivores were determined by taking three 15 cm x 10 cm soil cores from plots adjacent to where the vegetation was sampled. Samples were hand sorted for the larger herbivores and then subjected to extraction in Tullgren tunnels. Insect sampling took place at the same intervals as that for the vegetation. Detailed methodology is described in Southwood *et al.*, (1979) and Brown & Gange (1989).

## RESULTS

### Insect herbivores

The major herbivorous insect groups associated with the above-ground vegetative and reproductive parts of weed species included adult Coleoptera (Curculionoidea, Chrysomeloidea), adult and nymphal Homoptera (Cicadellidae, Aphididae), Heteroptera (Miridae), Thysanoptera and some larval Lepidoptera and Symphyta. The dominant below-ground herbivorous taxa were larval Coleoptera (Curculionoidea, Elateridae, Scarabaeidae), Diptera (Tipulidae, Bibionidae) and some soil surface-dwelling larval Lepidoptera. The relative abundances and distribution of these groups is given elsewhere (e.g. Brown & Southwood, 1987; Brown *et al.*, 1988; Brown & Gange, in press a).

### Effects of foliar-feeding insects

The application of foliar insecticide caused a significant increase in the cover of vegetation in the first year of colonisation of bare ground at the Silwood site, a trend which was continued into the second and third years (year 1:  $F = 52.1$ ,  $P < 0.001$ ; year 2:  $F = 81.2$ ,  $P < 0.001$ ; year 3:  $F = 68.5$ ,  $P < 0.001$ ). Figure 1 shows this difference, expressed as a ratio of the cover abundance in insecticide-treated plots to controls. However, of greater significance to vegetation dynamics is the difference seen in the various plant life-history groupings. For example, annual forbs were the dominant plant type in the first year of colonisation (there were very few annual grasses) and these showed the most marked response to foliar-insecticide treatment (Fig. 2a) ( $F = 51.6$ ,  $P < 0.001$ ). As the perennial grasses became established, they responded very dramatically to a reduction in foliar herbivory with their cover increasing significantly in the second and third years of colonisation (Fig. 2c,d) ( $F = 54.3$ ,  $P < 0.001$ ,  $F = 53.7$ ,  $P < 0.001$  respectively). In particular, it was the more vigorous-growing species (*Agropyron repens*, *Agrostis stolonifera*) which showed this trend most clearly. The increase in grass growth, as a result of insecticide treatment, resulted in a decline in the establishment of the competitively-inferior perennial forbs. This was seen in both cover abundance and species richness, the latter being significantly depressed by treatment with foliar insecticide ( $F = 27.8$ ,  $P < 0.001$ ).

Similar patterns were seen at the Wytham site, abandoned from agriculture for four years, with the cover abundance of vegetation being enhanced by the application of foliar insecticide, but only from the second year of treatment and then to a lesser extent than at the Silwood site (Fig. 1) (year 1:  $F = 2.6, P > 0.05$ ; year 2:  $F = 6.9, P < 0.05$ ; year 3:

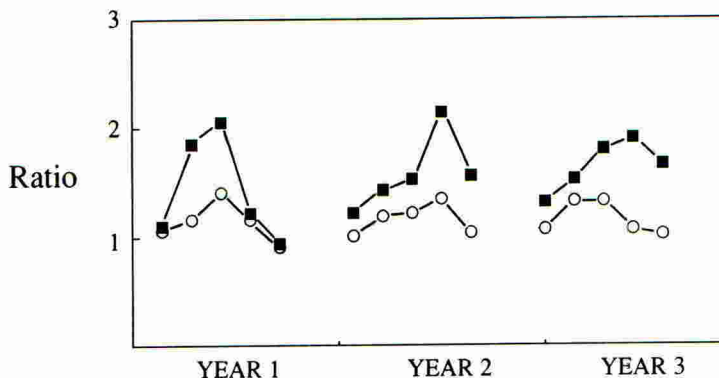


Fig. 1 The cover abundance of vegetation in control (natural levels of insect herbivory) and foliar insecticide-treated plots, expressed as the ratio of insecticide-treated : control ■ = Silwood Park, Berks.; ○ = Wytham, Oxon.

$F = 2.5, P < 0.05$ ). The strongest effect was seen in the perennial grasses, the cover of which was significantly increased by the application of foliar insecticide (year 2:  $F = 5.4, P < 0.05$ ; year 3:  $F = 14.1, P < 0.01$ ). Despite the potential for a much higher species richness of forbs on the calcareous soil, their cover was decreased (Fig. 2e,f), although their height increased as they competed with the much taller grasses. However, these differences were not significant because of the high degree of heterogeneity in the distribution of this plant type between plots. In the first year of the experiment, the short-lived perennial forbs, which succeeded the annuals, responded in the same way as the annual forbs at the Silwood site and were enhanced by the application of insecticide (Fig. 2b) ( $F = 2.8, P < 0.05$ ). The greatest effect was shown by Black Medick, *Medicago lupulina*.

#### Comparative effects of foliar-feeding and soil-dwelling insects

The most conspicuous effect of the application of soil insecticide was an increase in plant species richness (Fig. 3). Although this was marginally enhanced by the foliar insecticide in the first year ( $F = 5.1, P < 0.05$ ), in the second and third years the soil insecticide resulted in higher species richness (year 2:  $F = 20.9, P < 0.001$ ; year 3:  $F = 76.3, P < 0.001$ ). This difference became distinct from mid season in the second year, when the species richness in the control and foliar insecticide-treated plots declined, whereas the two treatments involving soil insecticide showed increased species richness. By the third year, only the soil insecticide treatment maintained a high species richness, while that in the combined treatment fell. Indeed, by this time, the species richness in the foliar insecticide-treated plots was depressed beneath that in the control plots.



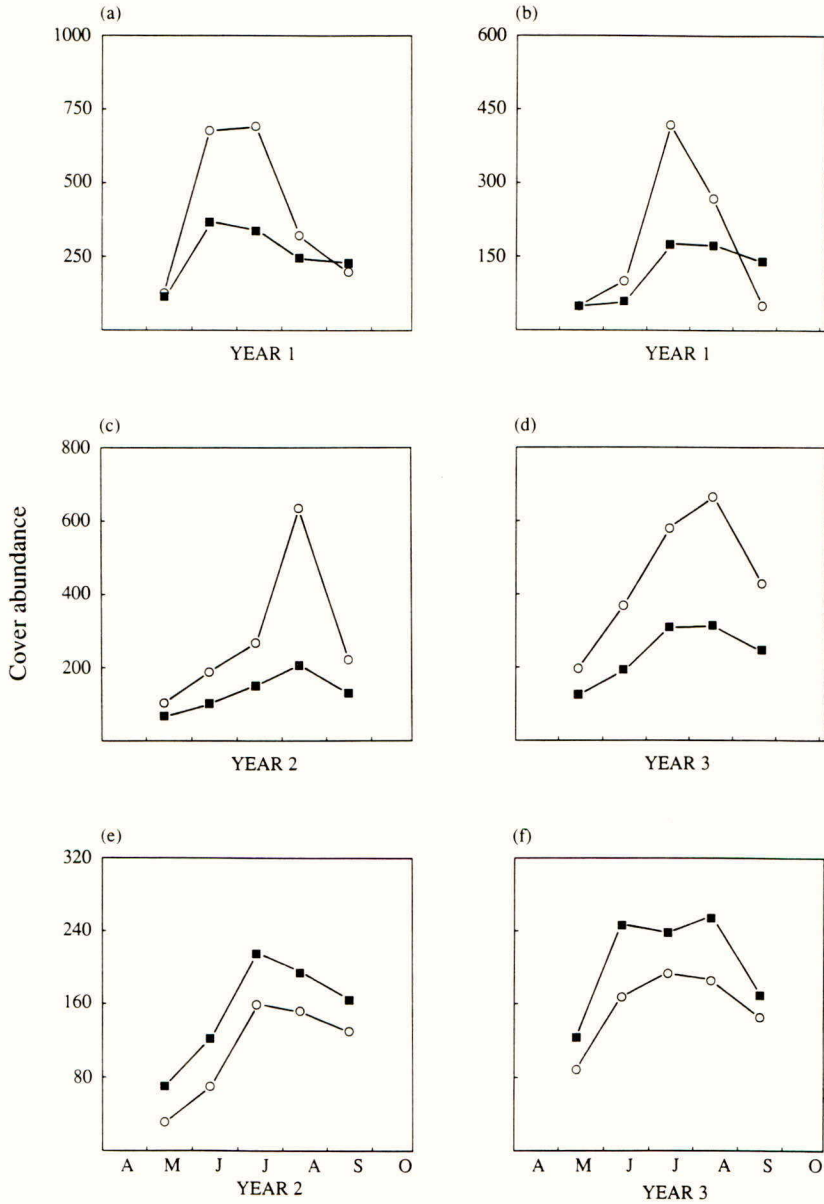


Fig. 2 The effects of foliar insect herbivory demonstrated by chemical exclusion methods on different plant life-history groupings at Silwood Park, Berks. and Wytham, Oxon.  $\circ$  = insecticide-treated;  $\blacksquare$  = control. (a) annual forbs (year 1) Silwood, (b) short-lived perennial forbs (year 1) Wytham, (c) and (d) perennial grasses (years 2 and 3) Silwood, (e) and (f) perennial forbs (years 2 and 3) Wytham.

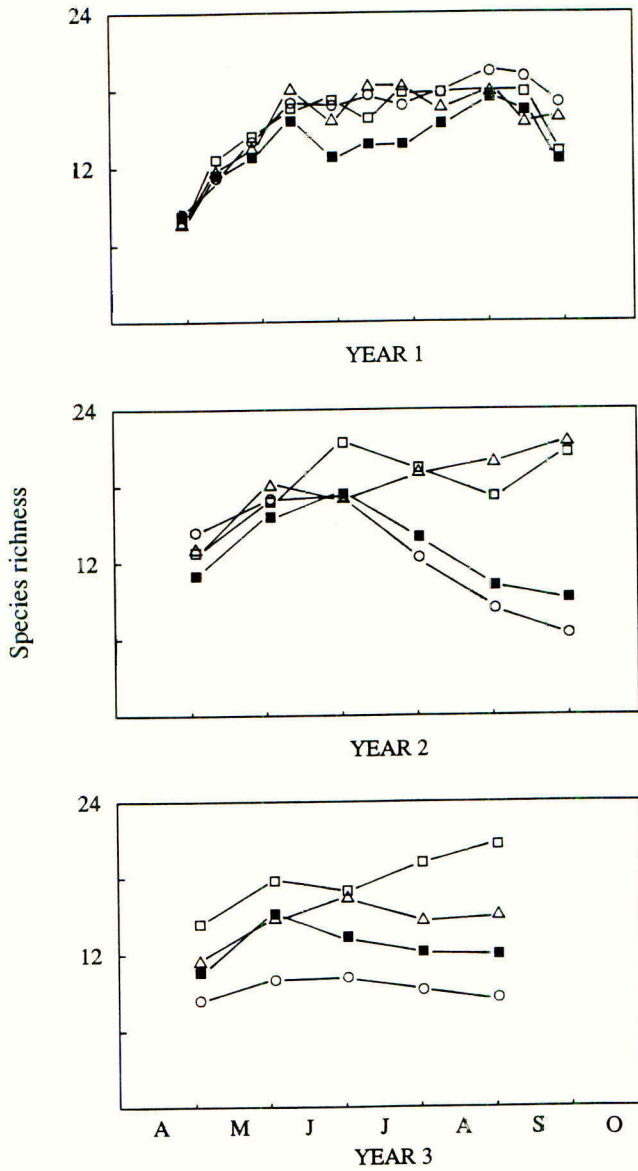


Fig. 3 The effects of foliar and root insect herbivory on plant species richness during the first three years of the colonisation of bare ground at Silwood Park, Berks. ■ = control; ○ = foliar insecticide; □ = soil insecticide; △ = foliar and soil insecticide. (from Brown & Gange, *in press a*).

Of the 98 plant species colonising in the first three years, three annual and twelve perennial forbs were only found where soil-dwelling insects were reduced. These species included *Crepis vesicaria*, *Glechoma hederacea*, *Leontodon taraxacoides*, *Stellaria graminea*, and *Rumex acetosa*, all of which were found in more than half the soil insecticide-treated plots. Other less common species were *Lamium album*, *L. purpureum* and *Stachys palustris*. This difference in species richness was visually apparent, particularly in mid season when many species were in flower. In the three seasons, the number of species flowering on each sampling date in the insecticide-treated plots was significantly higher than in the controls (year 1:  $F = 34.3$ ,  $P < 0.001$ ; year 2:  $F = 22.4$ ,  $P < 0.001$ ; year 3:  $F = 11.2$ ,  $P < 0.01$ ).

Although cover abundance of the vegetation was increased by the application of both compounds, the plant life-history groupings responded differently to above- and below-ground herbivory. In the first year, the annual forbs showed an increase in cover abundance in response to the application of both compounds (foliar insecticide:  $F = 56.4$ ,  $P < 0.001$ ; soil insecticide:  $F = 10.9$ ,  $P < 0.01$ ), although by the second year, this group only increased in response to the soil insecticide ( $F = 8.6$ ,  $P < 0.01$ ). However, the cover of perennial grasses was increased by both compounds from the second year, although the response to foliar insecticide was stronger (year 2: foliar insecticide  $F = 58.8$ ,  $P < 0.001$ ; soil insecticide  $F = 12.8$ ,  $P < 0.01$ ; year 3: foliar insecticide  $F = 84.1$ ,  $P < 0.001$ ; soil insecticide  $F = 11.9$ ,  $P < 0.01$ ). As in the first experiment, the application of foliar insecticide resulted in a relatively poor establishment of perennial forbs, while that of soil insecticide caused an increase in cover which was significant in the third year ( $F = 20.0$ ,  $P < 0.001$ ) (Fig. 4).

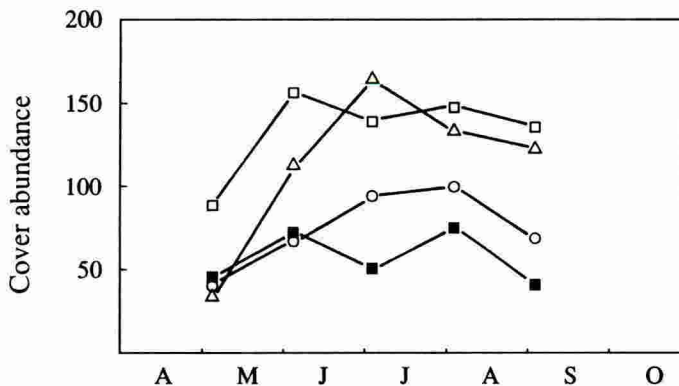


Fig. 4 The effects of foliar and root insect herbivory on the cover abundance of perennial forbs in the third year of colonisation of bare ground at Silwood Park, Berks. Conventions as in Fig. 3.

The higher species richness and performance of both annual and perennial forbs was related to the better opportunities for recruitment when below-ground herbivory was reduced. Recruitment is known to be limited by the availability of microsites (Harper, 1977). However, the amount of bare ground at the beginning of the second growing

season (when most of the perennial forbs were establishing) was similar in the control and soil insecticide-treated plots ( $F = 0.4$ ,  $P > 0.05$ ). Seedling mortality in control plots is known to be high (Brown & Gange, unpubl.) and it is also likely that there is substantial mortality of dormant seed and seed after germination but before seedling emergence. In this case though, with similar amounts of bare ground (= microsites), herbivory would appear to be the dominant factor.

## DISCUSSION

Whereas the effects of normal land management, e.g. by cutting or mammalian grazing, have dramatic and rapid effects on vegetation structure and species composition, those of the much smaller invertebrate herbivores might be expected to be more subtle or even non-existent. Manipulative field experiments, using chemical exclusion methods, can only aim to reduce natural levels of insect herbivory and, as such, results obtained are likely to be underestimates of the full impact of herbivory. Even so, results from two sites on different soils have demonstrated unequivocally that the effects of reducing either above- or below-ground herbivory can be considerable; a reduction in foliar herbivory favouring the establishment and growth of the perennial grasses, while a reduction in below-ground herbivory results in enhanced performance and species richness of the forbs (Brown & Gange, in press b). Furthermore, the lack of significant interactions between the effects of foliar and soil insecticides suggests that the effects of above- and below-ground herbivory are purely additive, at least at the community level (but see Brown & Gange, 1989). However, other factors such as differences in soil nutrient content, nutrient cycling and the soil microflora induced by the treatments may also be important. Several of these effects have already been considered by other workers (e.g. McGonigle & Fitter, 1988). For example, the separation of the effects of soil insecticides on insects, such as Collembola which can feed on root mycorrhizas, and root herbivores is important. Thus, an experiment is currently underway, with main treatments of soil insecticide, foliar insecticide and soil fungicide and all possible combinations, to resolve the importance of these interactions (Gange, Brown, Farmer & Salt, unpubl.).

The current work has several important implications for the management of set-aside or abandoned land. Firstly, the consistent finding that the perennial grasses are promoted at the expense of annual and perennial forbs when foliar insecticide is applied, highlights the potential danger of the use of such compounds, either directly or by drift, when a forb rich vegetation is desirable. Secondly, the application of a soil insecticide at an early stage in colonisation enhances forb species richness and maintains a balance between forbs and grasses which is desirable both for its visual impact and for components of the fauna which rely on specific plant species as a source of food. Such species may include certain beneficial insects as well as those of conservation interest. Such a low cost, easily implemented means of managing the early stages of colonisation may well warrant the consideration of farmers and landowners. In particular, the use of slow-release compounds which would preclude the disadvantages of regular application, should be explored. Although the results described here have focused on the early stages of plant colonisation, experiments currently in progress on mature natural vegetation are revealing similar trends and thus may be equally relevant in the management of more permanent habitats.

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## SELECTIVE WEED CONTROL IN FIELD MARGINS

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## ABSTRACT

The importance of field margins for conservation is considered in relation to the deterioration of margin floras and potential weed problems arising at field edges. Using herbicides selectively to control the most damaging weed species, a compromise may be achieved between the needs of crop production and wildlife conservation. The management of crop edges as "conservation headlands", using selective herbicides, is described, and some preliminary data given indicating that the concept of selective weed control may be extended to the field boundary. It is concluded that there is a pressing need for further research into field boundary management.

## INTRODUCTION

The importance of field margins for wildlife conservation

The term field margin includes the field boundary proper (hedge, fence, wall, grass baulk, windbreak etc.), all land between the field boundary and crop, and the "crop edge" i.e. the first few metres of crop (often taken to be synonymous with headland in the agricultural sense) (Greaves & Marshall, 1987).

Over large areas of land field margins may contain the only semi-natural (uncropped) habitat, and they are also areas of inherently high diversity. Many species of wildlife on arable land are dependent on field margins during at least part of their life cycle (Pollard *et al.*, 1974). Songbirds use hedges for breeding and feeding (O'Connor, 1987). Some of the most important insect predators of aphids overwinter in field boundaries and only move out into fields in the spring (Sotherton, 1984). Field boundary vegetation provides breeding sites for several species of butterflies and moths in addition to a range of other insects.

Few plants are restricted to field boundaries, the majority being relatively common species found in other habitats, notably broad-leaved woodland (Hooper, 1987). In contrast, most annuals characteristic of arable land are confined to regularly cultivated land, and many of these species are becoming increasingly rare. Several are already extinct (Smith, 1986). Recent evidence indicates that, where these plants persist in the seedbank, they are concentrated in or confined to the edges of arable fields (Wilson, 1989).

On many farms, the prime motivation for habitat management outside normal farming operations is to encourage game. Field margins are of great importance to gamebirds: grey and red-legged partridge nest almost entirely in field boundaries, and up to 30% of wild pheasants also nest there. Once the chicks hatch, however, broods do not remain in the field

boundary but move into adjacent crops to feed. Grey partridge broods feed almost exclusively in cereals, whilst red-legged partridges and pheasants make use of a wider range of crops. More time is spent feeding in the crop margin where food items are more abundant than in the rest of the field. Research has shown that sympathetic management of field margin habitats can greatly increase nesting success and chick survival (Rands, 1985; 1987) with considerable knock-on benefits for other forms of wildlife (Boatman *et al.*, 1989).

#### The farmer's view of field margins

Although field margins undoubtedly have a positive value in wildlife terms, on many arable farms they are viewed as potential harbours of weeds, pests and diseases. As a result, the herbaceous vegetation of the field boundary may be ploughed out, or sprayed with non-selective herbicides in an attempt to control the perceived weed problem.

An idea of the extent of such practises is given by recent surveys of farmer practise at Agricultural Shows. In a survey of 163 farmers at the 1985 Royal Show, carried out by Long Ashton Research Station, most farmers cultivated up to the hedge base, and 60% of respondents said they used herbicides in the hedge-bottom, mainly to control barren brome (*Bromus sterilis*) and cleavers (*Galium aparine*) (Marshall & Smith, 1987). In a more recent survey of 180 farmers carried out at Sprays and Sprayers and the Royal Show in 1989 by the Cereals and Gamebirds Research Project, similar results were obtained, with 62% of farmers questioned saying that they sprayed their field boundaries. The chemicals most frequently used were fluroxypyr (used by 46% of farmers who sprayed), glyphosate (28%), mecoprop (24%), paraquat (18%) and atrazine (7%). At least 20 other herbicides were used by one or more respondents, one farmer replying that he used anything left in the spray store! When asked to specify reasons for spraying (specifying target species where possible), all answers were clearly related to weed control. The species most frequently cited as targets were *G. aparine* (named by 54% of those who sprayed), *B. sterilis* (33%), and common couch (*Elymus repens* 18%), with black-grass (*Alopecurus myosuroides*), wild oats (*Avena* spp.) and thistles (*Cirsium* spp.) each named by 5-6% of respondents.

The perception of the field boundary as a source of weeds is often extended to the crop edge, or headland. Of farmers questioned in the Long Ashton Survey, 25% farmed the headland differently from the rest of the field, and most of these gave the reason as weed control, though a few did so to benefit wildlife (Greaves & Marshall, 1987). The species perceived as threats in the headland are similar to those cited in field boundaries. In a survey of 120 farmer subscribers to the Cereals and Gamebirds Research Project, respondents were asked to name species which they considered would make the omission of herbicides from headlands difficult to accept. *G. aparine* was the species most frequently mentioned, being identified by 59% of respondents. Others were *B. sterilis* (25%), *A. myosuroides* (9%), *Avena* spp., *Elymus repens*, *Poa* spp and *Matricaria* spp. (each 6%) (Boatman & Wilson, 1988). Experimental evidence also suggests that these species are abundant in field margins. For example Marshall (1989) found that *G. aparine*, *B. sterilis*, *E. repens* and rough meadow-grass *Poa trivialis*, among others, occurred at highest densities in the field boundary and declined exponentially with increasing distance into the crop, whilst *A. myosuroides* showed a "headland distribution", with peak density 3.25m into the field.

## Reconciling agriculture and wildlife conservation

Field margins on arable farms are of potential value for wildlife, including species useful for pest control and game conservation, but they may be threatened by agricultural operations aimed primarily at controlling weeds. In order to safeguard the wildlife interest of these areas, management is required which allows for the control of those weed species perceived as damaging. Only in this way can farmer-acceptability be achieved. In recent years considerable progress has been made in this direction, and it is the purpose of this paper to summarise the existing experimental evidence and highlight areas where more research is required. Two regions will be considered, the crop edge (headland) and the herbaceous component of the field boundary vegetation.

### THE CROP EDGE OR HEADLAND

Recent work has shown that modification of pesticide inputs to cereal crop edges to allow the survival of the less competitive weeds, including rare species, and their associated arthropod fauna, can have dramatic effects on the chick survival of grey partridges and pheasants (Rands, 1985; 1986; Sotherton *et al.*, 1989). Other groups present on farmland but not normally reliant on cereals also benefit, e.g. butterflies and small mammals. This system of modified pesticide use, known as "conservation headlands" (Boatman & Sotherton, 1988; Boatman *et al.*, 1989; Sotherton *et al.*, 1989) allows for the selective control of the most damaging weed species, i.e. most grass weeds and *G. aparine*. However, because headlands tend to have higher populations of these species, care is called for in the siting and management of conservation headlands if effects on crop husbandry are to be minimised. A number of factors may contribute to a higher incidence of pernicious weeds. Crops may be thin and uncompetitive due to soil compaction (caused by tractors turning), often leading to cloddy seedbeds, and a higher level of trash resulting from incomplete inversion by the plough. Headlands are also firebreak areas, and do not benefit from the effects of straw burning on weed seeds. Furthermore crops are often sown too close to hedges or other field boundaries, so that seeds of weeds growing in the field boundary are harvested by the combine and deposited further out in the headland. Various measures may be taken to overcome these problems and these have been discussed by Fielder (1987).

Crop edges most suitable for conversion to "conservation headlands" require careful selection. They should not be sited where crops are thin and uncompetitive, where known infestations of difficult weed species occur (especially *B. sterilis* and *G. aparine*), and heavy land should be avoided if possible. If weed populations begin to build up after the first year, conservation headlands may be rotated round the farm; alternatively weeds may be controlled in break crops where these are grown. Given these provisos, experience has shown that moderate levels of grass weeds and *G. aparine* can be selectively controlled, i.e. without damaging the remaining broad-leaved species.

### Selective use of herbicides in headlands

#### (a) Grass weed control

There are a number of herbicides which can be used to selectively control wild oats, *Avena fatua* and *A. sterilis* sp. *ludoviciana*, with



little or no effect on broad-leaved species. These include tri-allate, diclofop-methyl, flamprop-m-isopropyl, difenzoquat, and imazamethabenz-methyl.

Black-grass, *Alopecurus myosuroides* is less easy to control selectively, but good results have been achieved with diclofop-methyl, especially when used in sequence with tri-allate (Boatman, 1987). Unfortunately this sequence is expensive and diclofop-methyl, though effective, suffers from the drawback that timing is critical as it relies on foliar uptake. At spraying, *A. myosuroides* must have emerged, but efficacy is greatly reduced after the 3-leaf stage. However, preliminary trials with the development compound HOE 7113-01H have indicated that high levels of control of both *A. myosuroides* and *P. trivialis* can be achieved right up to flag leaf emergence. This degree of performance would make the selective control of grass weeds in conservation headlands much easier in practice.

*E. repens*, formerly a troublesome weed, is now effectively controlled by pre-harvest use of glyphosate. This late treatment can be used on conservation headlands, since most of the wildlife benefits have been gained and it pre-dates the more traumatic event of harvesting by only a few days. The selective control of *B. sterilis* in cereals is not possible at present, and conservation headlands should not be sited where infestations of this species occur. If *B. sterilis* has not become established in the crop, it should be possible to prevent this happening by the use of sterile or boundary strips (see below).

(b) Control of *Galium aparine*

*G. aparine* is the species of greatest concern to farmers in headlands. However, it is difficult to control without damaging other broad-leaved species. Mecoprop was usually used for the control of *G. aparine*, but recently fluroxypyr has proved more reliable, especially earlier in the year (Lutman *et al.*, 1987; Tottman *et al.*, 1987; 1988) and it can also be applied much later than mecoprop.

Fluroxypyr affects a number of broad-leaved weed species other than cleavers, so experiments were carried out to determine whether selectivity could be increased by adjustment of dose and/or application timing. Fluroxypyr was applied at a range of doses and times from December to May; April application gave the highest level of *G. aparine* control, but control of other species was also greatest at this time. Control of most species was lower in May, but control of *G. aparine* was not satisfactory. However, good levels of *G. aparine* control were achieved by fluroxypyr at 150g a.i./ha applied in December, and at 200g a.i./ha in late March (Boatman *et al.*, 1988). Effects on other species from such early applications were generally less severe than those resulting from April spraying. The valuable *Polygonum* species also remained unaffected because the main flush of germination did not occur until early April.

Further trials have confirmed the efficacy of fluroxypyr applied at 200g a.i./ha in late March (Table 1). Good control resulted from late December/early January treatments in some trials but performance was variable. Addition of ioxynil + bromoxynil in autumn, even at very low rate, tended to increase activity against other species more than against *G. aparine*, whilst a double application in autumn and spring gave no appreciable advantage over the single high dose in March (Table 1).

TABLE 1. Mean percentage reduction in plot dry weight of various weed species treated with fluroxypyr, with or without bromoxynil, in winter (late December-January) and/or spring (mid-late March). (Figures in parentheses indicate reduction was not statistically significant).

Species	Herbicide	Dose (g a.i./ha) and timing					
		150	150	150	150	200	150 x 2
	iox.+ brom.	-	95	380	-	-	
		winter	winter	winter	spring	spring	winter+ spring
	No. sites						
<i>Galium aparine</i>	3	63	68	94	87	93	95
<i>Stellaria media</i>	3	58	82	96	64	91	92
<i>Veronica persica</i>	3	22	35	89	(3)	30	25
<i>Papaver rhoeas</i>	3	9	89	100	(12)	24	(17)
<i>Tripleurospermum</i>							
<i>inodorum</i>	2	53	94	99	59	86	85
<i>Viola arvensis</i>	2	(28)	36	56	(12)	(15)	44
<i>Sinapis arvensis</i>	1	70	99	100	61	85	97
<i>Myosotis arvensis</i>	1	97	99	92	73	90	100
<i>Anagallis arvensis</i>	1	0	(11)	73	0	0	0
<i>Polygonum aviculare</i>	2						no significant reduction
<i>Fallopia convolvulus</i>	2						no significant reduction
<i>Legousia hybrida</i>	1						no significant reduction

Lutman *et al.* (1987) and Tottman *et al.* (1987) have also reported poorer activity of fluroxypyr against *G. aparine* at low temperatures, but applications in the second half of March have generally produced a high level of *G. aparine* control (Tottman *et al.*, 1987; 1988). Where poor results were obtained at one site, this was attributed to lack of competition from a thin crop. In a healthy competitive crop, excellent results were achieved at soil temperatures of 4°C and above.

Fluroxypyr is the best herbicide currently available for control of cleavers in conservation headlands, but even at optimum timing still damages a range of other species including some known to be important insect host plants. However, the new herbicide quinmerac (BAS 518H: Wuerzer *et al.*, 1985), offers the potential for greater selectivity between *G. aparine* and other weed species. Nuyken *et al.* (1985) reported activity against *G. aparine*, *Veronica hederifolia*, *V. persica*, *Lamium amplexicaule*, *L. purpureum* and *Sonchus arvensis*. Bond & Burch (1987) found *V. persica* to be highly susceptible, as were the umbelliferous crops, carrot, parsley and parsnip. They also reported some activity especially at high rates, against several weed species in the Compositae, but *Fumaria officinalis*, *Capsella bursa-pastoris*, *Solanum nigrum*, *Stellaria media* and *Thlaspi arvensis* appeared to be resistant. In an exploratory field trial in winter wheat, quinmerac at 0.5kg a.i./ha applied in December 1986 reduced numbers of *G. aparine* by 82% and *V. persica* by 57% in the following May, but no activity was detected against *Viola arvensis*, *Fallopia convolvulus*, *Myosotis arvensis*, *Polygonum aviculare*, *F. officinalis*, *Sinapis arvensis* or *Atriplex patula* (Boatman, unpublished data).

Further experiments were carried out in 1988/89 to investigate effects of timing and dose at 3 sites, with 8 subsidiary trials at a single dose and timing (0.75kg a.i./ha, post-emergence November/December). Good control of *G. aparine* was achieved at all doses and application times, with little difference between treatments (Table 2). Control of *G. aparine* by quinmerac at 0.75kg a.i./ha was high at all eleven sites, ranging from 92.6 to 100%. Other species controlled were *V. persica*, *L. purpureum* and *Papaver rhoeas* (Table 3). Species present in trials but not controlled included *S. media*, *V. arvensis*, *M. arvensis*, *Tripleurospermum inodorum*, *P. aviculare*, *Geranium molle* and *Cirsium arvense*.

TABLE 2. Percentage ground cover of *G. aparine* in June following treatment with quinmerac (BAS 518H) at different times and doses in 1988. All treatments significantly different from untreated at  $P < 0.001$ .

Site	Treatment timing and dose (kg a.i./ha)						
	0	pre-emergence (October)			post-emergence (December)		
		0.5	0.75	1.0	0.5	0.75	1.0
1	1.3	0	<0.1	0	<0.1	0	0
2	24.0	0.2	<0.1	0	<0.1	0	0
3	3.4	0.5	0.2	<0.1	0.1	0.1	0

TABLE 3. Mean percentage reduction in ground cover ( $\pm$  standard error) in June of various weed species in cereal headlands treated with quinmerac (BAS 518H) post-emergence at 0.75kg a.i./ha the previous autumn.

Species	No. sites	% reduction
<i>Galium aparine</i>	11	98.1 $\pm$ 0.7
<i>Veronica persica</i>	9	95.9 $\pm$ 3.1
<i>Papaver rhoeas</i>	4	90.9 $\pm$ 6.4
<i>Lamium purpureum</i>	2	86.4 $\pm$ 13.6

These results suggest that quinmerac is suitable for use in conservation headlands. It is autumn-applied, offers effective control of *G. aparine*, and affects few common weed species. Those which are controlled are not known to be important as insect host plants. Quinmerac is also being tested on a range of rare arable plant species (Bain & Boatman, 1989).

It is clear that there is scope for targeting specific weed species in cereals. Unfortunately the time has not yet come when specificity of action is seen as a positive advantage in the development of new chemicals; in fact there is a discernible trend towards the use of ever more broad-spectrum, long-lasting residual herbicides. However, as concern for the environment grows, farmers may demand a greater choice in the selectivity of pesticides available to them.

## THE FIELD BOUNDARY

Evidence for the farmers view of field boundaries as a source of weed infestation has already been described. Scientific data on the extent and rate of weed movement from field boundaries into crops is sparse, due to a surprising lack of research. However, pernicious weed species do commonly occur in field boundaries. Marshall (1989) found that only 25-40% of species occurring in the hedge-bottom also occur in the crop, a proportion of which were more important in the above-ground flora in the cropped area. Similar evidence was reported by Boatman & Wilson (1988) who showed that, whilst many of the most frequent annual weeds occur in field boundary vegetation, they have a higher frequency of occurrence in the crop itself. However, several serious weed species including *G. aparine*, *B. sterilis*, *E. repens* and *C. arvense* occurred with greater frequency in field boundaries, providing circumstantial evidence that field boundaries can act as "reservoirs" for these species. They were also among the ten most frequently occurring field boundary species (Boatman & Wilson, 1988).

In recent years there has been an apparent deterioration in the vegetation of many field boundaries to a species-poor flora dominated by aggressive, weedy species such as *G. aparine* and *B. sterilis*. Experimental evidence as to mechanisms causing this change is lacking, but disturbance due to ploughing right up to hedges, herbicide and fertiliser drift, deliberate broad-spectrum herbicide application and in some cases burning, are all implicated.

If field boundary vegetation is to be restored to a more diverse, perennial flora containing few annual weeds, it is axiomatic that the causal factors of the initial deterioration must be eliminated. A strip 1-2m wide adjacent to the permanent boundary element should be left undisturbed by cultivation, pesticides or fertiliser. Provided that sufficient plant resources remain for recolonisation, a succession to a perennial flora may take place. Meanwhile, the threat of crop invasion by rapidly colonising weedy species remains. To counter this, a "sterile" or boundary strip may be created, either by cultivation or residual herbicide, between field boundary vegetation and crop, to prevent seeds of species such as *B. sterilis* and *G. aparine* from being harvested and deposited in the crop edge (Bond, 1987; Boatman & Wilson, 1988).

In many cases, natural regeneration of perennials may be too slow, either because there are insufficient surviving plants or propagules, or because competition from the aggressive weedy species precludes their spread. In the latter case, selective control of the undesirable species may be sufficient to allow recolonisation by remaining perennials. In the most extreme situations, reseedling may be necessary. Information on how these objectives may be achieved is, however, very sparse, and there is a pressing need for research on (1) management techniques to encourage the spread of existing perennials (including cutting, use of selective herbicides and/or growth regulators); (2) suitable seed mixtures for sowing into field margins to achieve desired objectives, methods of establishment, optimum time of sowing and post-sowing management.

### Selective weed control in field boundaries

Research programmes are now under way which may provide answers to some of these questions. For example, promising results have emerged from

initial experiments investigating the selective control of *G. aparine* and *B. sterilis* in field boundaries by herbicides applied in late autumn (Table 4). At this time of year, autumn-germinating annuals are at susceptible growth stages, whereas perennials tend to be dormant and thus more resistant to herbicides. Preliminary results have indicated that few species were affected in the long-term, even by relatively broad-spectrum chemicals such as mecoprop (broad-leaved plants) and fluzifop-p-butyl (grasses), though some die-back occurred immediately after treatment, especially of perennial grasses treated with fluzifop-p-butyl. Selective herbicides such as quinmerac may provide a more acceptable alternative (Bain & Boatman 1989), but no herbicide with such a high degree of selectivity is currently available for the control of *B. sterilis*.

TABLE 4. Percentage ground cover on 30 May 1989, of different species in field boundary plots treated with herbicide on 8 December 1988. (Asterisks indicate significant difference from untreated at \* =  $P < 0.05$ , \*\* =  $P < 0.01$ , \*\*\* =  $P < 0.001$ ).

Species	Treatment and dose (kg a.i./ha)					
	un- treated	mecoprop 2.52	quinmerac 0.5	fluzifop p-butyl 0.2	mecoprop +fluzifop -p-butyl	quinmerac +fluzifop -p-butyl
<i>Galium aparine</i>	27.2	1.0**	0.2***	28.1	1.5**	0***
<i>Bromus sterilis</i>	24.1	18.1	19.3	1.2***	1.3***	0***
<i>Heracleum sphondylium</i>	23.4	41.2	30.2	24.3	58.0	34.8
<i>Chaerophyllum temulentum</i>	9.8	7.4	6.0	5.4	15.3	6.9
<i>Arrhenatherum elatius</i>	2.8	19.0	25.5	7.9	7.7	24.0
<i>Poa trivialis</i>	1.5	7.2	8.5*	0.6	1.0	2.8
<i>Mercurialis perennis</i>	0.9	0.7	9.8*	9.8*	10.2*	20.3**
Other broad-leaved spp.	12.8	13.1	5.1	22.7	11.9	12.7
Other grass spp.	2.6	-	3.2	0.7	-	0.4
Bare ground	-	0.9	-	2.1	9.4	5.3
No. species in 4.5m <sup>2</sup>	22	20	24	29	23	22

Before the use of any herbicide in field boundaries could be recommended, a research programme would be essential, under field as well as laboratory/glasshouse conditions, to determine optimum spray timing, minimum effective dose and selectivity against non-target species. It is important that the remaining undamaged field boundary floras and their dependent faunas are not threatened by over-hasty adoption of ideas based on limited data. However, the demand from both farmers and conservationists for reliable management techniques to renovate those field boundaries that have degenerated is such that research in this area should be given a high priority.

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## A PRELIMINARY ASSESSMENT OF THE IMPACT OF HERBICIDE DRIFT ON PLANT SPECIES OF CONSERVATION INTEREST

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## ABSTRACT

Some experiments to assess the impact of herbicide spray drift on a range of native plant species are described. These experiments simulated drift from standard agricultural hydraulic sprayers under field conditions. Damage to individual plants placed downwind was measured. Data from a representative experiment are presented and, in general, the results are consistent with driftdeposition models. It is suggested that buffer zones surrounding nature reserves and other sensitive habitats should be in the order of 5-10 m.

## INTRODUCTION

Herbicide use has increased greatly in recent years, and there has been concern that some chemicals could drift on to adjoining land where there is either a wildlife conservation or amenity interest, and cause damage (Sheail, 1985). Whilst it is relatively easy to show that herbicides and growth retardants affect semi-natural vegetation when sprayed at full recommended application rates (Balme, 1956; Marrs, 1985; Marshall, 1988; Marshall & Birnie, 1985; Parr & Way, 1984; Way & Chancellor, 1976; Willis, 1988), there have been few studies of the effects of sub-lethal doses arising from spray drift on native plant species.

Research on spray drift has been concerned with the factors that cause and influence spray drift and its effects on crop plants. Emphasis has been placed on understanding the physical factors affecting spray drift, for example, the spectrum of droplet sizes produced by different sprayers, and various meteorological factors including wind speed, atmospheric turbulence and stability, temperature, humidity and precipitation (Elliott & Wilson, 1983; Williams *et al.*, 1987). Attempts have also been made to produce drift deposition models relating drift to distance downwind from the sprayer (Arvidsson, 1985; Byass & Lake, 1977; Nordby & Skuterud, 1974; Yates *et al.*, 1978; Williams *et al.*, 1987). However, there is almost no information on the biological effects of herbicide drift on wild plant species.

In this paper we describe a range of screening trials where herbicide drift has been simulated under field conditions, and the effects on a range of common British species assessed. Results are presented and discussed in relation to measured herbicide deposition data, in an attempt to derive 'safe buffer zones' for the protection of vegetation on natures reserves, SSSI's and other areas adjoining agricultural land.



## SELECTION OF HERBICIDES AND PLANT SPECIES FOR STUDY

We selected five herbicides on the basis of three risk/usage categories devised by Williams *et al.* (1987): viz. (1) high use/high risk - MCPA and mecoprop; (2) high use/moderate risk - asulam and glyphosate; and (3) low use/high risk - chlorsulfuron ('Finesse' = chlorsulfuron + metsulfuronmethyl was used and is referred to here by its product name). Only 'Finesse' and glyphosate were used in the trial described. As the effects of a given herbicide depends on both uptake and its physiological and biochemical effects, there are likely to be marked differences between species. Accordingly, 10 species, were used to give a range of families, heights, architectures and leaf morphologies; the species chosen were - Cardamine pratensis, Centaurea nigra, Digitalis purpurea, Geum urbanum, Lamium galeobdolon, Lychnis flos-cuculi, Primula vulgaris, Prunella vulgaris, Silene dioica, and Stachys officinalis (nomenclature follows Clapham *et al.*, 1987).

TABLE 1. Herbicides tested and the application conditions in screening trials assessing drift damage downwind from a standard agricultural sprayer.

Time of spraying	Herbicide	Application rate (kg a.i. ha <sup>-1</sup> )
Autumn '87	'Finesse'	
	Chlorsulfuron	0.015
	+ metsulfuron-methyl	0.005
	glyphosate (low)	0.5
	glyphosate (high)	2.2
Wind speeds: all herbicides tested at low and high wind speeds.		
	low: 2.5 ± 0.2 ms <sup>-1</sup>	
	high: 3.5 ± 0.2 ms <sup>-1</sup>	
Sprayer: Tractor mounted Team sprayer (6 m boom) fitted with 12 Lurmark Red 03-F80 (BCPC code - F80/1.20/3) fan nozzles.		
	Tank pressure = 2 bar	
	Tractor speed = 6 km hr <sup>-1</sup> ; 200 litres ha <sup>-1</sup>	

## METHODS

Experimental methodology

In autumn 1987 6 applications were made, (Table 1) with individuals of 10 species placed at 7 distances downwind from the sprayer, viz. 0 (i.e. under the boom), 1, 2.5, 5, 10, 20 and 50 m. These plants were subjected to drift from a single pass of the sprayer. Plants were propagated either from seed or cuttings, and grown in 7 cm x 7 cm pots using SAI GP compost. One individual of each species was placed in an experimental tray (22 cm x 36 cm). Five replicate trays were then placed

at each of the test distances, sprayed, and left in situ for 2 h before transfer to an unheated glasshouse. Five replicates of each species remained untreated as controls. All plants were kept in the glasshouse for approximately 10 days and watered carefully at the soil surface to prevent herbicide run-off. This procedure may have partially reduced the soil-acting effect of 'Finesse'. The trays were then transferred to a sand bed in the open and watered when necessary, using standard horticultural techniques.

#### Assessment of plant performance

Each plant was assessed, first by visual rating of damage, and second by measuring yield. Visual rating was done in mid-summer (late July-early August) by one experienced observer without knowledge of the treatment. Each plant was rated on a yes/no basis for 3 effects: (1) living or dead - lethal effects; (2) damage symptoms present - damage effects; (3) flowering or non-flowering - flowering suppression. Where damage was found, the symptoms were noted. Each plant was harvested at the end of the growing season (mid-September), dried at 80°C for 24 h, and weighed. Prior to harvesting, the seed heads of 5 species (G. urbanum, L. flos-cuculi, Prunella vulgaris, S. dioica and S. officinalis) were collected and seed weight determined.

The mid-summer visual estimates of performance were discrete counts (maximum = 5), so it was difficult to calculate statistical relationships between effect and distance. Therefore, a simple rule-based method was used to estimate 'safe distances'. Starting at the plant directly under the sprayer, the numbers of dead, damaged and non-flowering plants were compared with those from the next higher distance and the untreated plants. The 'safe distance' was the first distance point at which either no deleterious effect on performance was found, or where the effect was the same as or lower than the untreated plants. Three 'safe distance' measures were used being:

- SLD = first distance at which no lethal effect was found
- SDD = first distance at which no symptoms of damage were found
- SFD = first distance at which no suppression of flowering was found

For plant yield data, mean values and standard errors were calculated and the minimum distance at which there was no significant suppression of yield and seed weight assessed.

#### RESULTS

Herbicide effects were generally, but not always, greater at the high wind speed. Here, only the higher safe distances derived from the 2 wind speeds are discussed. The lethal effects of both 'Finesse' and glyphosate (low and high rates) were confined to < 5 m of the sprayer (Table 2). Five of the 10 test species were relatively unaffected by 'Finesse' with SLD values of  $\leq 1$  m, C. pratensis and S. dioica were more sensitive (SLD = 2.5 m), and D. purpurea, L. flos-cuculi and Prunella vulgaris were most sensitive (SLD = 5 m). The results for the low and high application rates of glyphosate were similar for 9 species,

the exception being S. dioica which had an increased SLD at the higher dose. With glyphosate, 4 species had SLD values  $\leq 1$  m, 5 species had values of 2.5, and D. purpurea was the most sensitive at 5 m.

TABLE 2. 'Safe distances' (m) where no lethal effects (SLD), no damaging effects (SDD), and no flowering suppression (SFD) occur for drift of 2 herbicides applied in autumn; - denotes no assessment of flowering was made.

Species	Finesse			Glyphosate (low rate)			Glyphosate (high rate)		
	SLD	SDD	SFD	SLD	SDD	SFD	SLD	SDD	SFD
<u>Cardamine pratensis</u>	2.5	2.5	2.5	1	5	1	1	10	5
<u>Centaurea nigra</u>	1	1	1	1	2.5	1	1	2.5	2.5
<u>Digitalis purpurea</u>	5	5	2.5	5	5	2.5	5	10	10
<u>Geum urbanum</u>	1	2.5	1	1	1	1	1	1	1
<u>Lamium galeobdolon</u>	1	1	-	2.5	2.5	-	2.5	5	-
<u>Lychnis flos-cuculi</u>	5	10	1	2.5	2.5	1	2.5	2.5	2.5
<u>Primula vulgaris</u>	1	5	0	0	1	0	0	1	0
<u>Prunella vulgaris</u>	5	10	-	2.5	20	-	2.5	20	-
<u>Silene dioica</u>	2.5	5	1	1	1	1	2.5	2.5	1
<u>Stachys officinalis</u>	0	2.5	1	2.5	2.5	1	2.5	2.5	1

For some species the SDD was the same as the SLD (Table 2), but in most cases the SDD was greater. For 'Finesse', L. flos-cuculi and Prunella vulgaris were most sensitive (SDD = 10 m), but for glyphosate C. pratensis and D. purpurea (SDD = 10 m) and Prunella vulgaris (SDD = 20 m) were the most sensitive species.

'Finesse' suppressed flowering of most species only under the sprayer, except for C. pratensis and D. purpurea, where the SFD was 2.5 m. Similar results were found with the low application rate of glyphosate, but at the higher rate C. nigra and L. flos-cuculi had SFD values of 2.5 m, and C. pratensis and D. purpurea had values of 5 m and 10 m respectively (Table 2).

The quantitative assessment of plant yield generally confirmed the visual assessment. The minimum distance at which no growth reduction was found was  $\leq 2.5$  m for all species and herbicides (Table 3). Seed yield of the 5 test species showed that the minimum distance for no reduction increased at high wind speed, and G. urbanum, L. flos-cuculi and S. officinalis were particularly sensitive with minimum distances of 5 m in some experiments (Table 3).

#### Symptoms of damage found in the herbicide drift bioassays

Although twenty symptoms of damage were found in these experiments, they can be broadly classified into 5 groups:

- (1) Reduction in size
- (2) Leaf chlorosis and other leaf discolorations
- (3) Leaf necrosis

- (4) Epinasty  
 (5) Plants almost dead with very little chlorophyll remaining

TABLE 3. Distances (m) where no suppression of (a) yield and (b) seed production was found for drift of 2 herbicides applied in autumn.

Species	Finesse	Glyphosate (low rate)	Glyphosate (high rate)
(a) Yield			
<u>Cardamine pratensis</u>	1.0	1.0	1.0
<u>Centaurea nigra</u>	1.0	1.0	2.5
<u>Digitalis purpurea</u>	2.5	2.5	1.0
<u>Geum urbanum</u>	1.0	1.0	1.0
<u>Lamiasstrum galeobdolon</u>	1.0	0	1.0
<u>Lychnis flos-cuculi</u>	2.5	2.5	2.5
<u>Primula vulgaris</u>	1.0	1.0	0
<u>Prunella vulgaris</u>	2.5	1.0	1.0
<u>Silene dioica</u>	2.5	1.0	1.0
<u>Stachys officinalis</u>	1.0	1.0	1.0
(b) Seed production			
<u>Geum urbanum</u>	5.0	1.0	2.5
<u>Lychnis flos-cuculi</u>	5.0	2.5	5.0
<u>Prunella vulgaris</u>	2.5	2.5	2.5
<u>Silene dioica</u>	2.5	2.5	2.5
<u>Stachys officinalis</u>	2.5	2.5	5.0

Most of these symptoms are not specific to herbicide damage, being typical of, for example, mineral nutrient deficiency and disease. Epinasty is perhaps the exception, being usually caused by herbicides. In the autumn experiments 10-12% of plants were damaged with most plants being reduced in size. Some species were much more sensitive than others, with L. galeobdolon and Prunella vulgaris being most affected, while C. nigra, L. flos-cuculi and S. officinalis were less affected.

#### DISCUSSION

The aims of this work were to determine likely 'safe' buffer distances for nature reserves, and other areas of semi-natural vegetation, which were likely to be subjected to herbicide spray drift produced by standard agricultural hydraulic sprayers on adjacent agricultural land. The results from this and other experiments (Marrs *et al.*, 1989) suggest that most of the severe impacts (death and severe growth suppression) would be confined to a very short distance (c. 2 m) from the sprayer, which confirms the general conclusions of Elliott & Wilson (1983). Symptoms of plant damage and flower suppression were found at slightly greater distances, but most damage occurred near the sprayer. After autumn application, the minimum distance where no damage was detected was 2.5 m for most species, but 3 species were found to be

more sensitive ('safe distance' between 10-20 m). Although damage effects were found at greater distances than lethal ones, most affected plants recovered and showed no growth suppression at the end of the next season. Moreover, most of the symptoms of damage were not necessarily caused by the herbicide *per se*, as many were typical of nutrient, water imbalance, or pathogen attack. However, the incidence of these damage symptoms was increased by exposure to herbicide drift.

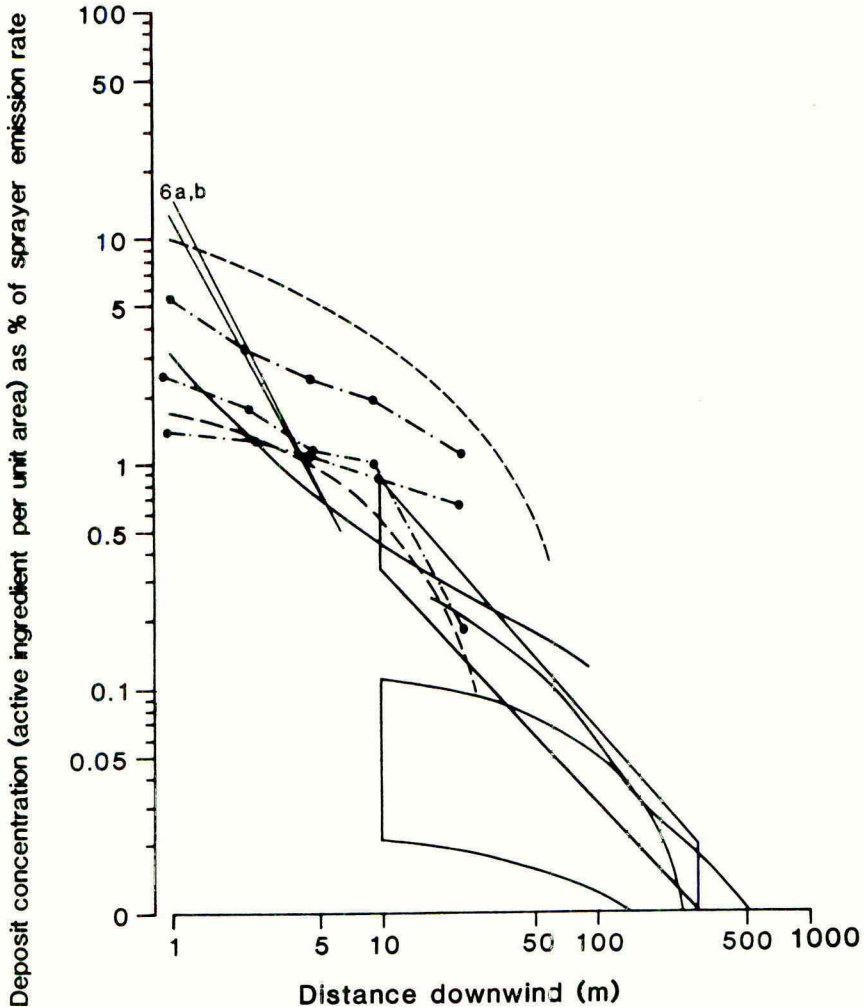


Figure 1. Relationship between drift deposit concentration and distance downwind: data from Byass & Lake (1977), Williams *et al.* (1987), lines 6a, b from this study.

The general conclusions are in line with the predictions from drift deposition data (Fig. 1). These data were collated by Williams *et al.*, (1987) from a range of literature sources, but have been augmented by results from two of the experiments reported here. These graphs show a decline in drift deposition to between 0.5-6% of the application rate at 5 m from the source. In this study (lines 6a, b; Fig. 1), a deposition of 1.5% of active ingredient reaching 2 m and 0.5% reaching 5 m would be expected, and these levels have had few detectable effects on plant growth. However, other bioassay studies have shown drift damage up to 100 m away (Byass & Lake, 1977), which may be vapour effects, but could also reflect either unusual environmental phenomena, or application problems. It is possible that unusual combinations of meteorological conditions with inappropriate sprayer settings could produce spray drift over much larger areas than are normally predicted.

No particularly sensitive 'indicator' species was found to any single herbicide, although some species appeared to be consistently more sensitive than others. It is unlikely that any field-grown species can be used as an indicator plant to assess spray drift, especially when under field conditions it is likely that they would be exposed more than one compound.

It is difficult to assess the longer-term significance of drift damage. These experiments take no account of potential competitive effects that are likely to occur when individuals are growing in a mixed species community. It is possible that a sensitive species, damaged by a low dose of herbicide, may decline because of competitive interference from unaffected or less-affected species. Moreover, these autumn-applied herbicides suppressed both flowering and seed production up to 10 m from the sprayer. This might affect regeneration within the community and hence species diversity in the longer term.

In summary, the effects of severe damage by herbicide droplet drift under realistic application conditions from an hydraulic sprayer suggest that buffer zones surrounding nature reserves and other sensitive vegetation could be quite narrow, in the order of c. 5-10 m. A buffer zone of this width would reduce lethal effects to almost zero, though certain sensitive species may show transient damage and have flowering suppressed within this zone. An unsprayed zone of this size is in keeping with the recommendations of the Game Conservancy, who suggests a 6 m unsprayed headland for enhancing gamebird populations (Boatman & Sotherton, 1988). Clearly, where larger unsprayed strips are left, e.g. 15 m strips under the new set aside regulations (MAFF, 1988), risks should be reduced even further. However, the present results are based on only one year's application under standard conditions, continuous applications or applications under other conditions might perhaps have more serious effects than those observed here.

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