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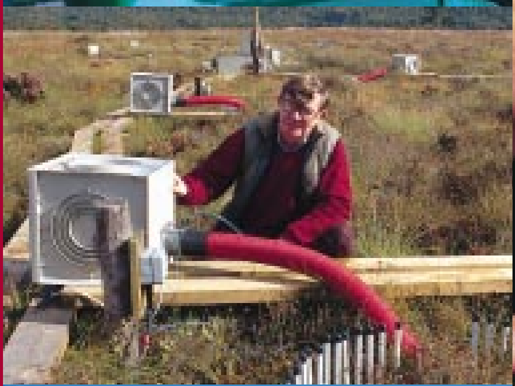

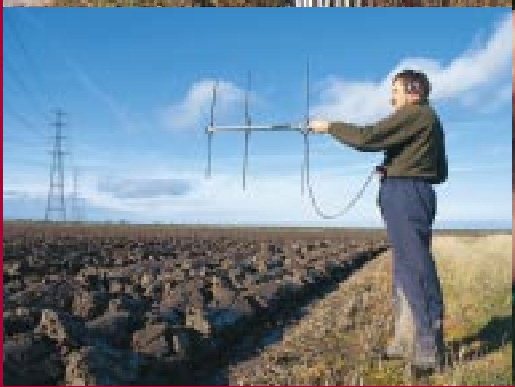

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The impacts of pesticide spray drift and fertiliser over-spread on the ground flora of ancient woodland

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Summary

Levels of spray drift from adjacent land into woodland were assessed by controlled experiments at Imperial College London's Silwood Park (Berks) and Wye (Kent) campuses.

The highest concentrations of spray drift were generally confined to within 5 metres of the spray boom, except in conditions with open margins and higher wind speeds, where drift may be detectable (although not necessarily in damaging concentrations) at least up to 10 metres.

Drift within the first 4 metres of the woodland margin was measured at concentrations that have been shown to have impacts on some woodland plants in separate greenhouse/field trials.

At low wind speeds the physical structure of the woodland margin had little effect on depth of penetration of drift. At higher wind speeds (but within recommended limits) the attenuation produced by dense marginal vegetation increased.

Studies of the potential impacts of herbicide spray drift on woodland plants are briefly described. A range of sensitivities to the herbicide glyphosate were observed.

Woodland margin ground flora was surveyed in 90 woodlands adjacent to three different agricultural land uses. Thirty margins were surveyed beside each of the following land-use types: Unimproved grassland, improved grassland and arable fields, assumed to represent low, medium and high agri-chemical input regimes respectively.

Differences in the ground flora of woodland margins adjacent to different land uses were significant in terms of overall species richness, diversity and abundance only in the outer two metres of the margin. Abundance, species richness and diversity were all highest in woodland margins adjacent to unimproved grassland, and lowest next to arable fields.

Analyses of the abundance of individual species and groups of species showed significant differences related to adjacent land use up to 12 m into woodland margins. Those species identified as highly sensitive to herbicide damage in the plant screens were found to occur significantly more frequently in woodland margins alongside unimproved grassland, with their lowest frequency being alongside arable fields.

The use of Ellenberg values for nitrogen suggest that fertiliser over-spread may have impacts on ground flora up to at least 4 m into the margin. The impacts were associated with both improved grassland and arable fields, with higher frequency of nitrophilous species and lower abundance of species associated with low nutrient sites.

These results indicate that developing unsprayed buffer zones and encouraging dense woodland boundaries could be effective in reducing herbicide spray drift into woods.

Contents

1. Introduction

The expansion of agriculture over the course of many centuries has led to the fragmentation of woodland habitats and their relative isolation within the wider agricultural matrix (Rackham 1986). Many British native woodland plant species are best represented within ancient semi-natural woodland. The current restricted distribution of many of these species reflects historical woodland loss and fragmentation, as well as relatively poor dispersal and colonising abilities. Consequently, remaining fragments of ancient semi-natural woodland are critical sites for conservation of many woodland plants.

Woodland plant communities are under threat from a number of different causes, particularly continued growth of conifers on planted ancient woodland sites (Curtis, Pryor and Peterken 2002) and increasing shade due to loss of traditional management (Kirby & Solly 2000). Other factors also include competition with introduced species (Gilbert & Bevan 1999) or with ruderal species (Boutin & Jobin 1998), over-grazing by rising deer populations (Kirby & Solly 2000), as well as changes in climate and/or disease (Barkham 1992).

In addition to these factors, agricultural intensification particularly over the past few decades has led to increased pressure on the remaining fragments of semi-natural woodland, through the direct and indirect impacts of agri-chemicals on their flora and fauna. Off-target deposition of pesticides has been estimated at around 10% of the amount applied (Elliot & Wilson 1983) and fertiliser overspread in field boundaries may be up to 195% (Rew, Theaker & Froud-Williams 1992). Tsiouris and Marshall (1998) have shown that peak deposition at the field edge can reach up to 150 kg N ha^{-1}. There is also evidence that forest edges may concentrate airborne pollutants (Weathers, Cadenasso & Pickett 2001). However, there is little direct research into the impacts of agri-chemicals on this habitat.

A number of studies have shown the importance of farmland habitats and in particular field margins for the conservation of biodiversity (Freemark, Boutin & Keddy 2002; Weibull, Ostman & Granqvist 2003). Therefore, this research into the effects of drift of pesticides and fertilisers from arable land into adjacent woodlands will be of particular interest to ecologists concerned with the conservation of woodland ecosystems.

1.1 Previous work conducted as part of this study

Preliminary results of spray drift studies indicated much variability in drift penetration of woodland margins. Many factors may influence the amount of drift measured, including wind speed, vegetation density, topography and local climatic conditions. These early studies have been summarised below.

The short-term impacts of herbicide and fertiliser applied at drift and over-spread type concentrations were conducted on fourteen species of woodland ground flora, in two greenhouse experiments. Glyphosate herbicide applied at typical drift concentrations (0 to 50 percent of field application rate (6 L/ha)) produced reductions in plant biomass and in some cases caused mortality, while fertiliser overspread was found to alter resource allocation in some species. Most species tested showed reduced growth rates and tissue damage even at concentrations as low as 5% of the field application rate. Field trials were then carried out to investigate long-term impacts of herbicide drift and fertiliser overspread under more realistic conditions. The most sensitive species showed substantially reduced growth at just 1% of the field application rate. These screens allowed the species to each be allocated to a high, medium or low sensitivity to the herbicide treatments (Table 1).

Table 1. Sensitivity of screened species to herbicide treatment (model herbicide – glyphosate)

High sensitivity	Intermediate sensitivity	Low sensitivity
Festuca gigantea	*Carex remota*	*Adoxa moschatellina*
Geranium robertianum	*Carex sylvatica*	*Anemone nemorosa*
Primula vulgaris	*Galium odoratum*	*Mercuralis perennis*
Sanicula europaea	*Hyacinthoides non-scripta*	*Viola riviniana*
Veronica montana	*Lamiastrum galeobdolon*	

The work carried out up to this point was supported by the John Stanley Foundation. Additional funds provided by English Nature and the Woodland Trust have allowed us to expand the work and to carry out some of the research detailed below.

1.2 Objectives

- To describe in greater detail the pattern of spray drift into British woodland margins in order to achieve a better understanding of the influence of relevant biotic and abiotic factors that affect drift penetration profiles.
- To survey ancient woodland ground flora in woodland margins subject to potentially contrasting pesticide drift and fertiliser overspread impacts, as represented by the adjacent agricultural matrix and land use histories.

2. Spray drift work

2.1 Methodology

Vertical line samplers (2 mm x 1 m polythene tubing) and horizontal deposition samplers (petri dishes) were placed in woodland margins, along transects perpendicular to the field edge. The samplers were positioned at 0, 1, 2, 3, 4, 6, 8 and 10 m from the margin in order to capture spray drift and deposition. Control samplers were positioned in the field edge 2 m from the wood margin and directly under the path of the spray boom. A tracer (sodium fluorescein) was applied in solution to the field edge, simulating standard agricultural practice in pesticide application. This was carried out using either, a wheelbarrow sprayer at Imperial College London's Silwood Park campus (4 m boom), or with a tractor-drawn agricultural sprayer at the Wye campus (24 m boom).

At the Silwood Park campus spray drift trials involved small-scale investigations of drift into a variety of woodland margins differing in aspect, density, composition etc. Five transects were set up in each margin, the tracer was applied only when the wind was blowing directly into the woodland margin. A typical herbicide spraying regime was followed; tank pressure 1.5 Bar, forward speed 4.25 km/hr, boom height 60 cm. Spray was applied using nozzles Lurmark orange (BCPC code F110/0.8/3), giving a flow rate of 0.5 l/min. In each trial 10 passes were made with the wheelbarrow sprayer. In total 30 trials were carried out over a number of seasons, representing the full range of weather conditions likely to be encountered by farmers during the application of pesticides.

The studies carried out at the Wye campus involved examination of drift at the field scale. Three trials were undertaken on separate days with different windspeeds. A long wood/field margin was used consisting of three woodland types, and three margin density treatments - control [no cut], edge cut [undergrowth removed from 0-5 m into the margin] and full cut [all undergrowth removed from 0-10 m]. Each treatment was 10 m wide and separated from the next treatment by at least 10 m of woodland buffer. The cut treatments involved the removal of all undergrowth up to 7 cm in diameter for the distance specified. There were two separate replicates of each treatment in each woodland type, giving a total of 18 individual treatments. The different treatments allowed comparison between open and closed woodland margins. In total eight passes along the field edge were made with the tractor-drawn boom sprayer. The boom was fitted with Lurmark Cambridge-blue nozzles (F110/1.6/3.0), using a spray pressure of 3 Bar and a forward speed of 10 km/hr, boom height was 85 cm at the centre and 35 cm at either end.

In both experiments each sprayer pass applied an equivalent volume to a typical field application of a herbicide, several passes were made in order to even out any inconsistencies in individual spray events, this also served to concentrate the tracer, thereby increasing the detection accuracy. Wind speed was measured using a hand-held anemometer, and the density of the margin vegetation was estimated for each transect by contrast analysis of digital photographs.

The samplers were collected and stored in re-sealable plastic bags until analysis. Immediately after collection the bagged samplers were stored in the dark to prevent degradation of the tracer. The samples were then eluted in the bag, with 25 ml distilled water, under laboratory lighting (low UV). The bags were vigorously shaken and the solution decanted into glass vials. The samples were then measured using a fluorimeter, and the concentration of fluorescein was calculated as a percentage of the applied solution. In this report, the amount of tracer captured by the samplers is presented as a percentage of the amount of tracer collected by the control samplers (beneath the spray boom).

2.2 Spray drift measurement results

2.2.1 Silwood Park trials

The results presented below are a brief summary of the data obtained from the spray drift measurement work at Silwood Park. Up to 2 m distance into the woodland margin spray drift is, at higher windspeeds (4+ km/hr), around 5-10% of full application and occasionally may be as much as 25%, with drift of 2-3 percent at 3-4 m (Figure 1i). At lower windspeeds (0-4 km/hr) drift concentrations become insubstantial beyond 1-2 m. Measurable (but low) amounts of drift were recorded up to 10 m from applications at higher windspeeds. To put these figures in perspective the Green Code - Code of Practice for the Safe Use of Pesticides on Farms and Holdings (MAFF 1998) recommends spraying when the wind speed is between 2 and 9.6 km/hr.

Spray deposition (ie the sedimentation of mostly larger droplets) tailed off very quickly from the edge of the sprayer boom (Figure 1ii). Only under the highest windspeeds was a detectable amount of spray deposition carried beyond the first few metres.

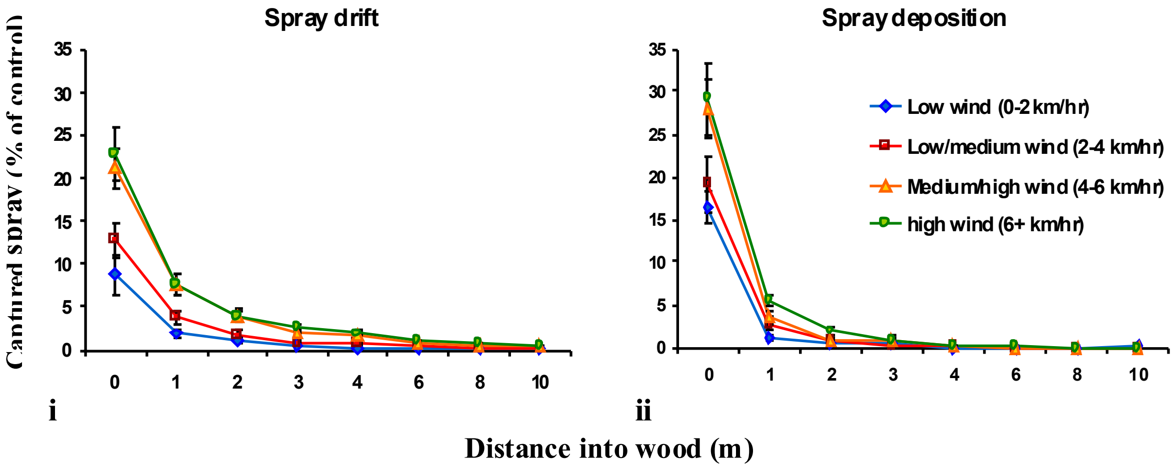

Figure 1. Influence of wind speed on the movement of i. spray drift and ii. spray deposition into woodland margins in the drift trials at Silwood Park campus. Thirty tests sub-divided into four wind speed classes from low (0-2 km/hr), through medium (2-4 km/hr and 4-6 km/hr) to high (6+ km/hr).

Both spray drift and deposition increased linearly with increasing wind speed (Figure 2i). Increasing density of vegetation at the margin decreased deposition concentration (Figure 2ii).

The effects of windspeed and margin density on spray drift into woodland at Silwood Park (Figures 2i, 2ii) were tested by multiple regression analysis (Table 2). The effect of wind speed on spray drift was highly significant at all three distances into the margin. The influence of wind speed on deposition was very significant close to the field edge (2-6 m), but was not significant further into the woodland margin. Only under higher wind speeds (still within the recommended limits) was very much deposition measured beyond 4 m.

The effect of density of the margin vegetation on drift and deposition at Silwood was less clear. While the influence of density on deposition was very significant at 2 m it was not significant at greater distances into the margin. Its influence on spray drift was significant at 2 and 6 m but not at 10 m. The density of vegetation at woodland margins can and does vary considerably, not only between margins but within them as well. This may go some way to explain why the multiple regression analysis results for the effect of density on spray drift were not as clear cut as for wind speed. The weak interaction effect seen may be explained by increased capture of drift by margin vegetation as the wind speed increases.

2.2.2 Wye drift studies

The three drift studies at Wye indicated that there was a significant influence on both spray drift and deposition by margin vegetation density (Table 3). As wind speed increased, the effect of density on the amount of spray drift and deposition became more significant (Figure 3).

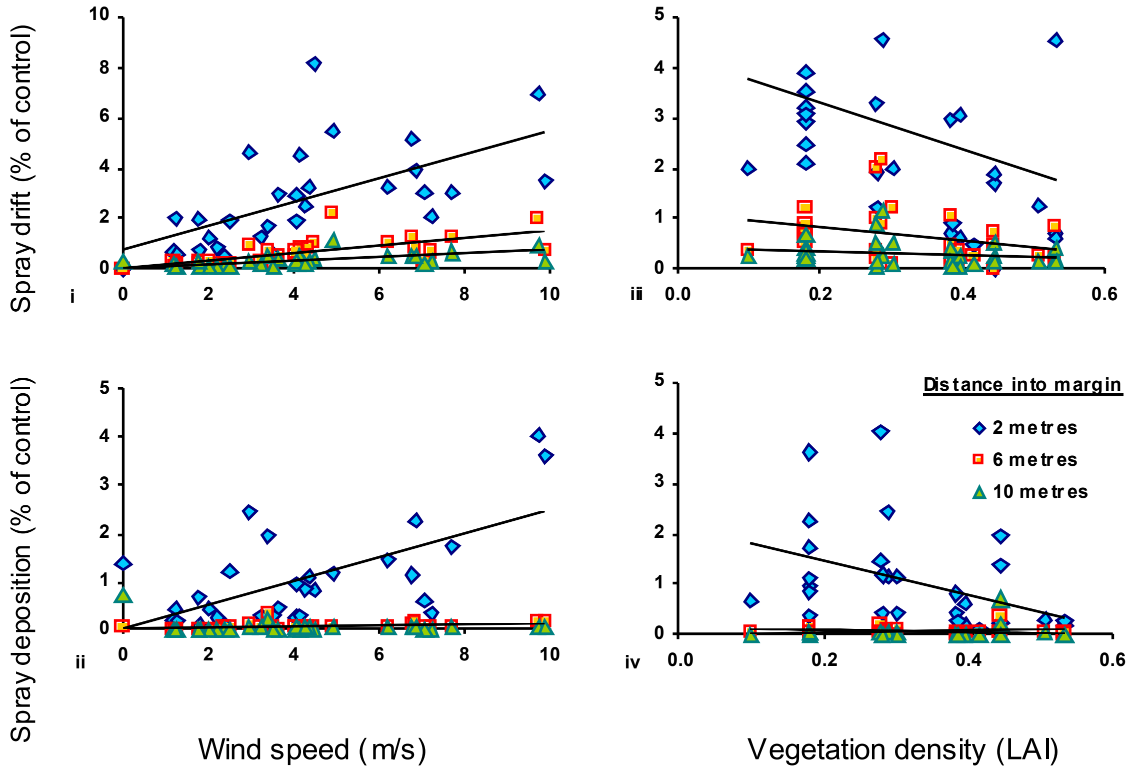

Figure 2. Effect of wind speed and vegetation density on spray drift into woodland margins in the drift trials, Silwood Park campus. The effect of wind speed on i. spray drift and ii. deposition is shown on the left. The influence of margin density on iii. spray drift and iv. deposition in the same margins is shown on the right.

Table 2. Multiple regression analysis of the effects of wind speed and vegetation density on spray drift and deposition within 30 woodland margins at Silwood Park (analysed at 2, 6 and 10 m into margin).

Test effect of:	Variable	Distance into margin (m)	df	F value	P value
Wind speed	**Drift**	2	3,26	21.57	**0.0001**
		6	3,26	22.42	**0.0001**
		10	3,26	12.57	**0.0015**
	Deposition	2	3,26	10.08	**0.0038**
		6	3,26	9.22	**0.0054**
		10	3,26	0.09	n/s
Density	**Drift**	2	3,26	9.84	**0.0042**
		6	3,26	8.87	**0.0062**
		10	3,26	2.04	n/s
	Deposition	2	3,26	11.83	**0.0020**
		6	3,26	2.42	0.0994
		10	3,26	0.09	n/s
Interaction	**Drift**	2	3,26	11.14	**0.0026**
		6	3,26	2.92	n/s
		10	3,26	0.18	n/s
	Deposition	2	3,26	1.09	n/s
		6	3,26	0.71	n/s
		10	3,26	3.92	n/s

Table 3. Multiple regression analysis of the effects of vegetation density on spray drift and deposition within woodland margin at Wye campus. Analyses at 2, 6 and 10 m distance, and shown as F values followed by P values.

Test	Distance into margin (m)	Degrees of freedom	Trial no.					
			1		2		3	
			F	P	F	P	F	P
Drift	2	1,16	3.36	0.0853	11.75	**0.0035**	20.61	**0.0003**
	6	1,16	4.41	0.0518	9.43	**0.0073**	23.72	**0.0002**
	10	1,16	2.21	n/s	15.25	**0.0013**	30.68	**<0.0001**
Deposition	2	1,16	0.33	n/s	2.65	n/s	5.04	**0.0392**
	6	1,16	4.92	**0.0413**	9.71	**0.0067**	6.22	**0.0240**
	10	1,16	No deposition		7.86	**0.0127**	6.72	**0.0196**
Wind speed (km/hr)			2.9		9.5		10.9	

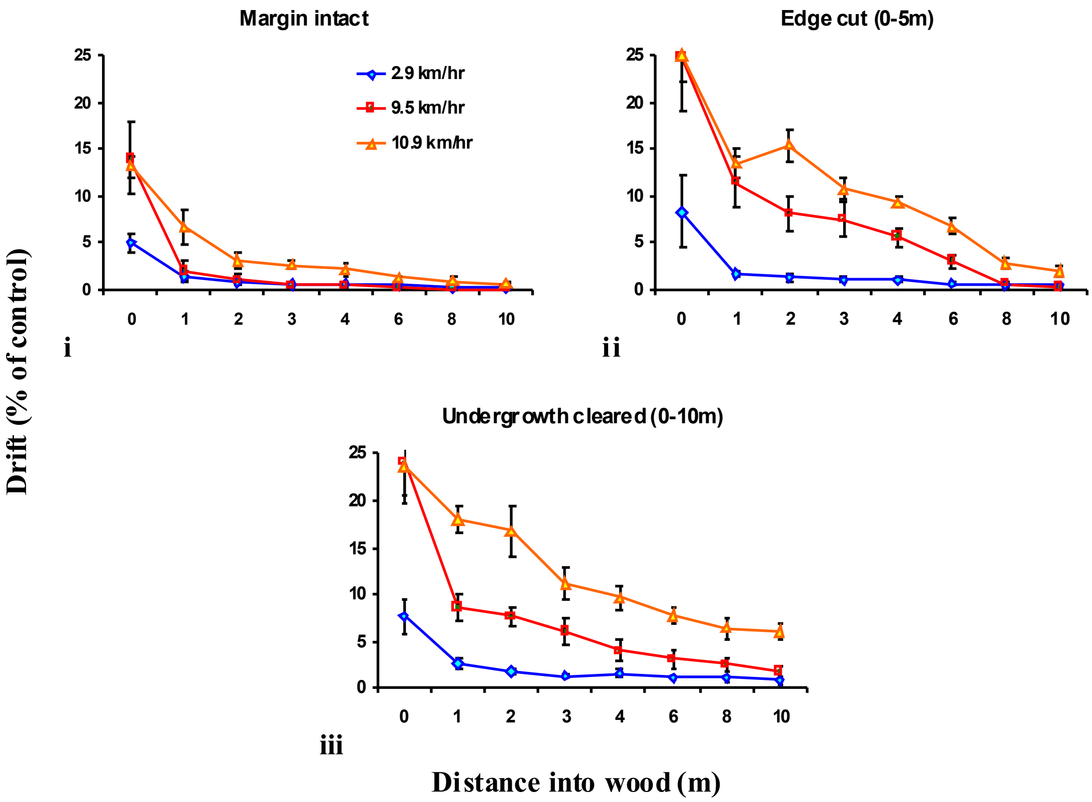

Figure 3. Effect of margin density and wind speed on drift from tractor driven sprayer, at Wye campus. **i.** Control treatment – high density margin (undergrowth left intact; **ii**. Edge cut treatment – medium density margin (undergrowth up to 7 cm diameter removed from the first 0-5 m from the field edge); **iii**. Cut treatment – low density margin (all undergrowth up to 7 cm diameter removed).

There were clear differences between high, medium and low density margins when compared under the same wind conditions at Wye campus (Figure 3). There was far greater drift at higher wind speeds where the undergrowth had been removed. The amount of drift measured in the intermediate edge-cut treatment was almost as high as that seen in the cleared plots for the first few metres (where the undergrowth was cleared), but it decreased after 5 m where the undergrowth was not cut (Figure 3ii).

The control spray drift curves in this experiment (Figure 3i) do not exactly replicate those shown above from Silwood Park for a number of reasons. Firstly, these are single spray events and not averages of a number of spray events as in the Silwood data. Secondly, there are a number of differences in the application of the spray, for example different nozzles, tank pressure, boom width and height and forward speed. Thirdly, the density of the margin vegetation at Wye may have differed from the 'average' Silwood density. Lastly, in the Wye work the comparisons were between treatments along the same margin and on the same day, rather than between different margins and at different wind speeds, on different days as in the Silwood Park experiments.

3. Woodland survey work

3.1 Methodology

Field surveys were carried out in woodland margins to investigate the potential impacts of herbicide spray drift and fertiliser run-off on the distribution of ground flora species (higher plants and ferns only).

A total of 90 woodland sites were selected on the North Downs of Kent (Appendix A). All the sites were within woods on chalk substrate (though in some cases there was an acidic 'clay with flint' drift overlying the chalk). Margins were surveyed alongside three different land-use types: Unimproved grassland, improved grassland and arable land, thought to represent low, medium and high agri-chemical input regimes. Thirty woodland margins were surveyed alongside each land-use. There has been some suggestion that ammonia emissions from improved grassland may be greater from than from arable land (Richard Smithers, personal communication). If this is the case then woodland margins adjacent to improved grassland might be exposed to high rather than medium levels of agri-chemicals.

At each site, a total of 6 transects were surveyed, each approximately 10 m apart. Each transect consisted of three large 2 x 4 m quadrats (Q), at distances of 0-2 m, 2-4 m and 10-12 m (Figure 4), termed outer margin, inner margin and interior for the purpose of analysis. Each large quadrat was subdivided into 8 smaller 1 x 1 m quadrats (q). Presence/absence of all species within each smaller quadrat was noted, allowing for a crude estimate of frequency and abundance at the greater quadrat level.

Associated biological and site variables, including soil type, slope, aspect, and vegetation density of the margin were also monitored, as well as anthropogenic variables such as woodland management.

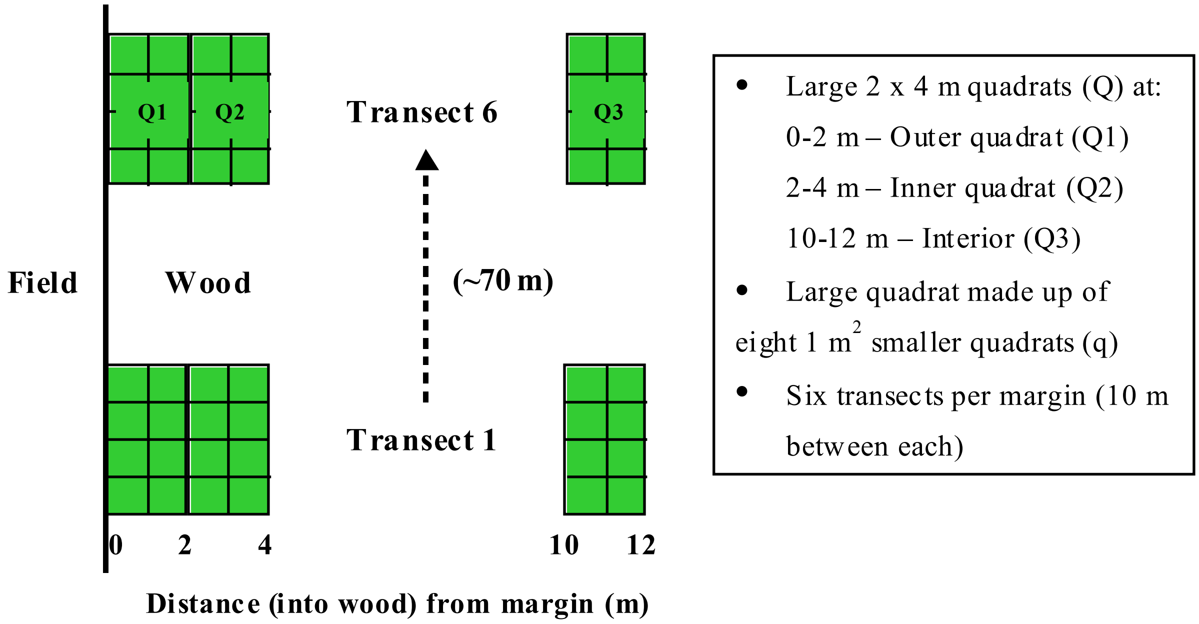

Figure 4. Layout of survey quadrats in a single woodland margin, showing positions of transects and quadrats.

3.2 Survey results

3.2.1 Preliminary analysis

Initial analysis of the survey results, using PCA and Kruskal-Wallis tests, indicated significant differences in community structure between the outer edge of woodland margins (0-2 m) alongside the three different land uses.

3.2.2 Whole data-set analysis

Species richness, diversity and abundance were extracted from the whole dataset for analysis. The Shannon-Wiener diversity index was used to calculate diversity scores. The analyses were performed using ANOVA in the statistical package S-plus. An error term was included in the analysis to account for the nesting of quadrat (Q) within each margin. Initially all three levels of Q were included in the analysis but when no significant differences between margin types at the 0.01 level were seen data for the interior quadrats were removed and the analysis was repeated. However, even with the interior quadrat data removed there were no significant responses for any of the tested factors at the margin type level.Analyses of the composition of vegetation of just the outer quadrat (0-2 m) between woodland margins alongside the three different land-uses indicated that there were significant differences between outer margins when taken alone. Changes in species richness and abundance between the outer margins were both highly significant ($P = 0.0014$ and $P = 0.0024$ respectively; $df = 2$), but differences in diversity were less significant ($P = 0.0303$; $df = 2$). There were fewer species and lower abundance (counting all species) in the outer margins alongside arable land compared to the other two land uses, and both parameters were highest alongside unimproved grassland (Figure 5).

There were significant differences at the quadrat (Q) level ($p<0.0001$) for abundance, species richness and diversity. This indicates that the community structure was not the same for the outer margin quadrats (0-2 m) compared with inner margin (2-4 m) or interior (10-12 m) quadrats. However, it is impossible to relate this directly to agri-chemical inputs as there are a number of other differences between these quadrats (such as light level, temperature, moisture etc). There were also significant interaction effects for abundance and diversity, these may reflect relative differences in the observations between margins adjacent to different land-uses at each distance into the wood.

The results discussed so far indicate that significant differences between sites next to different land uses can be seen only when the outer margin quadrats (0-2 m) were included in the analysis. It seems that the differences between ground flora communities alongside different land uses are subtle and when the data from quadrats further into the margins are included small differences in community structure which may exist are swamped.

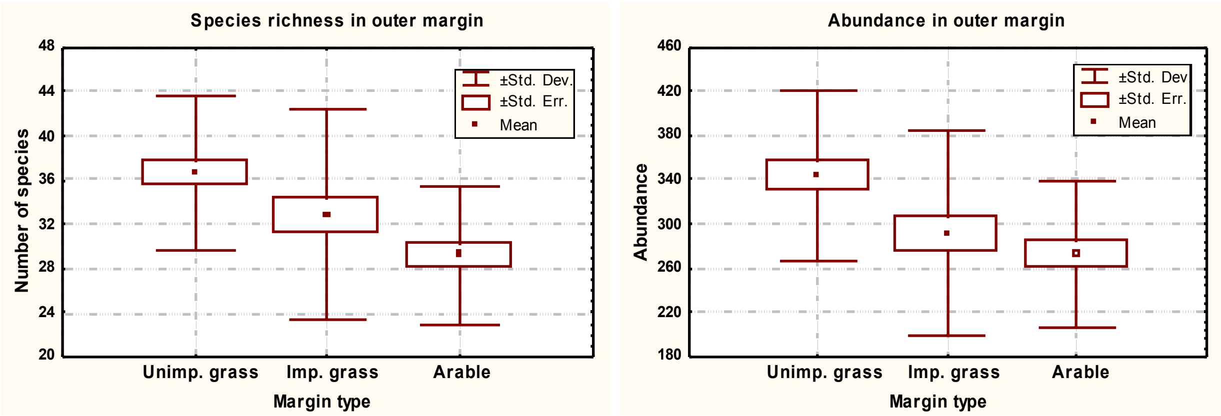

Figure 5. Changes in species diversity and abundance in the outer margin (0-2 m) alongside different adjacent land uses.

3.2.3 Ellenberg indicator values (nitrogen) analysis

Based on the assumption that fertiliser and manure addition to agricultural land might be likely to contribute to eutrophication of adjacent communities, it was thought that there might be differences in the type of plant growing within the woodland margins alongside different land uses. Therefore, weighted average Ellenberg values for nitrogen (EVN) and light (EVL) were calculated for each quadrat (based on the sum of abundance of each species multiplied by the Ellenberg value for the respective species divided by the total abundance for that quadrat). This method for calculating weighted averages was consistent with that established by Deikmann and Falkengren-Grerup (1998). Ellenberg's indicator values for nitrogen and light (Ellenberg 1991) adapted for the British climate by Hill and others (1999) were used, and analyses was carried out using ANOVA (in S-plus). Analysis of weighted EVL indicated that whilst there were no differences between woodland margins adjacent to different land uses there were significant differences with distance into the woodland margin. These findings indicate that plants in the outer margin were less adapted to shaded conditions than plants found further into woodland. Analysis of weighted EVN indicated that even with data for interior quadrats removed differences between the margin types was not significant. When only the outer margin quadrats were used was there still no significant difference ($P = 0.0893$; $df = 2$). However, if data for woodland margins adjacent to improved grassland and arable fields were pooled and compared to those for woodland margins next to unimproved grassland significant differences between the outer margin quadrats were seen ($p=0.0307$).

3.2.4 Individual species analysis

Common species were considered to be those which were observed in more than 100 of the larger quadrats (Q). The data for these species were arcsine transformed to make them normally distributed, allowing parametric statistical analysis. The analysis was carried out following the protocol described for whole dataset analysis (above). Each species was analysed individually for changes in its distribution within the different woodland margins. When the data for all quadrats were included in the analyses *Cardamine pratensis* and *Geranium robertianum* both showed significant differences between margin types ($p<0.05$). With the inner quadrat data removed *Bromopsis ramosa* and *G. robertianum* both showed significant differences at the level of margin type ($p<0.05$ and $p< 0.01$ respectively). When only the outer margin quadrat data were included in the analyses the distribution of both *B. ramosa* and *G. robertianum* were again significant ($p<0.05$ and $p< 0.01$ respectively). The only other species with differences in distribution in the outer margin was *Viola riviniana* ($p<0.05$). A much larger number of common species (29 out of 51) showed significant differences at the quadrat (Q) level, indicating that the distribution of many species was influenced by light intensity with some species preferring shaded and others light conditions. Two species showed a significant interaction effect at the $p<0.01$ level (*Hyacinthoides non-scripta* and *Glechoma hederacea*), this may be attributable to differences in the relative abundance of these species at different distances into the margin. The distribution of those species with significant differences can be seen in Figure 6. Both *B. ramosa* and *G. robertianum* was primarily associated with the outer margin of woodland, even though they are typical woodland species, *B. ramosa* is an indicator of ancient woodland (Rose 1999).

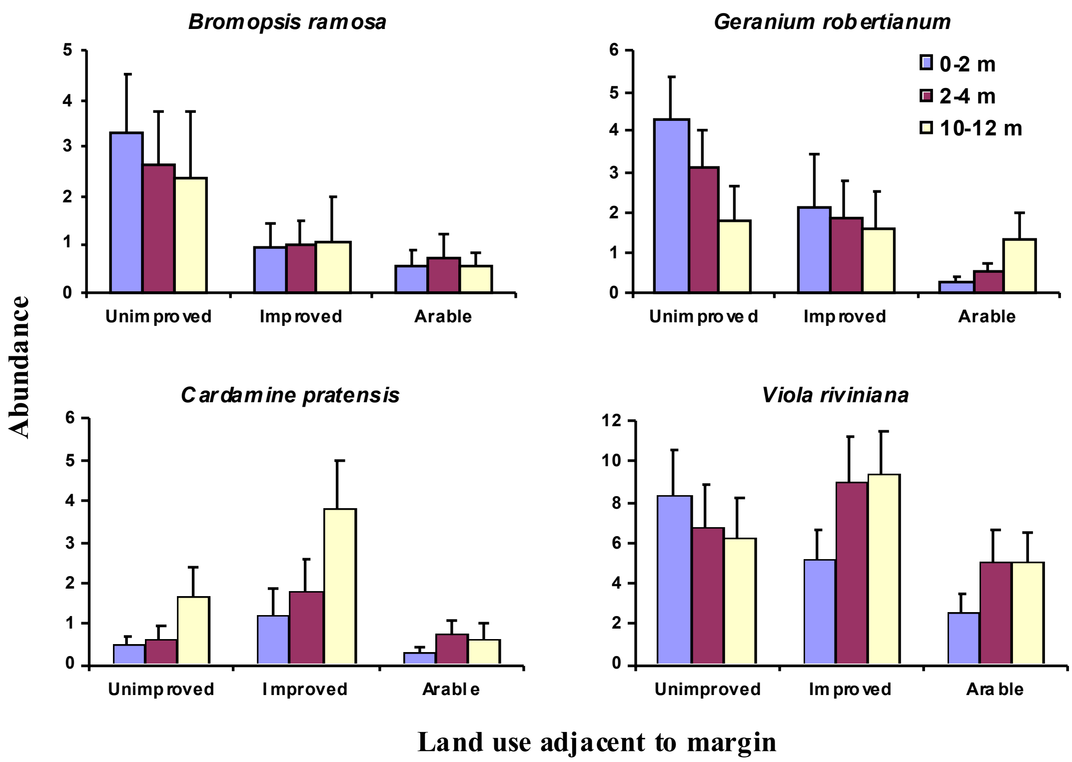

Figure 6. Distribution of individual species in woodland margins adjacent to three different land uses. Values given as mean abundance with standard error bars, 180 replicates per distance in each margin type.

3.2.5 Multiple species analysis

Following on from the individual species analysis, the data were assembled into groups of species with shared attributes and re-analysed (Table 4). The first test was for differences in the distribution of all common species, significant differences were only seen in the outer margin of woodland (0-2 m). In the next test the species were divided into two groups made up of those which are ancient woodland vascular plants in the SE region (Rose 1999), and those which are not. The distribution of non-indicator species was not influenced by adjacent land use. The distribution of indicator species was only significant in the outer part of the margin (0-2 m), with highest abundance adjacent to unimproved grassland. When only uncommon (Q<50) indicator species were considered as a single group there was evidence of significant differences when all 3 quadrat levels (0-12 m) were included (Table 4). The highest abundance of uncommon indicators was found in woodland margins adjacent to unimproved grassland, whilst the lowest was alongside arable fields. The lowest frequency of common species was also beside arable margins, but for the group containing all indicator species the lowest frequency was beside improved grassland margins. In both these groups of plants their highest abundance was found adjacent to unimproved grassland.

Table 4. Two-way ANOVA of arcsine transformed abundance data for grouped species contrasting adjacent land use (margin type), comparing data from distances Q1, Q1&2, Q1, 2&3, where Q1 = 0-2 m; Q2 = 2-4 m; Q3 = 10-12 m. Results given as F and P values with significant values are marked in bold; non-significant values are marked n/s unless P<0.1. Species groups based on frequency (common (Q>100)); ancient woodland indicator status (Rose, 1999) (uncommon indicators - Q<50); Ellenberg values for nitrogen (EVN) with species grouped into those commonly associated with relatively infertile sites (EVN ≤ 4), infertile sites (EVN ≤ 3), fertile sites (EVN ≥ 7) or very fertile sites (EVN ≥ 8); screened species sensitivity bands (see Table 4.11). 180 replicates per distance in each margin type; degrees of freedom: margin type, 2.

Tested species group	**No. spp.**	**Quadrat level (distance into margin)**					
		Q 1, 2 &3		**Q 1 &2**		**Q 1**	
		F	**P**	**F**	**P**	**F**	**P**
All common species	51	1.18	n/s	2.03	n/s	6.43	**0.0025**
Indicators (all)	52	0.46	n/s	0.94	n/s	3.37	**0.0388**
Indicators (uncommon)	35	4.80	**0.0105**	7.83	**0.0007**	10.03	**0.0001**
Non-indicators	148	0.54	n/s	0.99	n/s	2.72	0.0712
EVN ≤ 3	19	1.54	n/s	1.08	n/s	2.31	n/s
EVN ≤ 4	54	0.95	n/s	1.41	n/s	4.29	**0.0167**
EVN ≥ 7	45	0.49	n/s	0.61	n/s	0.75	n/s
EVN ≥ 8	9	2.96	0.0572	3.46	**0.0359**	3.44	**0.0365**
High sensitivity (screened)	5	5.63	**0.0050**	6.57	**0.0022**	9.39	**0.0002**
Intermediate sensitivity (screened)	5	0.17	n/s	1.07	n/s	5.23	**0.0072**
Low sensitivity (screened)	4	0.46	n/s	0.69	n/s	2.53	0.0855

Analyses of species grouped into those commonly associated with infertile sites or fertile sites were also carried out (Table 4). The results show that the abundance of plants typical of infertile sites are only significantly influenced by adjacent land use in the outer margin of woodland (0-2 m). However, those species typical of very fertile sites (eg *Stachys sylvatica* and *Urtica dioica*) were significantly more abundant up to at least 4 m into the margin. The abundance of plants associated with infertile sites were highest adjacent to unimproved grassland and lowest next to improved grassland. The distribution of plants typical of fertile soils was the opposite, with the highest abundance adjacent to improved grassland. These results suggest that over-spread of fertiliser into woodland adjacent from agricultural fields may take place, and impacts may be measured several metres into the margin.

3.2.6 Screened species grouped analysis (survey data)

Using the sensitivity bands shown in Table 1, data just for the three groups of screened species were extracted from the survey data as a whole. When these three groups were analysed the frequency of the high sensitivity screened species was significantly related to margin type (Table 4) with data from all three quadrat distances included in the analysis (0-12 m). The data shows that there was a much higher frequency of these sensitive species alongside unimproved margins compared with the other two land uses, the lowest frequency was alongside arable margins. The intermediate sensitivity species only showed significant differences when just the outer quadrat data were included in the analysis (0-2 m). The abundance of low sensitivity species in woodland margins did not show any significant differences which could be attributed to adjacent land use. These results confirm that the distribution/abundance of those species which were judged to be moderately or very sensitive to herbicide treatments in controlled experiments, may be affected in the field to a substantial degree. This also provides evidence that land use can have an impact on the community composition of adjacent woodland habitats, and that the surveying of groups of sensitive species may highlight changes which were overlooked in studies of the whole community. Since the screened plants were mostly ancient woodland vascular plants, it is impossible to say that these species are generally more at risk from spray drift than other species. However, if other species are found to be similarly sensitive to herbicide drift, and if the changes seen here are repeated across the country, then there could be implication for the conservation of those species.

Similar results to those described above have been seen in woodland margins bordering farmland in North America (Jobin, Boutin & DesGranges 1997). Their work showed that species diversity was higher adjacent to fields where herbicides had not been used recently compared to those where herbicides had been used. On the other hand surveys of field boundaries in the Netherlands by Kleijn and Verbeek (2000) shows that fertiliser inputs influence boundary vegetation, but that herbicides do not. However, pot experiments by the same author have indicated that both fertilisers and herbicides decrease boundary vegetation diversity (Kleijn & Snoeijing 1997).

4. Conclusions, implications and further work

The highest drift concentrations in woodland are generally confined to within 5 m of the spray boom, except in conditions with open margins and higher wind speeds, where drift may be detectable (although not necessarily at damaging concentrations), at least up to 10 m.

Spray drift, mainly within the first 4 m, has been measured at concentrations which have been shown to have impacts on certain woodland plants, in both greenhouse and field studies. The species tested showed a range of sensitivity to the herbicide used (glyphosate). However, only 14 species have been tested and it remains to be seen which other species would fall into the sensitive category.

At lower wind speeds the physical structure of the woodland margin is largely irrelevant, as it has little impact on the amount of drift measured. However, as the wind speed increases (within the recommended spraying limits) so the attenuating effect of margin density increases. Therefore margin structure may be important in reducing the impacts of the most extreme drift events.

Analysis of woodland survey data suggests that some key species may be affected by agri-chemical usage on adjacent land. Whilst the most obvious impacts are limited to 0-4 m into the margin, impacts on sensitive species have been shown as far as 12 m.

Buffer zones of 5-10 m would protect woodland margin plants from the most damaging effects of drift. Wider buffer zones may be required to protect the most sensitive species, particularly where these occur at wood edges, to minimize cumulative impacts, or to facilitate recruitment.

These results primarily relate to the impacts of herbicides on woodland ground flora. Care should be taken with respect to the application of buffer zone recommendations to mitigate the potential impacts of other groups of pesticides which may display different toxicities and risk of drift. For example, both insecticides and fungicides are often applied in much finer sprays than herbicides and may carry greater environmental risks, leading to the need for more extreme measures and wider buffer zones to limit their potential impacts.

We intend to take this work further by using the data detailed above as a starting point in the development of a combined predictive model of spray drift and drift impacts under a variety of environmental scenarios. The proposed model would encompass empirical information on drift of herbicides, insecticides and fungicides, and on their drift impacts on a variety of habitat types. Such a model would be valuable in informing policy and practice on pesticide applications.

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Appendix A List of woodland sites surveyed

Survey number	Woodland name	Date surveyed	Map reference	Margin type
1	Richards wood	3-Apr-01	TR 082 457	Arable
2	Richards wood	7-Apr-03	TR 079 458	Improved
3	Hurst wood	9-Apr-03	TR 084 463	Unimproved
4	Hurst wood	14-Apr-03	TR 085 464	Improved
5	Wood beside Little Coombe	16-Apr-03	TR 085 462	Arable
6	Collyerhill wood	23-Apr-03	TR 094 461	Improved
7	Collyerhill wood	25-Apr-03	TR 078 461	Unimproved
8	Collyerhill wood	27-Apr-03	TR 077 463	Arable
9	Towns wood	30-Apr-07	TR 088 472	Unimproved
10	Wood by Pett Street Farm	2-May-03	TR 080 471	Arable
11	Towns wood	6-May-03	TR 087 471	Arable
12	Towns wood	7-May-03	TR 090 472	Improved
13	Newgate scrubs	8-May-03	TR 082 447	Unimproved
14	wood by Winchcombe farm	9-May-03	TR 090 495	Improved
15	wood by Sole Street	13-May-03	TR 092 493	Unimproved
16	Warren wood	14-May-03	TR 076 480	Improved
17	Beech wood	15-May-03	TR 074 473	Arable
18	Collyerhill wood	16-May-03	TR 077 468	Unimproved
19	Stump Shave	19-May-03	TR 089 513	Unimproved
20	Down wood	21-May-03	TR 096 509	Arable
21	Denge wood	22-May-03	TR 091 521	Unimproved
22	Down wood	23-May-03	TR 088 518	Improved
23	Barton wood	23-May-03	TR 098 501	Arable
24	Church wood	24-May-03	TR 080 529	Improved
25	Denge wood	26-May-03	TR 096 509	Arable
26	Down wood (side extention)	27-May-03	TR 081 524	Improved
27	Down wood (side extention)	27-May-03	TR 079 524	Arable
28	Down wood	29-May-03	TR 084 523	Unimproved
29	Dunstans wood	30-May-03	TR 110 503	Improved
30	Dunstans wood	30-May-03	TR 107 503	Arable
31	Bavinge wood	1-Jun-03	TR 105 472	Unimproved
32	Bow Lease	2-Jun-03	TR 104 454	Unimproved
33	Shrub's wood	2-Jun-03	TR 100 456	Improved
34	Shrub's wood	3-Jun-03	TR 101 458	Arable
35	Wood next to Smeed farm	4-Jun-03	TR 086 457	Unimproved
36	Newlands wood	4-Jun-03	TR 093 455	Arable
37	wood next to Dean farm	6-Jun-03	TR 127 463	Unimproved
38	Elham Park wood	6-Jun-03	TR 168 459	Unimproved
39	The Junipers	13-Jun-03	TR 069 468	Arable
40	The Junipers	13-Jun-03	TR 067 472	Improved
41	The Junipers	15-Jun-03	TR 071 467	Unimproved
42	Dencher wood	16-Jun-03	TQ 966 494	Arable
43	Westwell downs	16-Jun-03	TQ 974 487	Arable
44	Stubyer's wood	17-Jun-03	TQ 979 488	Improved
45	Atchester Wood	17-Jun-03	TR 157 478	Unimproved

Survey number	Woodland name	Date surveyed	Map reference	Margin type
46	Sunny Banks	18-Jun-03	TQ 991 496	Unimproved
47	The Willows	18-Jun-03	TQ 992 493	Improved
48	Foxbury Woods	19-Jun-03	TQ 989 492	Improved
49	Bourne Wood	20-Jun-03	TQ 985 487	Improved
50	Hanger Wood	22-Jun-03	TQ 988 484	Improved
51	Bourne Wood	24-Jun-03	TQ 986 484	Unimproved
52	Wrotham Wood	24-Jun-03	TQ 980 492	Arable
53	Catsdane Wood	24-Jun-03	TQ 985 497	Improved
54	Foxbury Wood	25-Jun-03	TQ 986 492	Arable
55	Sutton Hook Wood	26-Jun-03	TR 115 489	Arable
56	Yawlings Wood	26-Jun-03	TR 112 495	Improved
57	Hobday's Wood	27-Jun-03	TR 115 494	Arable
58	Sutton Hook Wood	27-Jun-03	TR 115 489	Improved
59	Earley Wood	30-Jun-03	TR 120 501	Improved
60	Earley Wood	1-Jul-03	TR 118 502	Arable
61	Buckholt Wood	2-Jul-03	TR 120 507	Improved
62	Edord's Wood	3-Jul-03	TR 130 451	Arable
63	Dunlies Wood	3-Jul-03	TR 125 489	Arable
64	Spong Wood	4-Jul-03	TR 124 458	Arable
65	Edord's Wood	7-Jul-03	TR 128 453	Unimproved
66	Yockletts Bank (back)	8-Jul-03	TR 125 476	Arable
67	Yockletts Bank (top)	8-Jul-03	TR 128 471	Improved
68	Yockletts Bank	9-Jul-03	TR 124 485	Unimproved
69	Yockletts Bank	9-Jul-03	TR 123 480	Improved
70	Wadden Hall Wood	10-Jul-03	TR 134 493	Arable
71	Wadden Hall Wood	10-Jul-03	TR 132 498	Improved
72	Partridge Wood	11-Jul-03	TR 100 432	Arable
73	Partridge Wood	11-Jul-03	TR 101 433	Unimproved
74	Becks Wood	14-Jul-03	TR 093 441	Arable
75	South Hill Farm Wood	14-Jul-03	TR 098 443	Unimproved
76	Unnamed by Atchester Wood	17-Jul-03	TR 154 484	Unimproved
77	Manns Wood	18-Jul-03	TR 161 494	Improved
78	Manns Wood	18-Jul-03	TR 161 494	Unimproved
79	Peafield Wood	21-Jul-03	TR 172 476	Unimproved
80	Lower Quilters Wood	21-Jul-03	TR 166 487	Unimproved
81	Quilters Wood	22-Jul-03	TR 169 493	Arable
82	Quilters Wood	22-Jul-03	TR 167 490	Unimproved
83	Bursted Wood	24-Jul-03	TR 161 500	Unimproved
84	Bursted Wood	24-Jul-03	TR 158 500	Arable
85	Bursted Wood	28-Jul-03	TR 159 503	Improved
86	Colehill Wood	28-Jul-03	TR 178 488	Improved
87	Hoath Wood	30-Jul-03	TR 196 487	Improved
88	Jumping Downs	30-Jul-03	TR 193 486	Unimproved
89	Bedlam Wood	31-Jul-03	TR 201 463	Unimproved
90	Lodge Lees Down	31-Jul-03	TR 203 468	Improved

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