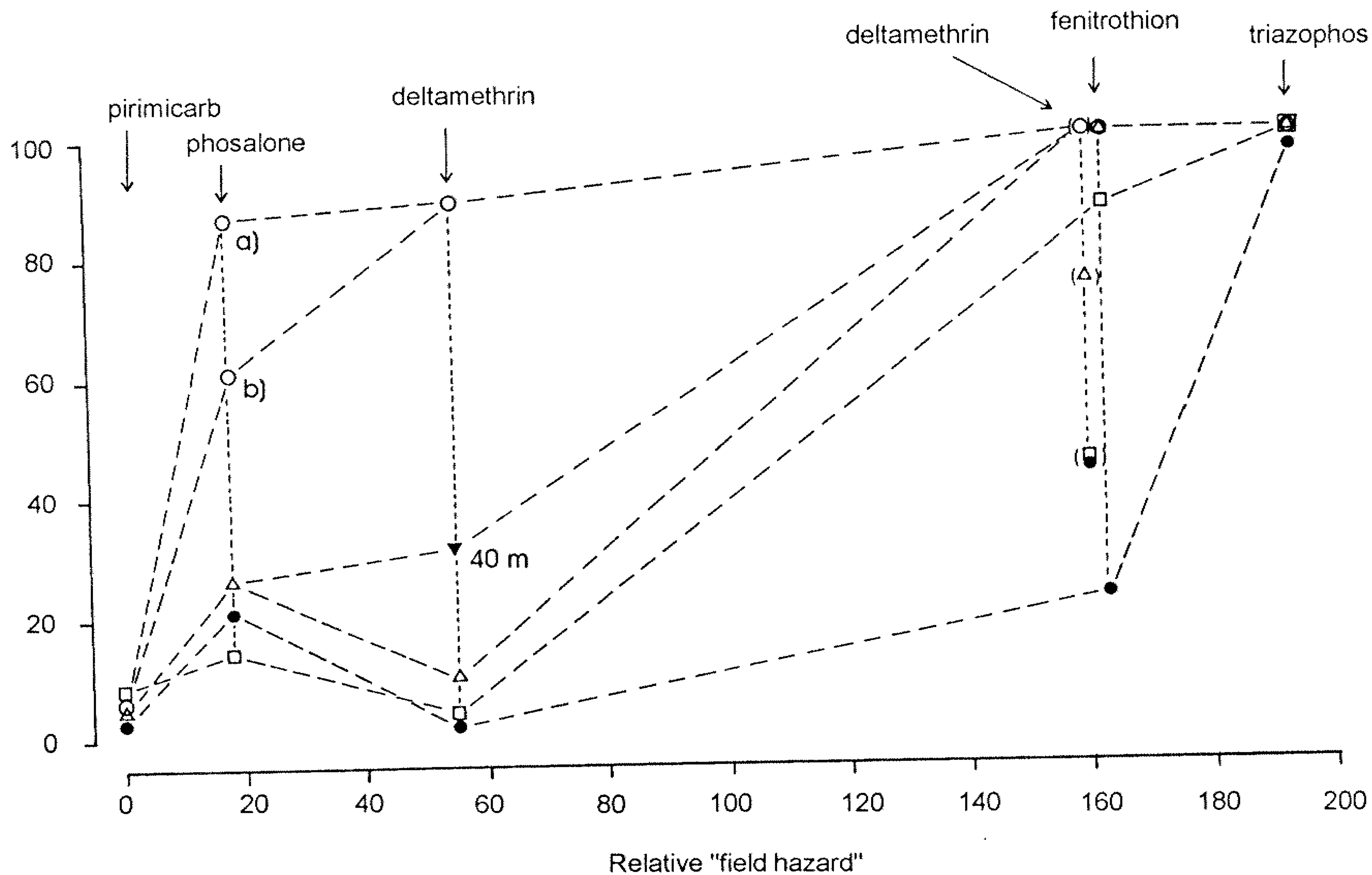
Figure 1.33. Relationship between relative field hazard for *Pieris brassicae* caterpillars and mortality from spray drift for the five compounds and six trials in Table 1.11, at four distances downwind: 0 m = O, 50 m = △, 100 m = □ and 150 m = ●.
The results for the Chatteris deltamethrin trial are shown in brackets since mortality was only assessed over 12 hours.



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USE OF BIOASSAY TECHNIQUES TO ASSESS THE EFFECTS OF ASULAM WHEN APPLIED BY HELICOPTERS

2 USE OF BIOASSAY TECHNIQUES TO ASSESS THE EFFECTS OF ASULAM WHEN APPLIED FROM HELICOPTERS

R H Marrs & A J Frost

2.1 INTRODUCTION

There has been increasing concern for many years that herbicide spray drift from agricultural, forestry and other sprayed land can affect plant species growing on adjacent nature reserves. Two situations pose particularly severe problems: where nature reserves are part of a mosaic of patches within a landscape where large areas of 'weeds' are to be treated, and where aerial applications are made.

In Britain the control of bracken (*Pteridium aquilinum*, (L.) Kuhn) in upland areas causes concern for nature reserves on both these counts. Large areas of bracken are often sprayed from the air as part of a region-wide campaign to reduce bracken infestation on moorland. Often, within the bracken-moorland matrix there are areas of high conservation interest, where spray drift might cause damage to rare species of fern such as *Athyrium filix-femina* (Lady-fern), *Blechnum spicant* (Hard-fern), *Dryopteris affinis*, (Scaly Male-fern), *D. dilatata* (Broad Buckler-Fern), *Gymnocarpium dryopteris* (Oak-fern), *Oreopteris limbosperma* (Lemon Scented-Fern), and *Phegopteris connectilis* (Beech-fern) (nomenclature follows Stace, 1991). Spray from aircraft drifts further than from most ground sprayers (Elliott & Wilson, 1983; Williams *et al.*, 1987), with drift being detected between 400-1000 m away from the application point (reviewed by Davis & Williams, 1990). There is, however, very little information on the likely biological effects of this drift.

Asulam is the main herbicide used to control bracken and was originally developed for the control of docks (*Rumex* spp.). Other ferns are susceptible (Horrill, Dale & Thomson, 1978; Marrs & Griffiths, 1986) and are the most likely candidates to be affected by asulam drift in upland spraying campaigns. Because bracken control is a priority in many parts of upland Britain for effective management of sheep and grouse, and for moorland and landscape conservation, it is unlikely that asulam use will reduce in the near future. Indeed asulam applications from the air have increased greatly during the 1980s from 828 ha in 1981 to 5778 ha in 1990 (Sly & Neale, 1983; Thomas & King, 1992). Asulam is by far the most commonly used herbicide in aerial applications, accounting for more than 98% of the total herbicide applied by air in 1990 (MAFF, pers comm.). Therefore, for the protection of nature reserves near bracken-treated areas, it is essential that estimates of safe 'buffer zone' distances can be made, so that sensitive sites can be protected by spray-free areas.

Here, we describe an experimental field approach mainly using bioassay plants sensitive to asulam, but augmented with estimates of drift deposition, to make a first approximation of the size of the buffer zone needed.

In previous publications we have reported our first attempts to develop field bioassay techniques to estimate buffer zone distances and assess the likely impact of asulam drift damage on native ferns

(Marrs *et al.*, 1992, 1993a, 1994; Cooke, 1994). In this report we review all of this previous work but extend it to report two new experiments done in 1992 and 1993. These additional experiments were done to make sure that the basic bioassay test was repeatable and to validate our initial estimates of buffer zone distance. In this report three different types of study are presented:

(1) Initial trial - the pilot study done to see whether the bioassays were feasible; it also considered the influence of wind and spraying direction on drift damage,

(2) Three experiments (1990, 1992 and 1993) - to determine safe buffer zone distances downwind of sprayed areas.

(3) An experiment to determine the distribution and effect of asulam in a sprayed area where rare ferns were present. The aim was to determine whether any protection was afforded these rare species either through spatial position within the clough or through an overstorey of bracken.

2.2 METHODS

2.2.1 General approach

This study concentrated on the use of bioassay plants to detect drift from aerial spraying of asulam by helicopter, when applied under normal field application conditions. In each case asulam was applied at a rate of 4.4 kg ai/ha (11 litres Asulox/ha) in 44 litres spray/ha, containing a non-ionic wetter (Agral at 0.1% vol:vol)). To augment the biological damage assessment some measures were also made of drift deposition in each study.

(a) Bioassay methodology

Rumex acetosa (common sorrell) was the main test plant used in this study as this species is known to be susceptible to asulam, and is available in large numbers. After 2-3 weeks the leaves of affected plants show severe chlorosis, followed in some instances by necrosis and death. Usually seeds of *Rumex* were usually sown in January and then potted individually into 7 cm x 7 cm x 8 cm pots containing SAI GP compost; in experiment 3 older stock plants, which had been sown the previous season, were used. The developing flowering stems were cut to prevent premature dormancy, and at the time of spraying the plants had between 10-40 mature leaves.

In addition to the *Rumex* plants, a smaller number of the non-native fern *Adiantum pubescens* was also used in all experiments; in experiment 1 an additional fern *A. fragrens* was also included. The ferns were obtained from a horticultural supplier in June and repotted immediately as described above for *Rumex*.

Seed trays containing six pots of either *Rumex* or *Adiantum* were used for field bioassays. After spraying, the plants were left *in situ* for 2 hours to dry, before being transferred to Monks Wood Experimental Station. The *Rumex* plants were placed on a sand bed outside and given an appropriate horticultural watering regime. The *Adiantum* were maintained in an unheated glasshouse under normal horticultural conditions. Three weeks after exposure each individual

Rumex plant was assessed visually for damage by counting (1) the total number of leaves, and (2) the number of these leaves that were showing chlorotic or necrotic symptoms. The mean percentage (± S.E.) of leaves damaged at each exposure point was then calculated. In experiment 4 each plant was also harvested. Six weeks after exposure the foliage of all *Adiantum* plants in each replicate seed tray was harvested. In experiment 4 the height of each fern was also measured. All harvested plant material was oven dried at 80°C and weighed.

(b) **Drift deposition assessment**
In all studies drift deposition was assessed using water sensitive papers (Sinha, Lakhani & Davis, 1990). In experiment 4 additional information on drift deposition was also collected using a lithium tracer.

Wind speed and direction was continuously monitored during the spraying periods using a Vector Instruments R500 recording anemometer.

(c) **Statistical analysis**
Exponential and logistic relationships were fitted to some of the relationships between drift/damage and distance downwind using the Maximum Likelihood Program (Ross, 1979). Other statistical analyses were done using SAS (SAS, 1985). Parameters of equations discussed here are given in Appendix I.

2.2.2 Experiment 1: Stanford PTA, Norfolk

This experiment was set up around a small bracken patch surrounded by grass heath in a relatively flat area on the Stanford Practical Training Area in Norfolk (Grid reference TL 874914). The patch was mapped using a combination of aerial photographs and ground survey. Twenty-six transects were laid out in June 1989 concentrating the sampling effort on the leeward side (Figure 2.1). The starting point for each transect was 5 m inside the bracken area (-5 m position) and sampling points were set up at the bracken/heath boundary (0 m) and at 1, 2.5, 5, 10 and 20 m into the grass heath. *Rumex* plants were placed at these positions on 18 transects and mixtures of *Adiantum* and *Rumex* were placed on the remaining 8 transects. A water sensitive paper was also placed at each sampling position on the *Adiantum/Rumex* transects.

Asulam was applied using a Bell 47 helicopter with an 8 m boom fitted with 24 T-jet nozzles, and using a tank pressure of 2.7 bar. Spraying was done on a warm dry day with a wind speed of 3.7 m/s - range (1.5-6 m/s).

2.2.3 Experiment 2: Bamford Edge, Derbyshire

A map of the experimental area at Bamford Edge in Derbyshire (Grid reference SK 214842) is shown in Figure 2.2. The site is a steep escarpment reaching a gently rising plateau at an altitude of approximately 400 m. In July 1990, dense bracken (> 20 fronds/m^2; 1.5 -2.0 m tall) covered the steep slope, and the vegetation changed abruptly into moorland at the edge of the plateau. At the experimental site, eight transects (six with *Rumex* and two with *Adiantum*) each 2 m apart, were laid out at right angles downwind of the bracken front into the moorland. On each transect trays were placed 10 m inside the bracken patch within a small cleared area (designated -10 m), at the boundary between the bracken patch and moorland (0 m) and thereafter at 2.5, 5, 10, 20, and at subsequent 20 m intervals until 240 m downwind into the moorland. Two water sensitive papers were also placed at each distance.

Asulam was applied by a Bell 47G3B1 helicopter at a height of between 5-10 m. A 12 m boom was used fitted with 36 Raindrop and 36 Cone nozzles and the tank pressure was 2 bar. The upper edge of the bracken patch was sprayed in three swaths flying perpendicular to the transects (Figure 2.2) starting at the upper edge and moving down the slope. The wind direction was constant, and was from the south-east. Wind speed varied between 6-10 m/s at a height of 2 m. There was no rain during the spraying period.

2.2.4 Experiment 3: Painscastle, S Wales

The experimental area was near Painscastle in South Wales (Grid reference SK 214842). The site is a gently rising plateau at an altitude of approximately 400-500 m. On 27 July 1992, the experiment was laid out at the edge of a dense bracken patch (c. 2 ha) with bracken at a density of 20 fronds m^{-2} and about 1 m tall and a *Vaccinium myrtillus* dominated moorland (c. 30 cm tall). At the experimental site, eight transects (six with *Rumex* and two with *Adiantum*) each 2 m apart, were laid out at right angles downwind of the bracken front into the moorland. On each transect, trays were placed 10 m inside the bracken patch within a small cleared area (designated -10 m), at the boundary between the bracken patch and moorland (0 m) and thereafter at 2.5, 5, 10, 20, and at subsequent 20 m intervals until 180 m downwind into the moorland. Two water-sensitive papers were placed at each distance.

Spraying was done with a Hillier 12E4 helicopter carrying a load of approximately 200 litres of spray. The helicopter was equipped with a 12 m Standard Simplex Hydraulic Boom, fitted with modified Raindrop nozzles, and operated at a tank pressure of approximately 2 bar. Spraying height was meant to be between 3-6 m above ground level, but ground observations suggested that spraying was done at or near the lower level (3 m).

The edge of the bracken patch was sprayed in four swaths flying perpendicular to the transects. The wind direction was constant, and was from the north-west. Wind speed was approximately 4 m/s at a height of 2 m during the spraying. There was no rain during the spraying period.

2.2.5 Experiment 4: Wooler, Northumberland

This experiment was set up on the College Valley Estates near Wooler in Northumberland (Grid reference NT 894286) in a joint project with the NRA. The bracken patch was downwind of a small conifer wood and the transect extended along a former cultivation terrace. The bracken was fairly dense (20-30 fronds/m^2) and was between 0.5-1.0 m tall at the time of spraying (19 August 1993). The grassland was a fairly typical upland wet meadow; a full species list is shown in Table 2.1. There was evidence of recent cattle grazing and sheep were present.

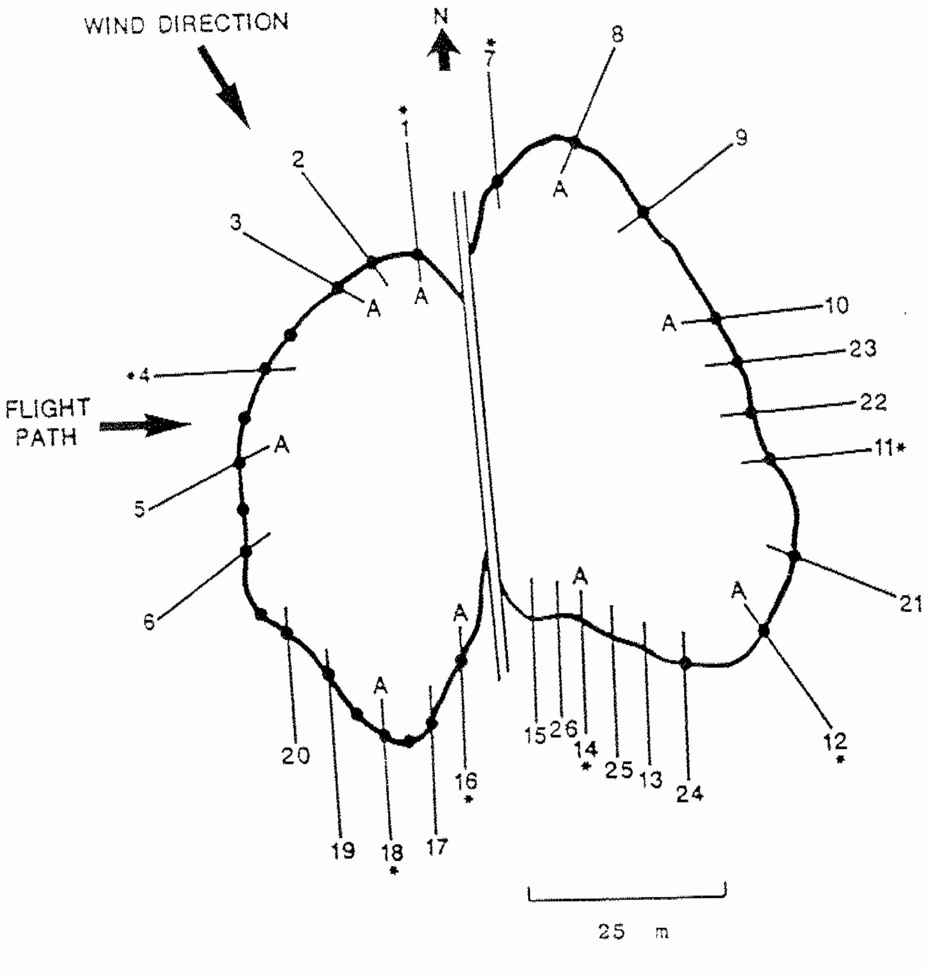

Figure 2.1 Map of bracken patch showing the distribution of transects, flight path and wind direction at Stanford PTA; * = transects with ferns as well as *Rumex acetosa* (see text for explanation).

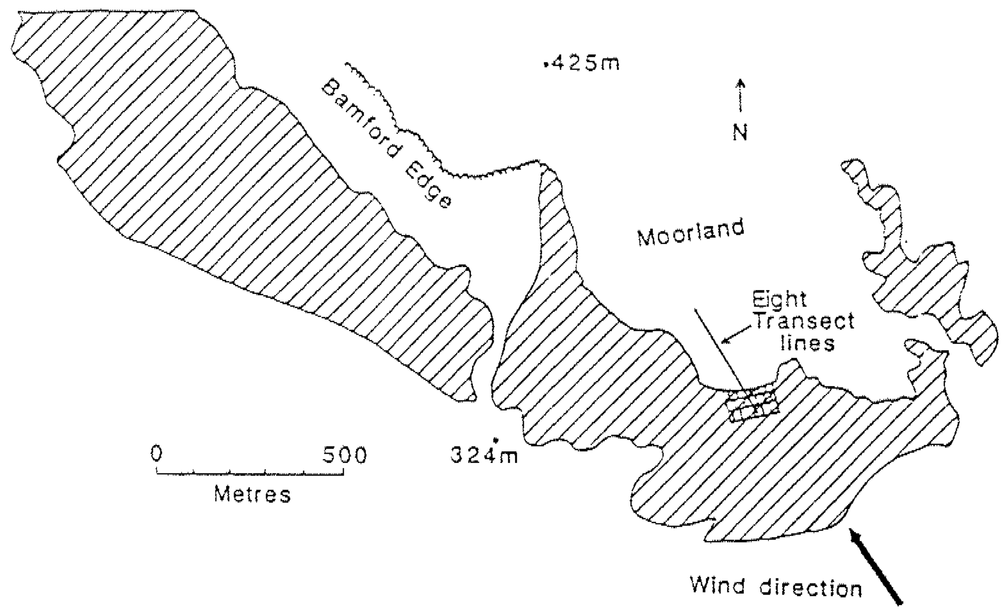

Figure 2.2 Schematic map of the study site at Bamford Edge showing the bracken areas (hatched), and the approximate position of (a) the eight transect lines, and (b) the sprayed area (double hatched).

Eight transects (six with *Rumex* and two with *Adiantum*) each 2 m apart, were laid out at right angles downwind of the bracken front into the grassland. Trays were placed 15 m and 5 m inside the bracken patch within a small cleared area (designated -15 and -5 m), at the boundary between the bracken patch and moorland (0 m) and thereafter at 5, 10, 20, 30, 40, 50, 60 m and at subsequent 20 m intervals until 180 m downwind. Two types of drift collector were also placed at each distance, water sensitive papers and hair curlers (Davis, Brown & Frost 1993).

Asulam was applied by a Bell 47G3B1 helicopter at a height of between 5-10 m. A 12 m boom was used fitted with 36 Raindrop and 36 Cone nozzles and the tank pressure was 2 bar. The upper edge of the bracken patch was sprayed in four swaths flying perpendicular to the transects. Wind speed was between 4-5 m/s with occasional gusts to 6 m/s at a height of 2 m and was from south-south-west. There was no rain during the spraying period.

In this experiment a lithium tracer (1.8 kg lithium sulphate) was added to the tank mix (crudely estimated at c. 230 litres); the aim was to achieve a tank concentration of approximately 855 mg/litre of spray. As this mix was made up under field conditions accuracy could not be guaranteed and samples of the tank mix were taken and analyzed to determine lithium concentration. The amount of lithium deposited on the collectors was determined as follows. The water sensitive papers were cut up and soaked overnight in 2% nitric acid. The hair curlers were stored in sealed glass jars until analysis. The lithium was washed from the curlers by shaking them vigorously in 10 ml 2% nitric acid, allowing them to equilibrate for 30 min and then shaking again. After both extractions the acid solution was decanted for analysis. The amount of lithium in these solutions and in the tank mix samples was measured by ICP-MS spectrophotometry. Internal standards of beryllium, indium and bismuth were used and 5 replicate determinations were made on each sample. Results were corrected using analyses on blank collectors.

2.2.6 Experiment 5: Stable Clough, Derbyshire

The experimental site was at Stable Clough (Grid reference SK 100994) near Glossop in Derbyshire. The site was a steep valley with dense bracken covering the moorland top and extending part way down the clough sides. On the steep sides the bracken gave way to open grassland and rocky outcrops and ledges, and in the bottom there was both *Calluna* heathland and open stony ground. A transect line was established across the clough and eight transect points established

Table 2.1. Species composition of the grassland at the Wooler site (Experiment 4).

Monocotyledons

Agrostis capillaris
Anthoxanthum odoratum
Arrenatherum elatius
Briza media
Cynosurus cristatus
Dactylis glomerata
Deschampsia cespitosa
Juncus articulatus
Juncus effusus
Holcus lanatus

Dicotyledons

Achillea millefolium
Achillea ptarmica
Campanula rotundifolia
Cerastium fontanum
Cirsium palustre
Cirsium vulgare
Galium palustre
Leontodon autumnalis
Lotus uliginosus
Potentilla palustris
Prunella vulgaris
Ranunculus repens
Rumex acetosa
Stellaria media
Thymus polytrichus
Trifolium repens

for assessment of asulam drift in July 1990. The transect points were chosen to reflect different types of habitat in the clough where rarer ferns could persist. These points were arranged from west-east (Figure 2.3) within the area to be sprayed with asulam as follows:

(1) Clough Top - outside bracken canopy
(2) Clough Top - under bracken canopy
(3) Clough Side - open
(4) Clough Bottom - in *Calluna* vegetation
(5) Clough Bottom - in open ground
(6) Clough Side - open stony ground
(7) Clough Top - under bracken canopy
(8) Clough Top - outside bracken canopy

Five trays of *Rumex*, three trays of *Adiantum* and four water sensitive papers were placed randomly at each of these points immediately before spraying. Asulam was applied by a Bell 47G3B1 helicopter. A 12 m boom was used fitted with 36 Raindrop and 36 Cone nozzles and the tank pressure was 2 bar. Flying height was between 5-10 m. The entire clough and its surrounding bracken was sprayed in a series of uphill and downhill swaths parallel to the transect across the clough (Figure 2.3). The wind direction was easterly with some gusts from the north-east. The wind speed was approximately 3.5 m/s (range 2-7 m/s) at a height of 2 m. There was no rain during the spraying period.

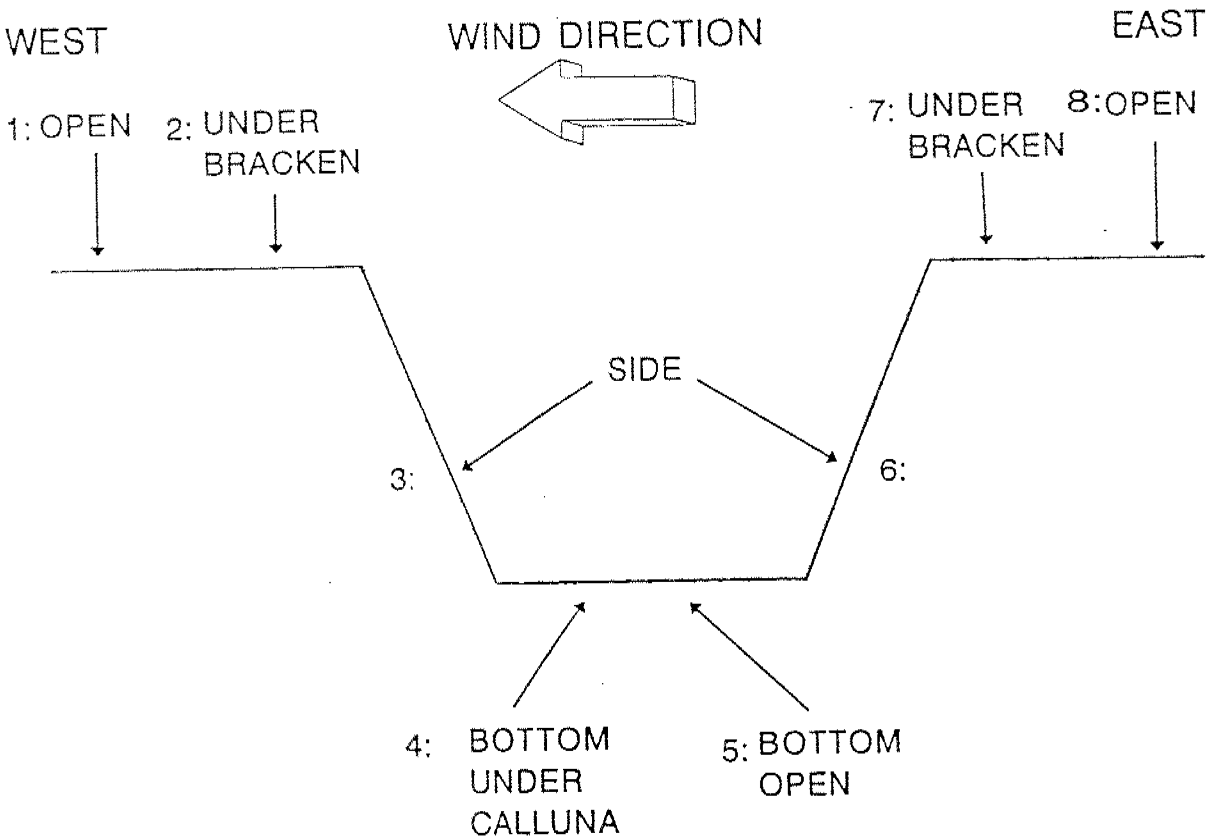

Figure 2.3 Plan of the transect across Stable Clough with eight sampling points; see text for explanation. The helicopter applied the asulam at right angles to the transect line, i.e. in a north-south direction.

2.3 RESULTS

2.3.1 Experiment 1: Stanford PTA, Norfolk

A map of the drift deposition based on the water sensitive papers showed that there was considerable drift extending to at least 20 m (Figure 2.4). In some areas there was greater deposition outside the bracken patch than within. Although this result was found mainly in the east-west direction (direction of spray), it could not have been solely accounted for by overspray, because levels were greater than 100% of applied levels. This result indicates that deposition was greater in some areas outside but immediately adjacent, the patch and is probably a result of turbulence.

In this study the distance at which no obvious damage to the *Rumex* plants was found was determined (Table 2.2). The transects have been split for convenience into four sectors based on wind direction. The windward sector had least damage with only one of the transects showing damage to 15 m (no damage at 20 m). All other transects showed damage to 20 m, the maximum distance tested.

2.3.2 Experiment 2: Bamford Edge, Derbyshire

Drift deposition and damage to the *Rumex acetosa* test plants declined with distance downwind of the sprayer (Figures 2.5, 2.6).

Deposition of drift measured with the water-sensitive papers declined rapidly downwind of the sprayer, with only 10% of the applied rate reaching 33 m. This technique under-estimates the deposition of small droplets, but even so 0.2% of the amount detected at 0 m was found at 220 m.

Damage to *Rumex acetosa* extended to much greater distances than suggested by the deposition data with 10% of leaves damaged at 131 m. Untreated 'control' plants had a mean value (±S.E.) for leaf damage of 3.5 ± 0.4%. The no-effect level was estimated at 5% leaf damage (NEL = untreated mean + 1.96 x S.D.), and the predicted distance required to achieve this level was 161 m downwind.

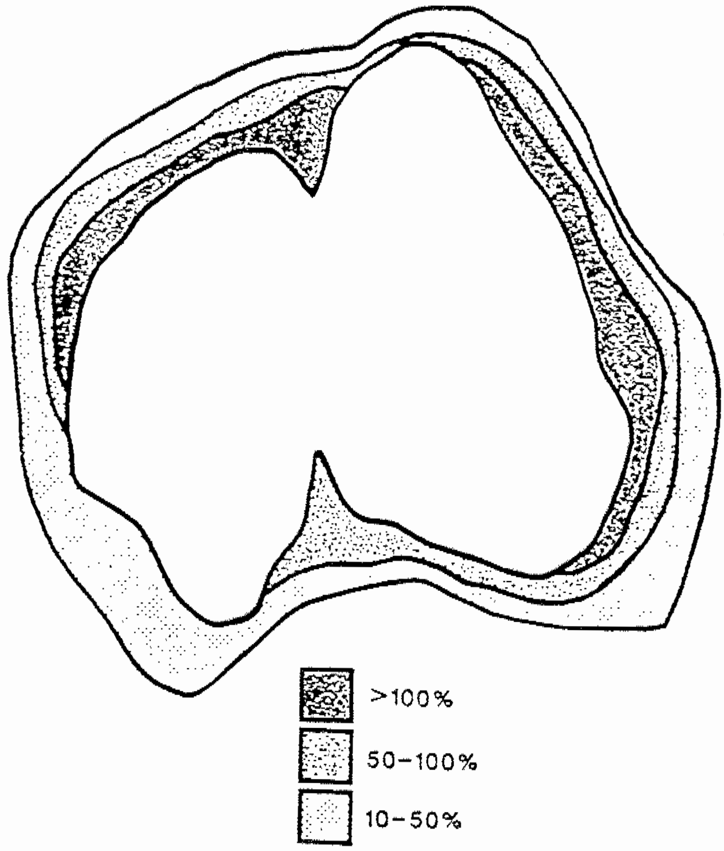

Figure 2.4 Deposition of spray drift assessed as a % of mean deposition within the bracken patch at Stanford PTA; bracken patch is the central white area.

Table 2.2. Distance at which no detectable damage was found on _Rumex_ test plants after applying asulam by helicopter at Stanford PTA (Experiment 1). The damage was assessed after 3 weeks.

Direction of spray	Transect Number	Distance (m)
Windward	1	15
	2	15
	3	5
	7	2.5
	8	20
	9	10
Overspray-east	10	20
	11	>20
	21	>20
	22	20
	23	>20
Overspray-west	4	20
	5	>20
	6	10
Leeward	12	>20
	13	>20
	14	>20
	15	>20
	16	>20
	17	>20
	18	15
	19	>20
	20	15
	24	>20
	25	>20
	26	>20

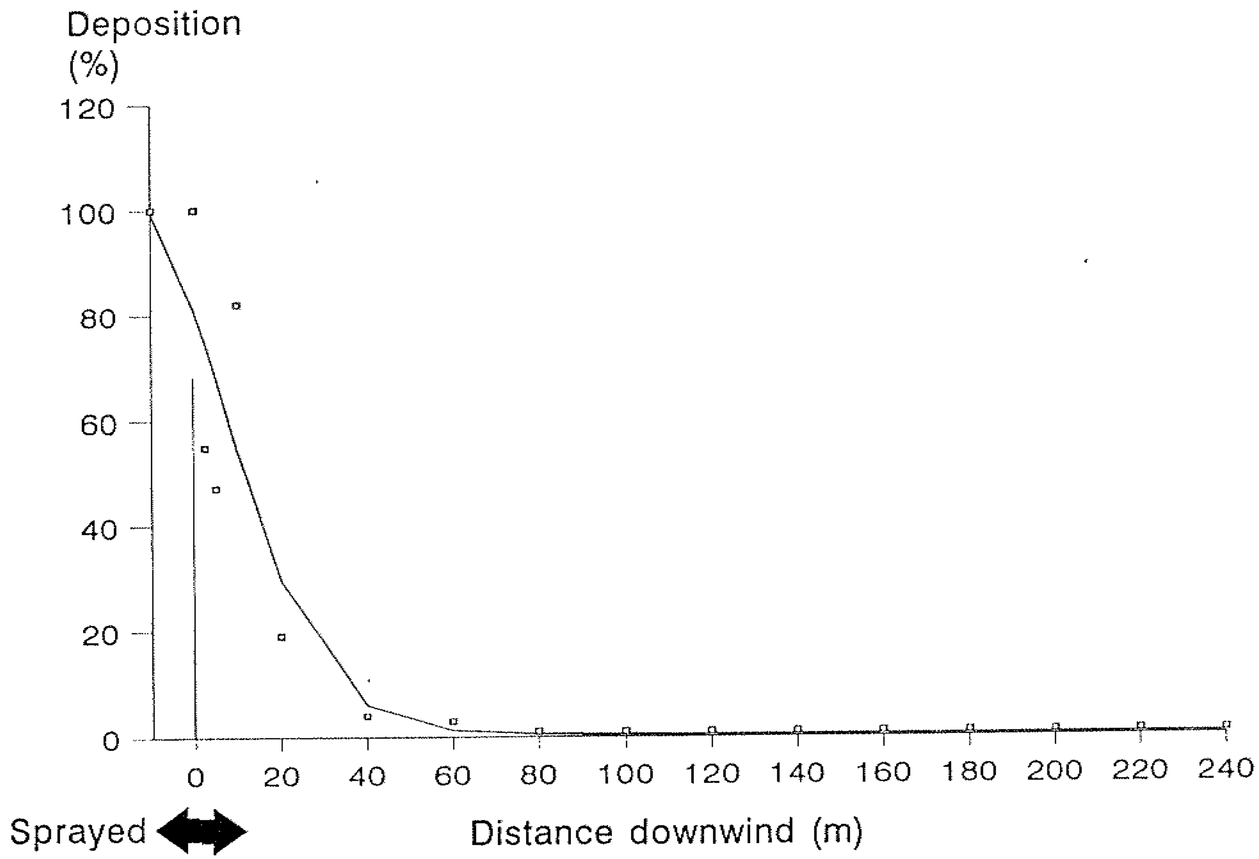

Figure 2.5 Mean deposition of visible spray on pairs of water sensitive papers, expressed as a % of deposition at the 0 m position, and a logisitic curve fitted to these data (Appendix I), in the experiment at Bamford Edge, Derbyshire.

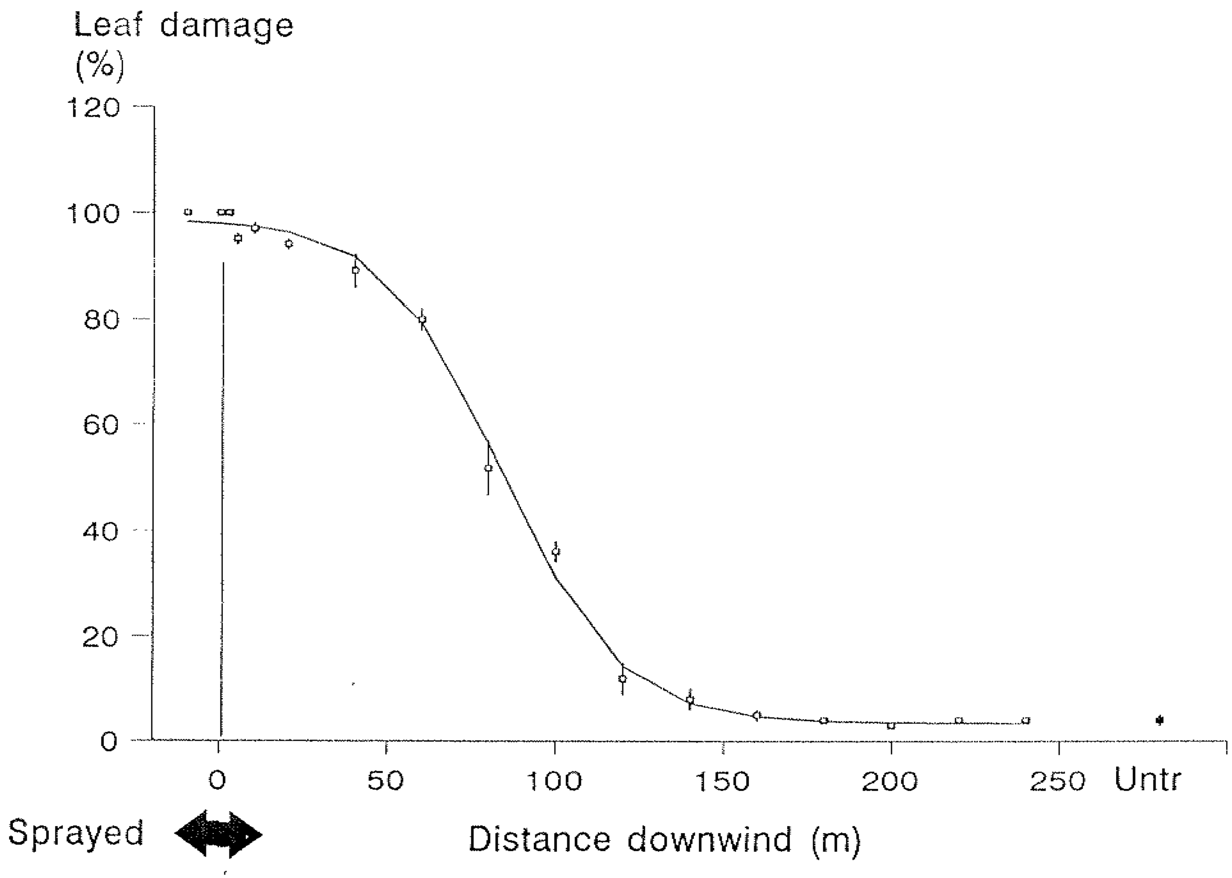

Figure 2.6 Mean values ± S.E. (n=8) for leaf damage on test plants (Rumex acetosa) caused by asulam drift downwind of a sprayer, and a logisitic curve (Appendix I) fitted to these data, in the experiment at Bamford Edge, Derbyshire. The mean values ± S.E. (n=12) for untreated controls are also presented for comparison.

2.3.3 Experiment 3: Painscastle, S Wales

The absolute amount of spray found on the water sensitive papers was lower than that found in previous years (Marrs, *et al.*, 1993a). Deposition was greatest in the immediate downwind zone, with maximum capture at the 0 m position rather than directly under the sprayer (Figure 2.7). It is interesting to note that the point at which 10% deposition of the amount detected in the bracken patch in the present study was found between 20-40 m downwind. This range is in keeping with results from the Bamford Edge study, where the estimated 10% level was at 33 m. Very little deposition was found beyond 40 m, although there was a small amount detected even at 180 m. The pattern of drift was, thus, similar to our previous study, although the absolute amounts of spray was lower.

The *Rumex* test plants showed very little damage even when exposed directly under the sprayer (Figure 2.8). This is in direct contrast to the results in our previous studies where almost all leaves of the test plants were affected. There was also a difficulty that even our untreated plants showed significant leaf damage on this occasion, probably because the experiment was started at relatively short notice and old stock plants were used. Whilst this is a complicating factor in the interpretation of the results it should not have affected the impact of the herbicide under the sprayer. Moreover, in all previous studies leaf damage was much more sensitive than deposition on water sensitive papers; viz. if deposition was found on water sensitive papers then *Rumex* leaf damage was considerable. Whilst, leaf damage was found at some distances - 0 m, 60 m and 100 m - it is not known whether these results are because of subtle deposition effects interacting with turbulence or random noise.

The results from the ferns (Figure 2.9) were similar to those of *Rumex* except that increased damage was only found at the 100 m position.

As the results from this experiment did not give the clear cut responses that were obtained in previous and subsequent experiments the study site was re-visited in 1993, the year after spraying, to see if the asulam had had an effect on the bracken. The site was visited twice (3 June and 21 July), when 10 randomly positioned 1m^2 quadrats were placed in sprayed areas and in an adjacent untreated area. Within each quadrat the density and height of all fronds was assessed.

On both visits the general appearance was not that of a site where the asulam effect was successful. After successful asulam treatment there are few fronds apparent and the main visual impact is the litter layer. On the first visit, immediately after frond emergence, there was little evidence of any difference between the sprayed and unsprayed areas (Table 2.3). On the later visit in mid summer, the sprayed area showed differences across the site. At the front of the sprayed site the bracken appeared more vigorous than further inside the patch. Approximately 15 m inside the patch (denoted hinterland) fronds emerged in 1993 but they had been killed, presumably by frost. The fronds visible in July had either escaped or had emerged subsequently. In mid summer, the sprayed bracken had a lower density

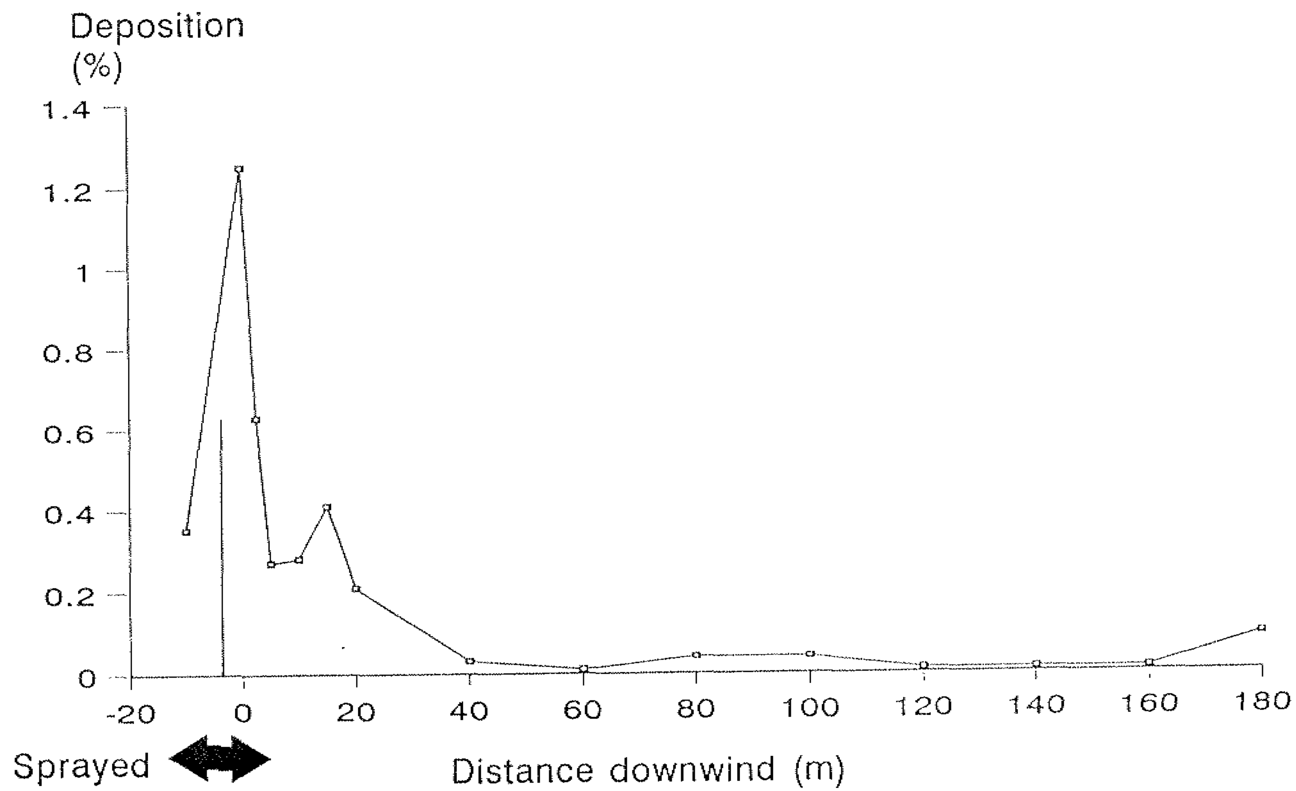

Figure 2.7. Deposition of spray drift on water sensitive papers along the transect in the Painscastle experiment; mean values of two replicate papers are presented along with a fitted equation (Appendix I)

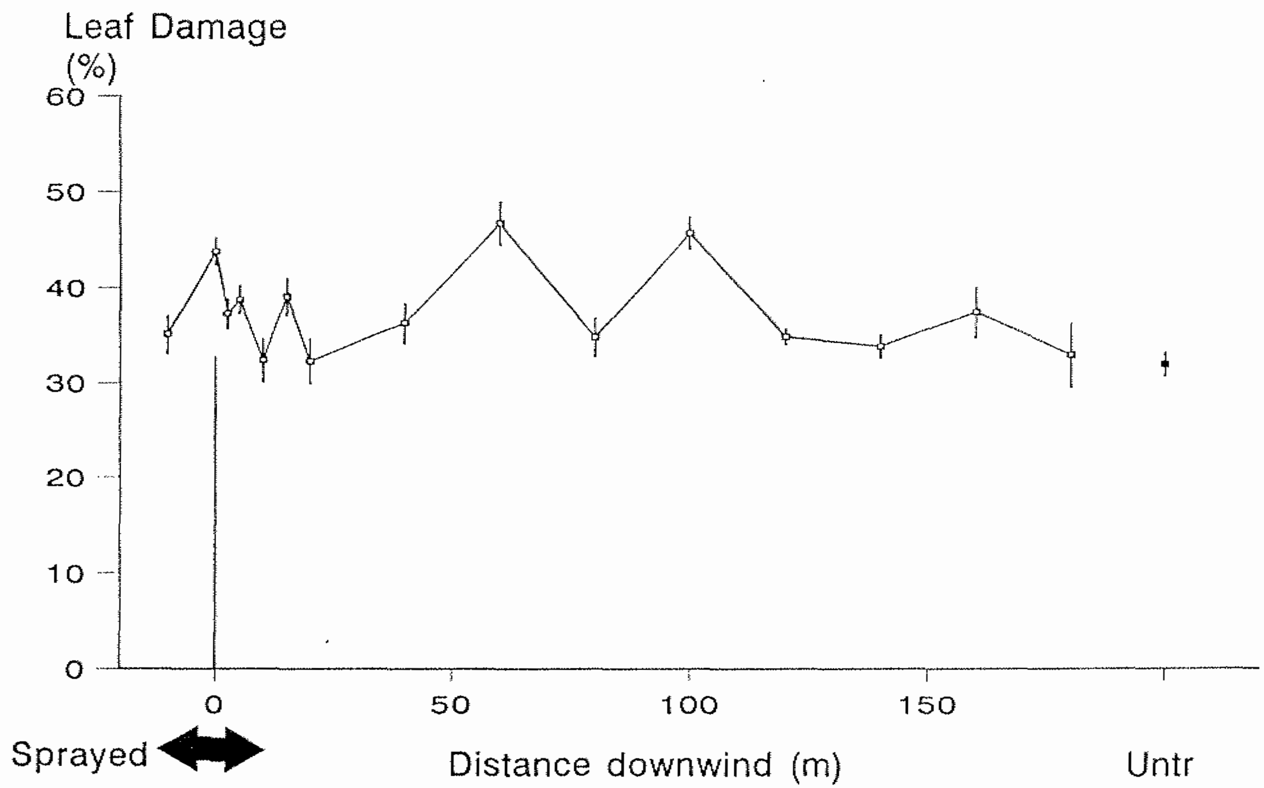

Figure 2.8 Mean damage ± S.E. (n=6) of leaf damage to <u>Rumex acetosa</u> downwind of asulam applications in the Painscastle experiment and compared to untreated (untr) plants.

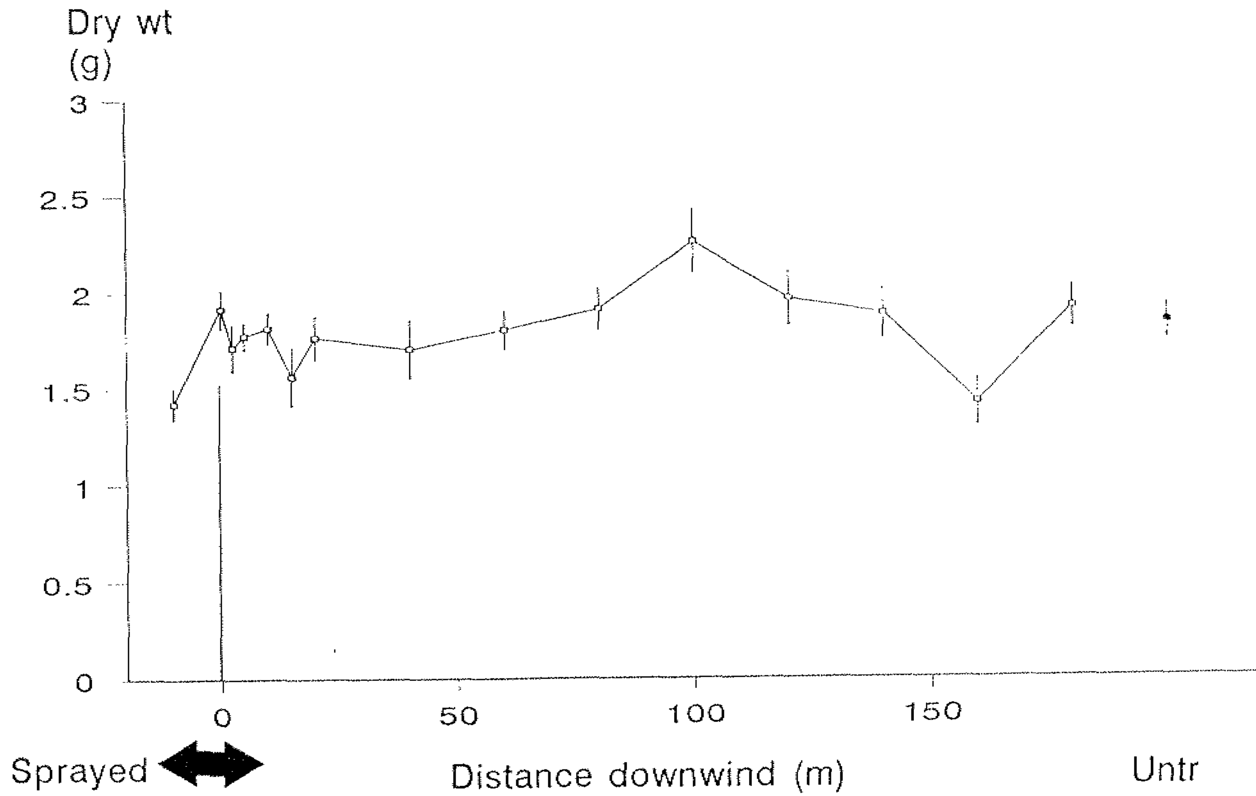

Figure 2.9 Mean dry weight (± S.E., n=3) of <u>Adiantum pubescens</u> downwind of asulam application in the Painscastle experiment and compared to untreated (untr) plants.

Table 2.3. Frond densities and heights in sprayed and unsprayed areas of bracken at the Painscastle test site (Experiment 3); mean values ± S.E. (n = 10) are presented.

Sampling date - 3 June 1993

	Sprayed	Unsprayed
Mean frond density (fronds/m^2)	9.7±1.1	13.8±1.6
Mean frond height (cm)	24.9±0.9	19.2±0.9
Frond height range (cm)	7-37	6-32

Sampling date - 21 July 1993

	Sprayed		Unsprayed
	Front	Hinterland	
Mean frond density (fronds/m^2)	7.0±1.8	1.7±0.4	48.0±3.3
Mean frond height (cm)	22.4±4.6	39.4±4.8	51.2±8.4
Frond height range (cm)	23-66	2-48	18-79

and height than those untreated, but frond densities were greater at the front, although heights were greater in the hinterland (Table 2.3). Clearly, the asulam spraying at this site was not as effective as it might have been, and this may have resulted in less clear cut results in both deposition and damage.

2.3.4 Experiment 4: Wooler, Northumberland

The amount of lithium in the tank mix was estimated from two replicate samples analyzed at Monks Wood and one sample analyzed by NRA. There was considerable variation in the replicate analyses (Monks Wood 300 and 722 mg/litre and NRA 367 mg/litre; mean ± S.E. 463±131). This discrepancy was not because of analytical errors and it is presumed that these differences are because of difficulties in sampling as the materials were mixed. However, it is evident the intended concentration of 855 mg/litre was not achieved and it is likely that either the spray volume was under estimated or that the lithium sulphate did not fully disperse.

Deposition on the water sensitive papers (Figure 2.10) shows a rapid exponential decline as in previous studies. The distance at which 10% of deposition under the sprayer was found to be 20 m. Nevertheless, 0.56% of the applied rate was found at 180 m.

Lithium deposition on the hair curlers showed a similar pattern (Figure 2.11), dropping to 10% of amounts under the sprayer at 32 m. Very low amounts were detected on these collectors beyond 50 m and there was no detectable lithium found beyond 160 m (0.06 ± 0.003 µ.g Li at 160 m, approximately 0.7% of the amount detected under bracken 8.4 ± 0.6 µg Li).

Lithium deposition on the water sensitive papers showed a slightly different pattern; the same general decline was found up to 20 m, but thereafter there was an almost constant deposition up to 180 m (Figure 2.12). At 180 m 0.64 µg Li was detected, 6% of the amount detected under the sprayed area (10.2 ± 1.9 µg Li).

Both measures of *Rumex* damage showed effects under the sprayer, with a rapid change downwind to approximately 50 m (weight) and 100 m (leaf damage) (Figures 2.13, 2.14). Thereafter the relationship appeared to reach an asymptote, which in both cases was different from the untreated bioassay plants. This result suggests that a damaging effect occurred up to 180 m, the maximum distance tested.

Damage to the *Adiantum* showed a similar response to *Rumex* (Figures 2.15, 2.16) reaching asymptotes at 50 m (dry weight) and 100 m (height). The height measures were lower, but the weights were in the same order of magnitude (from 50 m downwind), as unexposed plants.

Deposition measures were all highly correlated with each other ($r > 0.90$; $\underline{P} < 0.001$). Correlations between all measures of damage were also highly significant with each other and with measures of deposition (Table 2.4).

The absolute amounts of asulam that were deposited and caused the phytotoxic effects at 180 m can be estimated from the amounts of lithium deposited on the water sensitive papers. Application concentrations were 100 g asulam/litre and 463 mg lithium/litre (the mean value for tank mix concentration was used). Assuming that the behaviour of asulam and the lithium in the drift was the same, this means that 1 mg of lithium was the equivalent of 0.216 g of asulam (1 µg lithium equivalent to 0.216 mg asulam). As 0.64 µg lithium was detected on the water sensitive papers at 180 m this implies that 0.138 mg of asulam was deposited. As this deposition occurred on a 37.5 cm^2 water sensitive paper the amount per unit area equals 36.9 mg asulam/m^2. This deposition rate is approximately 8% of the theoretical rate of asulam applied (440 mg/m^2).

2.3.4 **Experiment 5: Stable Clough, Derbyshire**

In the two open areas (positions 1 and 8 at the top of the clough where asulam deposition should be at the full recommended dose similar amounts of deposition (c. 4% of the water-sensitive paper) were detected (Table 2.5). On the downwind western half of the clough similar amounts were deposited on the clough side (position 3) and on the clough top under dense bracken (position 2). In other areas (clough bottom (points 4,5), eastern side (position 6) and under bracken on the eastern top (position 7) the deposition was much lower, approximately 25% of the amount found at full exposure (positions 1 and 8).

Damage to *Rumex* was severe in all six situations tested, with > 50% damage found, which was much greater than the 3.5% found in the untreated controls (Table 2.5). The mean percentage damage was highly correlated with mean deposition rates on water sensitive papers (r = 0.95; n=7) and the relationship was described by the following equation:

$$Y_{damage} = 8.45\, X_{drift\ deposition} + 50.24$$
$$(F=50.7; \underline{P}<0.001)$$

An important point to note is that biological damage was found even when the deposition on water-sensitive papers was below the detection limit (c. 0.1% of the water-sensitive paper).

Damage to the *Adiantum* was less clear cut, although a significantly lower yield than the untreated controls was found at all transect points (Table 2.5).

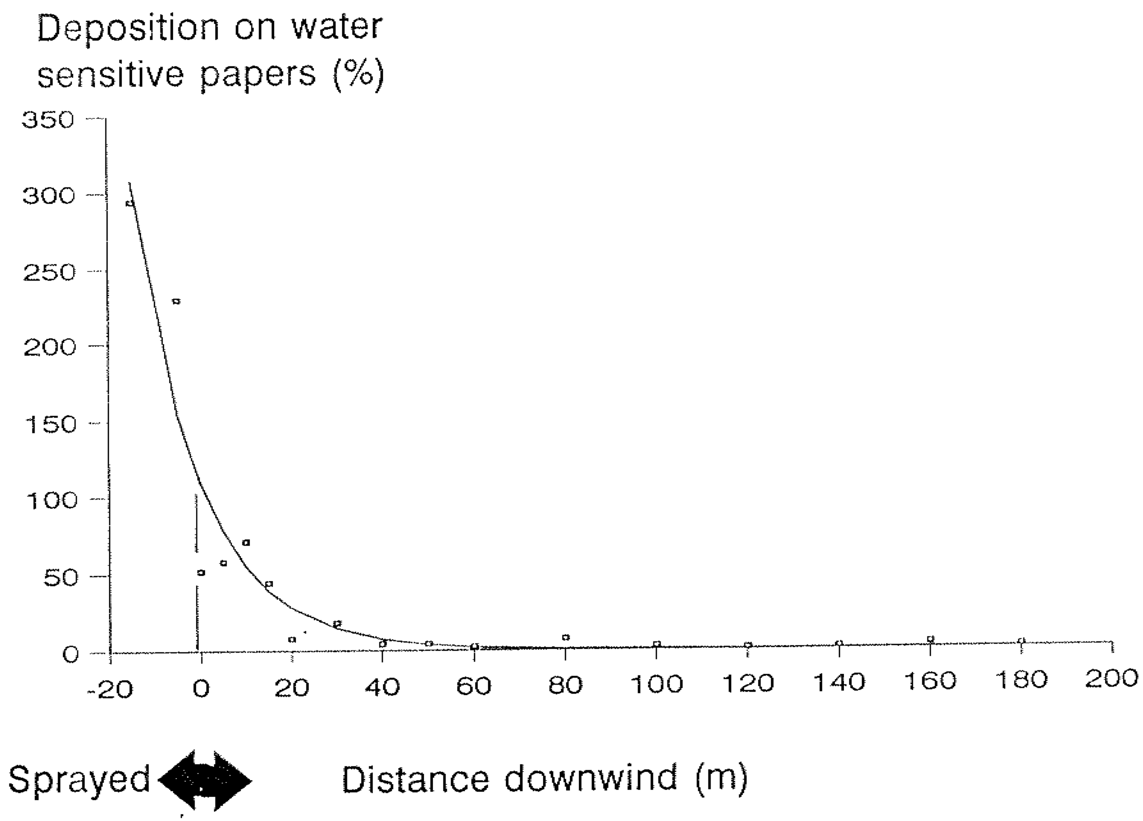

Figure 2.10 Deposition of drift on two pairs of water sensitive papers downwind of the sprayer in the Wooler experiment; the fitted equation is presented in Appendix I.

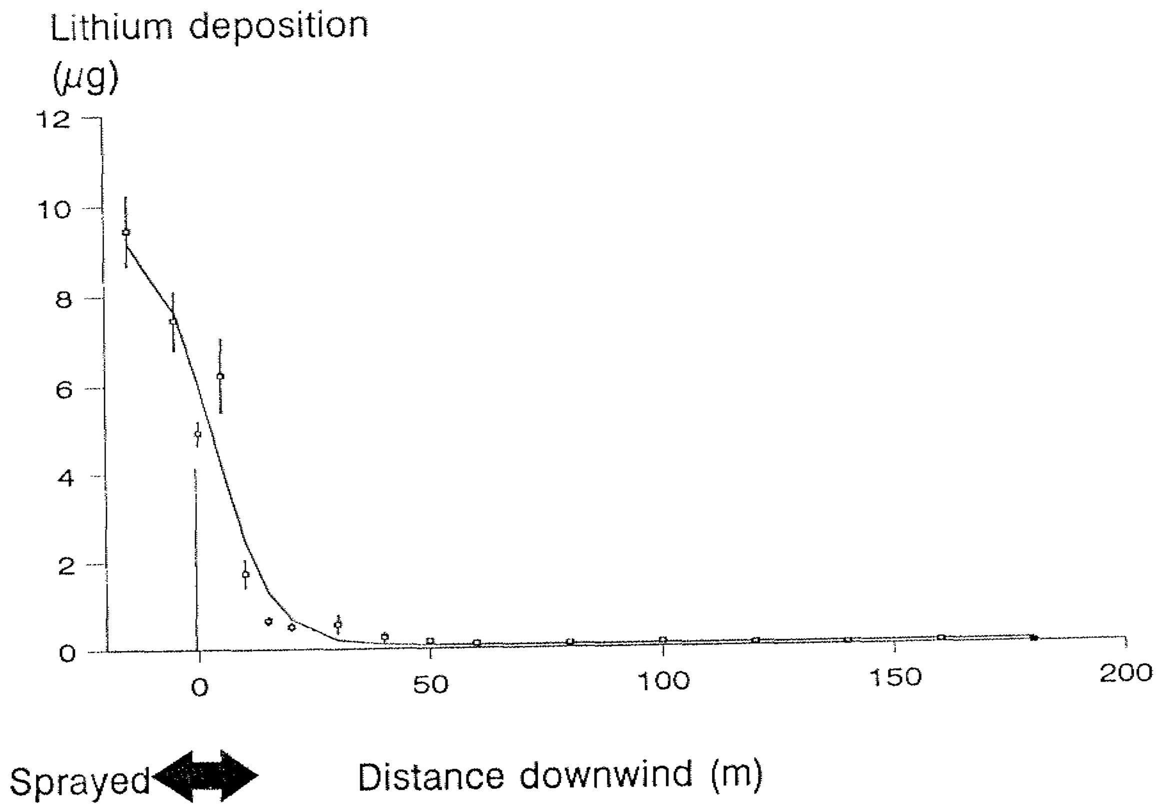

Figure 2.11 Lithium deposition on hair curler collectors downwind of the sprayer in the Wooler experiment; mean values ± S.E. (n=4) are presented and the fitted curve is given in Appendix I.

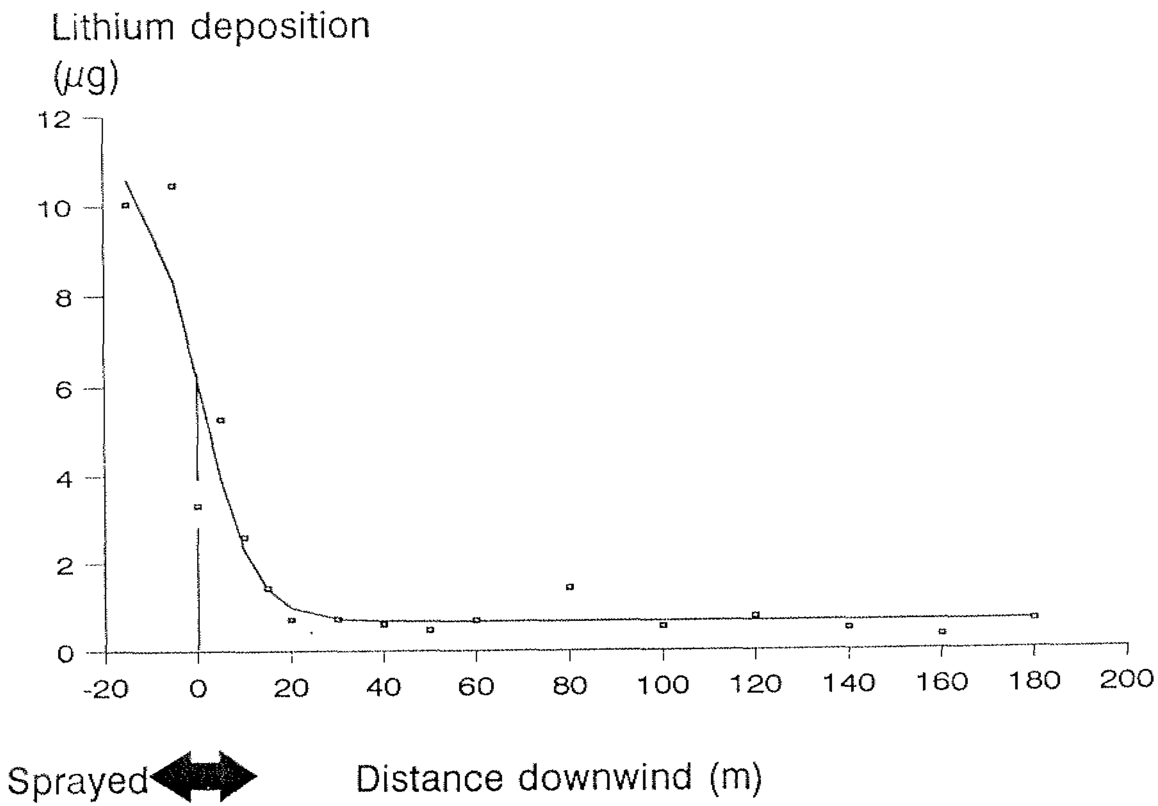

Figure 2.12 Lithium deposition on water sensitive papers downwind of the sprayer in the Wooler experiment; the fitted curve is given in Appendix I.

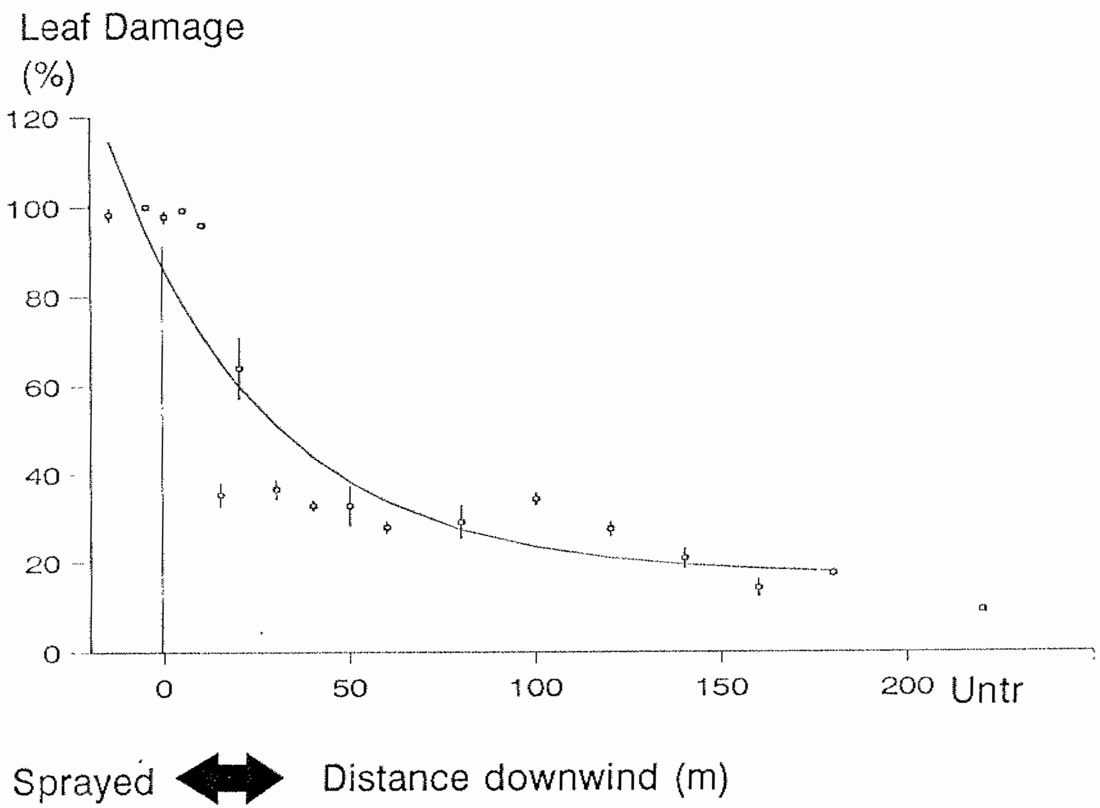

Figure 2.13 Mean leaf damage (± S.E., n=6) to <u>Rumex acetosa</u> downwind of the sprayer in the Wooler experiment and compared to untreated (untr) plants. The fitted curve is given in Appendix I.

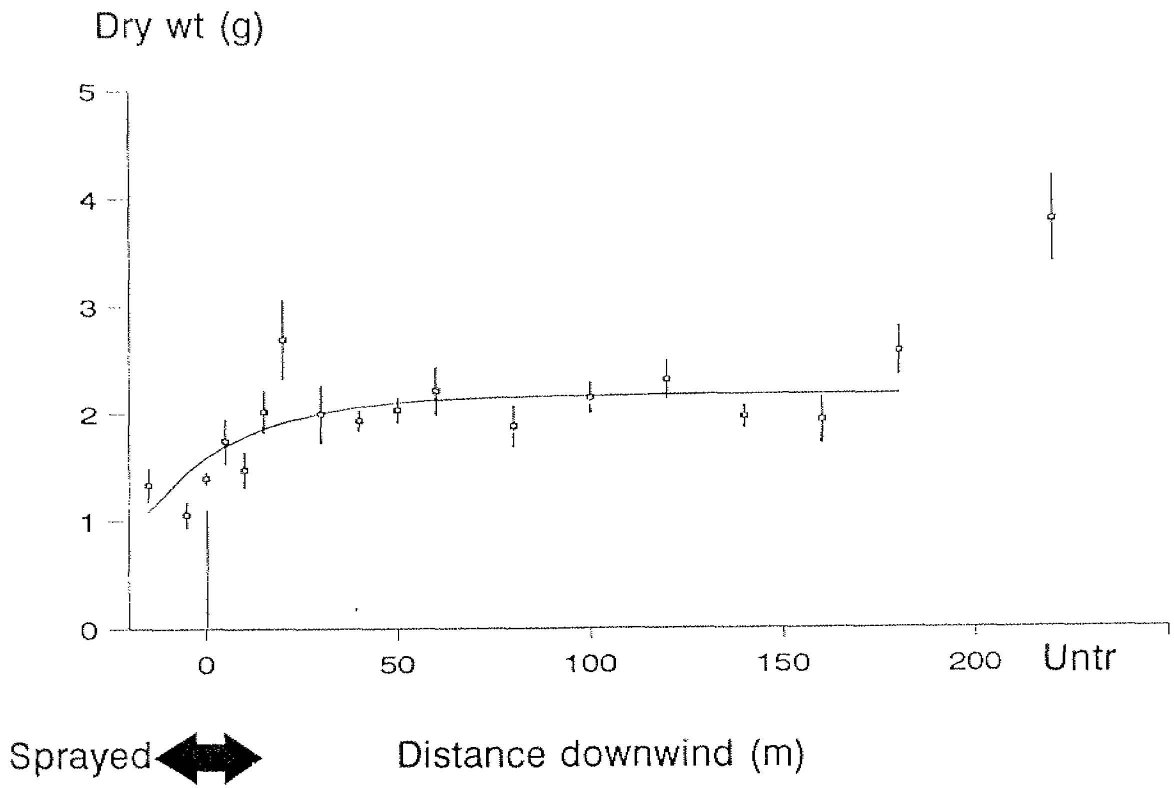

Figure 2.14 Mean shoot weight (± S.E., n=6) of Rumex acetosa downwind of a sprayer in the Wooler experiment and compared to untreated (untr) plants. The fitted curve is given in Appendix I.

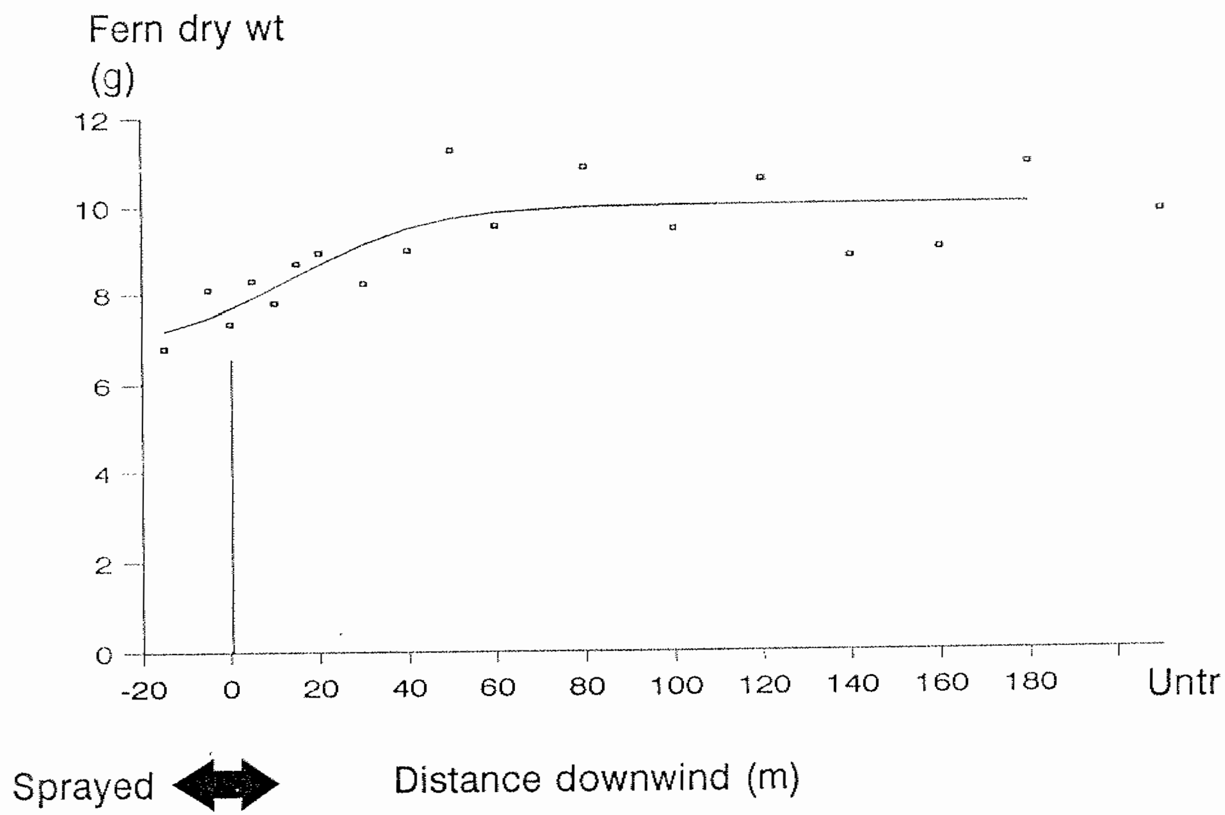

Figure 2.15 Weight of Adiantum pubescens (g) exposed downwind of the sprayer in the Wooler experiment and compared to untreated plants (untr). Fitted curves are given in Appendix I.

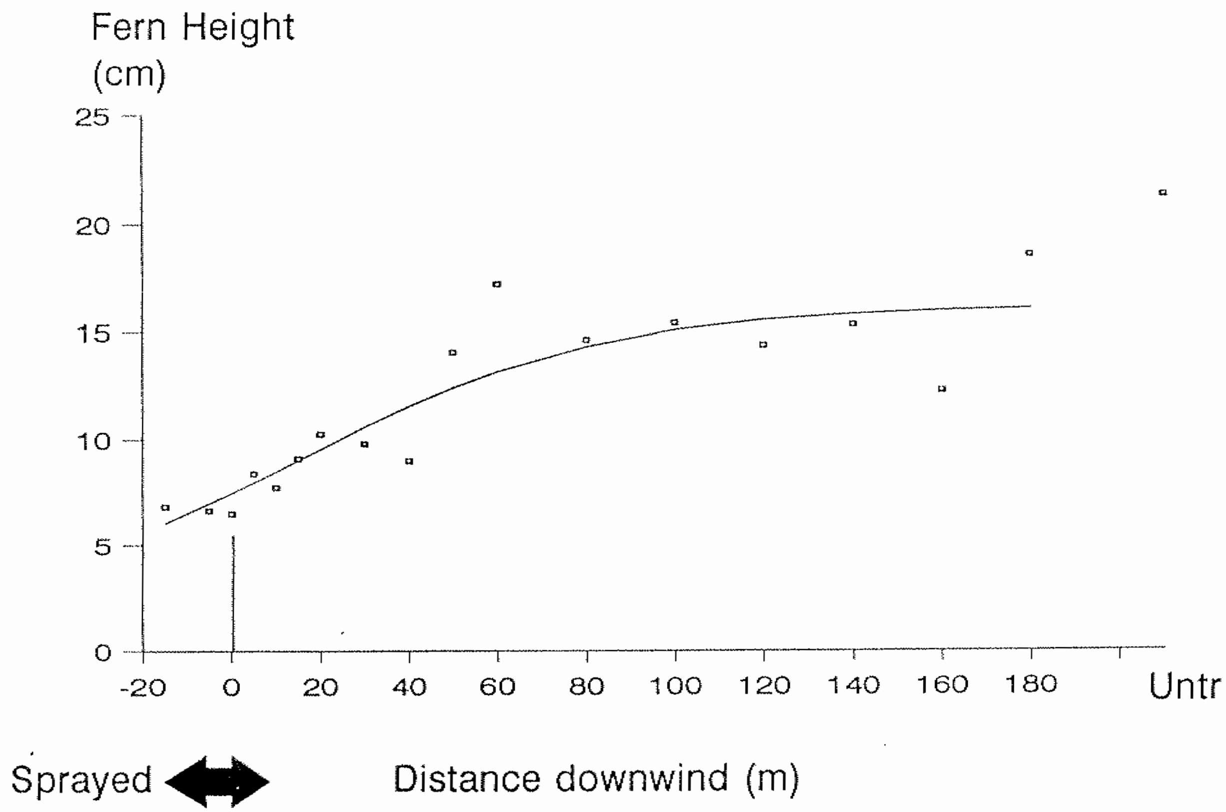

Figure 2.16 Height of <u>Adiantum pubescens</u> (cm) exposed downwind of the sprayer in the Wooler experiment and compared to untreated (untr) plants. Fitted curves are given in Appendix I.

Table 2.4. Correlation coefficients (n=17) between the amounts of drift deposition detected and the measures of damage on bioassay plants in the Wooler experiment (Experiment 4); * = P < 0.05, ** = P < 0.01; *** = P < 0.001; WSP= Water Sensitive Papers.

	Lithium WSP	Lithium Curlers	Drift WSP	*Rumex* Leaf Damage	*Rumex* Dry Weight	*Adiantum* Dry Weight	*Adiantum* Height
Lithium WSP	-	0.9568 ***	0.9604 ***	0.7884 ***	-0.7708 ***	-0.6011 *	-0.6307 **
Lithium Curlers		-	0.9022 ***	0.8650 ***	-0.7593 ***	-0.6898 **	-0.6923 **
Drift WSP			-	0.7140 **	-0.7368 ***	-0.6309 **	-0.6180 **
Rumex Leaf damage				-	-0.7045 **	-0.7309 **	-0.8025 **
Rumex Dry weight					-	0.6576 **	0.7065 ***
Adiantum Dry weight						-	0.8153 ***
Adiantum Height							-

Table 2.5. Deposition of herbicide on water sensitive papers, leaf damage assessment of *Rumex* and dry weight of *Adiantum* at the various positions on the Stable Clough transect (Experiment 5); mean values ± S.E. are presented.

Position on transect across Clough		Deposition on water sensitive papers (%) (n=4)	Damage to *Rumex* (% of leaves damaged) (n=5)	*Adiantum* dry weight (g) n=3)
Top - outside bracken	W	3.6±0.4	77±16	4.0±0.2
- outside bracken	E	4.3±1.0	83±3	4.9±0.1
Top - under bracken	W	4.7±0.5	97±2	4.6±0.2
- under bracken	E	0.8±0.2	50±14	6.1±0.1
Side -	W	5.9±1.3	99±6	3.3±0.1
-	E	0.9±0.1	58±4	4.0±0.3
Bottom - under *Calluna*		0.9±0.3	68±5	5.9±0.5
- in open			64±5	4.6±0.4
Untreated 'controls'		-	3.5±0.4	7.1±0.4