APPENDIX I-I

Species which showed a significant difference in yield and performance between species in the '1988' and '1989' microcosms placed 8 m downwind of the sprayer and those untreated.

'88 Microcosms

Measures	No. of contrasts	Type of response	Year	Species	Grass (+/-)	8m	Untreated	LSD ($P<0.05$)
Yield (ln g+1)	68	+ ve	88	D. purpurea	-	1.853	1.583	0.215
			88	S. sylvatica	-	2.717	2.266	0.413
		- ve	88	L. perenne	+	1.607	2.102	0.479
			90	F. ulmaria	-	0.200	0.367	0.154
			90	P. veris	-	0	0.064	0.061
Performance 89	48							
Shoot no.		+ ve	89	H. hirsutum	-	8.2	3.0	5.02
Leaf no.			89	R. acris	+	19.8	6.6	11.06
Performance 90	16	nd	90	-				
Seed production 90 (ln mg+1)	16	nd	90	-				

'89 Microcosms

Measures	No. of contrasts	Type of response	Herb	Year	Species	Grass (+/-)	8m	Untreated	LSD ($P<0.05$)
Yield (ln g+1)	153	+ ve	MCPA	90	G. urbanum	-	1.391	0.843	0.196
				90	P. veris	+	0.109	0.002	0.104
			Meco	90	L. corniculatus	-	3.745	3.003	0.553
		- ve	Glyp	91	S. dioica	+	2.320	6.336	3.922
				91	C. rotundifolia	-	0.161	1.181	0.611
			Meco	91	C. nigra	+	1.200	2.737	1.059
Performance 90 Flower no.	48	- ve	Meco	90	S. dioica	-	1.303	3.243	1.919
Seed production 90 (ln mg+1)	48	- ve	Meco	90	L. corniculatus	-	4.891	6.507	1.536

APPENDIX I-II

Species which showed a significant difference in the '1988' microcosms when placed directly under a spray boom and exposure to mecoprop. Results are of the contrast between mean at 0 m (0) and the pooled mean of microcosms downwind (1,2,4,8 m), both expressed as a % of untreated. Significance * = P<0.05, ** = P<0.01, *** = P<0.001.

Measures	No. of contrasts	Type of response	Species	Year	Grass (+/-)	0m	Pooled mean (1,2,4,8m)	Significance
Yield	68	0>rest	F. ulmaria	90	-	124	53	*
			H. hirsutum	89	-	4587	158	**
				90	-	164	5	**
			L. perenne	89	+	226	94	***
				90	+	199	95	**
				91	+	255	30	***
			P.veris	91	-	4650	881	*
			S. sylvatica	89	-	472	194	**
		0<rest	F. ulmaria	91	+	780	3713	*
			G. mollugo	89	+	11	110	**
				90	+	18	194	**
				91	+	2	146	**
				88	-	30	71	*
				89	-	0.2	52	**
				90	-	0	19	**
			L. flos-cuculi	89	+	199	95	*
				90	+	63	132	*
				91	+	25	76	*
				88	-	40	87	**
				89	-	21	128	***
				90	-	98	211	***
				91	-	38	354	***
Performance 89								
Stem height	48	0>rest	S. sylvatica	89	-	137	71	**
Shoot no.		0<rest	G. mollugo	89	+	12	125	***
Shoot no.					-	0	95	***
Shoot length					-	0	105	***
Flower stem no.			L. flos-cuculi	89	-	0	92	***
Flower no.					-	0	78	***
Leaf no.			P. veris	89	+	18	99	***
Leaf length					+	24	118	***
Flower stem no.					+	0	77	*
Flower stem height					+	0	81	***
Flower no.					+	0	80	*
Performance 90	16	nd	-	90				
Seed production 90	16	nd	-	90				

APPENDIX I-III

Species which showed a significant difference in the '1989' microcosms when placed directly under a spray boom and exposure to glyphosate (Glyp), mecoprop (Meco) and MCPA. Results are of the contrast between mean at 0 m (0) and the pooled mean of microcosms downwind (1,2,4,8 m), both expressed as a % of untreated. Significance * = $\underline{P}<0.05$, ** = $\underline{P}<0.01$, *** = $\underline{P}<0.001$.

Measures	No. of contrasts	Type of response	Species	Herb	Year	Grass (+/-)	0m	Pooled mean (1,2,4,8)	Significance
Yield	153	0>rest	C. rotundifolia	Glyp	89	+	255	61	**
					90	+	288	53	*
				MCPA	90	+	204	74	*
					91	+	2527	166	*
				Meco	91	-	1633	99	***
			L. corniculatus	Meco	89	+	143	89	*
			L. perenne	MCPA	90	+	157	86	**
					91	+	592	142	***
				Meco	89	+	218	71	***
					91	+	482	111	***
			P. veris	MCPA	89	-	249	63	**
		0<rest	C. nigra	Glyp	90	+	1	125	**
					91	+	0	32	**
					90	-	14	122	*
			D. purpurea	Glyp	89	+	6	124	***
					89	-	33	117	*
			F. ulmaria	Glyp	91	-	17	145	*
					90	-	1	125	*
			G. urbanum	Glyp	91	+	46	142	**
			L. corniculatus	Glyp	89	+	35	117	*
					91	+	14	149	**
					91	-	7	143	**
				MCPA	91	+	2	341	**
					90	-	0	125	***
					91	-	1	234	*
			S. dioica	Glyp	89	+	14	122	***
					90	+	15	121	*
					91	+	6	37	**
				MCPA	89	+	41	115	***
				Meco	89	+	7	123	***
					89	-	26	118	***
					90	-	22	119	**
Performance 90	48	0>rest	S. dioica	Meco	90	-	7	47	**
Seed production	48	0>rest	G. urbanum	MCPA	90	-	20	2	***

APPENDIX I.IV

Significant regression equations (n=25) between (a) yield and (b) performance in 1989 and distance downwind of the sprayer in the '1988' microcosms. Significance * = P<0.05, ** = P<0.01, *** = P<0.001.

(a)

Species	Grass (+/-)	Year	Int	b1	b2	r^2	F	Significance
F. ulmaria	+	91	52.0	285.7	-35.7	0.35	4.65	*
G. mollugo	+	89	41.5	45.7	-5.2	0.33	4.3	*
	+	90	62.7	95.5	-10.8	0.38	5.2	*
	+	91	-47.0	130.2	-13.3	0.65	15.6	**
	-	91	-11.0	54.5	-5.5	0.40	5.8	*
L. perenne	+	89	192.0	-55.2	5.5	0.46	7.4	**
	+	90	157.8	-13.9	-	0.27	6.6	*
	+	91	124.0	-17.8	-	0.40	5.8	*
L. flos-cuculi	+	90	55.4	16.2	-1.4	0.34	4.4	*
	-	88	61.3	5.6	-	0.22	5.2	*
	-	89	25.1	55.3	-4.9	0.70	26.1	***
P. veris	+	88	7.2	32.6	-3.5	0.41	5.8	*
	+	89	6.0	2.8	-	0.29	7.5	*
R. acris	+	90	47.0	18.3	-	0.45	14.5	**
S. sylvatica	+	89	627.7	-62.5	-	0.42	13.2	**

(b)

Species	Performance measure	Grass (+/-)	Int	b1	b2	r^2	F	Significance
D. purpurea	Leaf length	+	-3.1	11.8	-	0.21	6.2	*
	Flowering stem height	+	-13.1	19.6	-	0.21	6.2	*
G. mollugo	Stem no.	+	9.8	47.5	-4.1	0.58	15.2	***
		-	18.1	37.2	-3.8	0.40	7.5	**
	Stem length	-	8.7	41.8	-3.8	0.61	16.7	***
H. hirsutum	Stem no.	-	386	-147	15.0	0.27	4.0	*
	Stem length	-	358	-159	18.4	0.59	15.9	***
L. flos-cuculi	Flowering stem height	+	4.7	14.7	-0.8	0.31	5.0	*
		-	6.3	34.1	-2.9	0.81	47.4	***
	Stem no.	+	7.3	23.4	-	0.17	4.7	*
		-	21.3	10.4	-	0.43	17.3	**
	Flower no.	+	22.4	14.0	-	0.46	19.6	**
		-	26.8	12.0	-	0.40	15.6	**
P. veris	Leaf no.	+	14.4	38.4	-3.5	0.56	13.8	**
		-	37.8	6.2	-	0.20	5.9	*
	Leaf length	+	57.5	10.5	-	0.26	8.0	**
	Flowering stem no.	+	3.7	32.8	-3.0	0.27	4.1	*
		-	10.9	15.9	-	0.46	19.3	**
	Flowering stem height	+	20.3	11.0	-	0.38	14.3	**
		-	30.1	7.7	-	0.20	5.9	*
	Flower no.	+	17.8	11.6	-	0.21	6.1	*
		-	10.4	14.3	-	0.39	15.0	**
R. acris	Flowering stem height	+	9.3	18.0	-	0.28	8.7	*
S. sylvatica	Stem no.	+	174	-13.3	-	0.30	9.7	*

APPENDIX I-V

Significant regression equations (n=25) between yield and performance measures and distance downwind of the sprayer in the '1989' microcosms. Significance * = P<0.05, ** = P<0.01, *** = P<0.001; Glyp=glyphosate and Meco=mecoprop.

Measure Herb	Species	Grass (+/-)	Year	Int	b1	b2	r^2	F	Significance
Yield									
Glyp	C. rotundifolia	+	89	158.0	-19.3	-	0.16	4.3	*
	C. nigra	+	89	33.9	22.0	-	0.38	13.8	**
		+	90	51.9	16.0	-	0.22	6.4	**
		+	91	-2.2	9.2	-	0.68	13.4	*
	D. purpurea	+	89	20.1	65.9	-6.9	0.58	15.1	***
	G. urbanum	+	90	64.5	11.8	-	0.34	11.8	**
	S. dioica	+	89	59.6	13.4	-	0.40	15.4	***
	C. nigra	-	89	58.3	13.9	-	0.19	5.2	*
	L. corniculatus	-	89	60.0	14.7	-	0.24	7.2	**
	S. dioica	-	90	52.9	42.4	-4.7	0.24	3.5	*
		-	91	3.6	5.9	-	0.37	13.4	**
MCPA	C. rotundifolia	+	90	175.1	-71.4	8.2	0.29	4.6	*
		+	91	1829.9	-876.8	84.1	0.29	4.49	*
	C. nigra	+	90	67.0	10.9	-	0.30	10.0	**
	L. perenne	+	90	158.8	-42.1	4.0	0.36	6.1	**
		+	91	526.8	-217.1	21.0	0.48	10.4	***
	L. corniculatus	+	91	-50.3	288.4	-31.8	0.40	7.2	**
	P. veris	+	89	15.0	28.3	-	0.27	8.7	**
		+	90	8.0	30.6	-	0.21	6.2	*
		+	91	52.6	20.6	-	0.37	8.3	**
	S. dioica	+	89	48.4	41.2	-4.2	0.52	12.1	***
		+	91	52.6	20.6	-	0.37	13.5	***
	C. rotundifolia	-	90	144.5	-77.3	11.0	0.29	4.6	*
	F. ulmaria	-	90	39.8	20.1	-	0.40	15.4	***
		-	91	0.9	102.7	-11.4	0.31	4.9	**
	G. urbanum	-	90	57.8	14.1	-	0.58	32.3	***
	L. corniculatus	-	89	63.7	12.1	-	0.26	8.0	**
		-	90	10.3	58.3	-5.0	0.56	14.2	***
	P. veris	-	89	167.8	-22.6	-	0.22	6.7	*
Meco	C. nigra	+	89	21.0	62.0	-6.3	0.31	4.9	**
	D. purpurea	+	90	-68.6	167.9	-19.7	0.27	4.1	*
	F. ulmaria	+	89	141.3	-13.8	-	0.18	5.1	*
	G. urbanum	+	91	389.3	-141.1	13.5	0.45	8.94	**
	L. perenne	+	89	186.9	-58.8	5.3	0.58	15.2	***
		+	90	148.7	-43.0	4.7	0.44	8.6	**
	S. dioica	+	90	48.9	40.2	-4.1	0.33	5.6	**
		+	91	1.0	5.21	-	0.23	7.0	**
	C.rotundifolia	-	91	1217.9	-627.8	63.1	0.41	7.5	**
	C. nigra	-	89	59.1	13.6	-	0.34	12.1	**
	F. ulmaria	-	90	19.2	26.9	-	0.25	7.7	*
	S. dioica	-	89	53.0	40.6	-4.4	0.43	8.3	**
		-	90	66.2	11.2	-	0.18	5.0	*
Performance 90									
Glyph	C. nigra	+	90	100.0	40.0	-	0.16	4.4	*
MCPA	L. corniculatus	+	90	63.6	-5.2	-	0.17	4.6	*
Meco	S. dioica	-	90	5.2	28.2	-3.0	0.27	4.1	*
Seed Yield 90									
Glyph	C. nigra	+	90	42.0	46.2	-	0.29	9.3	**
MCPA	G. urbanum	-	90	15.0	-7.6	0.7	0.35	5.7	**

2 EFFECTS OF AERIAL SPRAYING WITH ASULAM

R H Marrs, A J Frost, R A Plant & P Lunnis

2 EFFECTS OF AERIAL SPRAYING WITH ASULAM

2.1 DETERMINATION OF BUFFER ZONES AROUND SENSITIVE SITES WHERE ASULAM IS SPRAYED FROM THE AIR TO CONTROL BRACKEN

There has been increasing concern for many years that herbicide spray drift from agricultural, forestry and other treated land can affect plant species growing on adjacent nature reserves. Two situations pose particularly severe problems: (1) where nature reserves are part of a mosaic of patches within a landscape where large areas of 'weeds' are to be treated, and (2) where aerial applications are made.

In Britain the control of bracken (Pteridium aquilinum) 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 or semi-natural communities. 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 838 ha in 1981 to 5292 ha in 1990 (Sly & Neale, 1983; MAFF, pers. comm.). 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, unpub.). Therefore, for the protection of nature reserves near bracken-treated areas, it is essential that a safe 'buffer zone' distance is estimated, so that sensitive sites can be protected by spray-free areas.

Here, we use an experimental field bioassay approach, using plants sensitive to asulam, to make a first approximation of the size of the buffer zone needed.

2.1.1 **Methods**

(a) Plant propagation

Rumex acetosa L. (common sorrell) was the test plant used in this study as it had already been shown to be susceptible to asulam drift in pilot studies (Marrs, Frost & Plant, 1990). After 2-3 weeks the leaves of affected plants show severe chlorosis, followed in some instances by necrosis and death. Seeds of Rumex acetosa were sown in January 1990 and then potted individually into 7 cm x 7 cm x 8 cm pots containing SAI GP compost. Six pots were then placed in seed trays for bioassay use in the field. The developing flowering stems were cut to prevent premature dormancy, and at the time of spraying the plants had between 10-40 mature leaves.

(b) Experimental layout

A map of the experimental area at Bamford Edge in Derbyshire (National grid reference SK 214842) is shown in Figure 2.1. 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 study site, eight transects each 2 m apart, were laid out at right angles downwind of the bracken front into the moorland on 22 July (Figure 2.1). 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. On two transects water-sensitive papers were placed to provide a crude assessment of spray drift deposition using the method of Sinha, Lakhani & Davis (1990). Twelve trays of Rumex acetosa were kept as untreated 'controls', these plants were treated in an identical manner to treated ones except that they were not exposed to asulam on the transects.

The spraying was done by a commercial operator as part of a wider bracken control programme within the North Peak Environmentally Sensitive Area (ESA). Asulam was applied by a Bell 47G3B1 helicopter at a height of between 5-10 m and a rate of 4.4 kg a.i. ha^{-1} (11 litres Asulox ha^{-1}) in 44 litres ha^{-1} spray containing a 0.1% non-ionic wetter (Agral). A 12 m boom was used fitted with 72 Raindrop 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 2.1) starting at the upper edge and moving down the slope. During the spraying wind speed and direction was continuously monitored using a Vector Instruments R500 recording anemometer. The wind direction was constant, and was from the south-east. Wind speed varied between 6-10 m s^{-1} at a height of 2 m. There was no rain during the spraying period.

After spraying, the plants were left in situ for 2 hours to dry, before transfer to Monks Wood Experimental Station. The Rumex

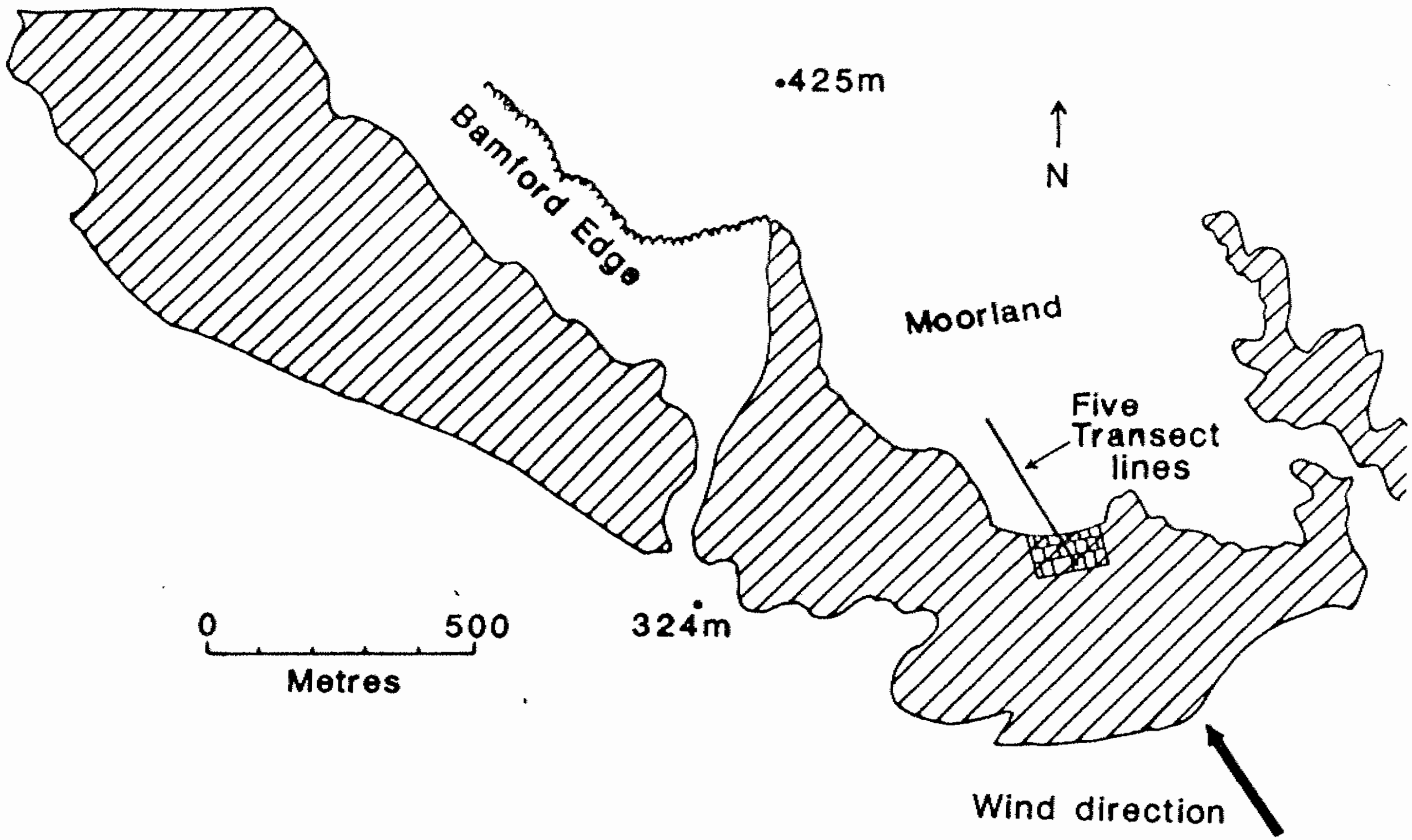

Figure 2.1. Schematic map of the study area showing the bracken area (hatched), and the approximate position of (1) the five transects and (2) the sprayed area (double hatched).

plants were placed on a sand bed outside and given an appropriate horticultural watering regime.

After three weeks each individual plant was assessed visually for damage by counting (1) the total number of leaves, and (2) the number of these leaves which were showing chlorotic or necrotic symptoms. The percentage of leaves damaged at each transect point was then calculated based on the six replicate individuals in each tray.

2.1.2 Results

Drift deposition and damage to the Rumex acetosa test plants declined with distance downwind of the sprayer (Figures 2.2, 2.3). Logistic equations fitted to these data using the Maximum Likelihood Program (Ross, 1980) gave the following equations, which were used to estimate safe buffer zone distances:

$$Y_{drift} = 0.44206 + \frac{116.08568}{1+e^{0.09502(x-8.48837)}}$$

(n=17; df=13; r^2=0.71)

$$Y_{damage} = 3.41984 + \frac{95.32509}{1+e^{0.05693(x-84.01972)}}$$

(n=136; df=132; r^2=0.99)

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 with this method 0.2% of the applied rate was detected 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.

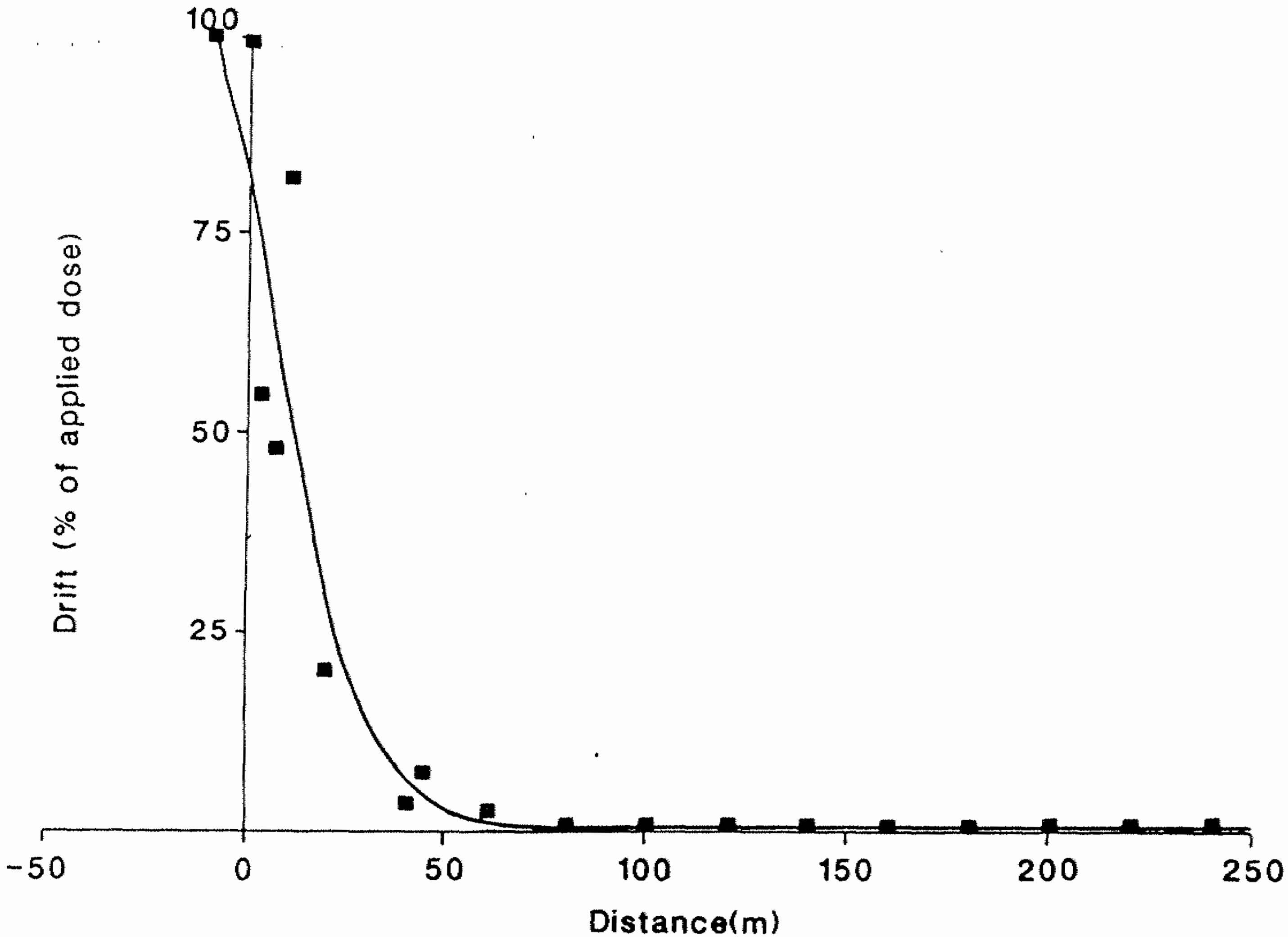

Figure 2.2. Mean deposition of visible spray on pairs of water sensitive papers, expressed as a % of deposition at the 0m position, and a logistic curve fitted to these data, in the bioassay study at Bamford Edge Derbyshire.

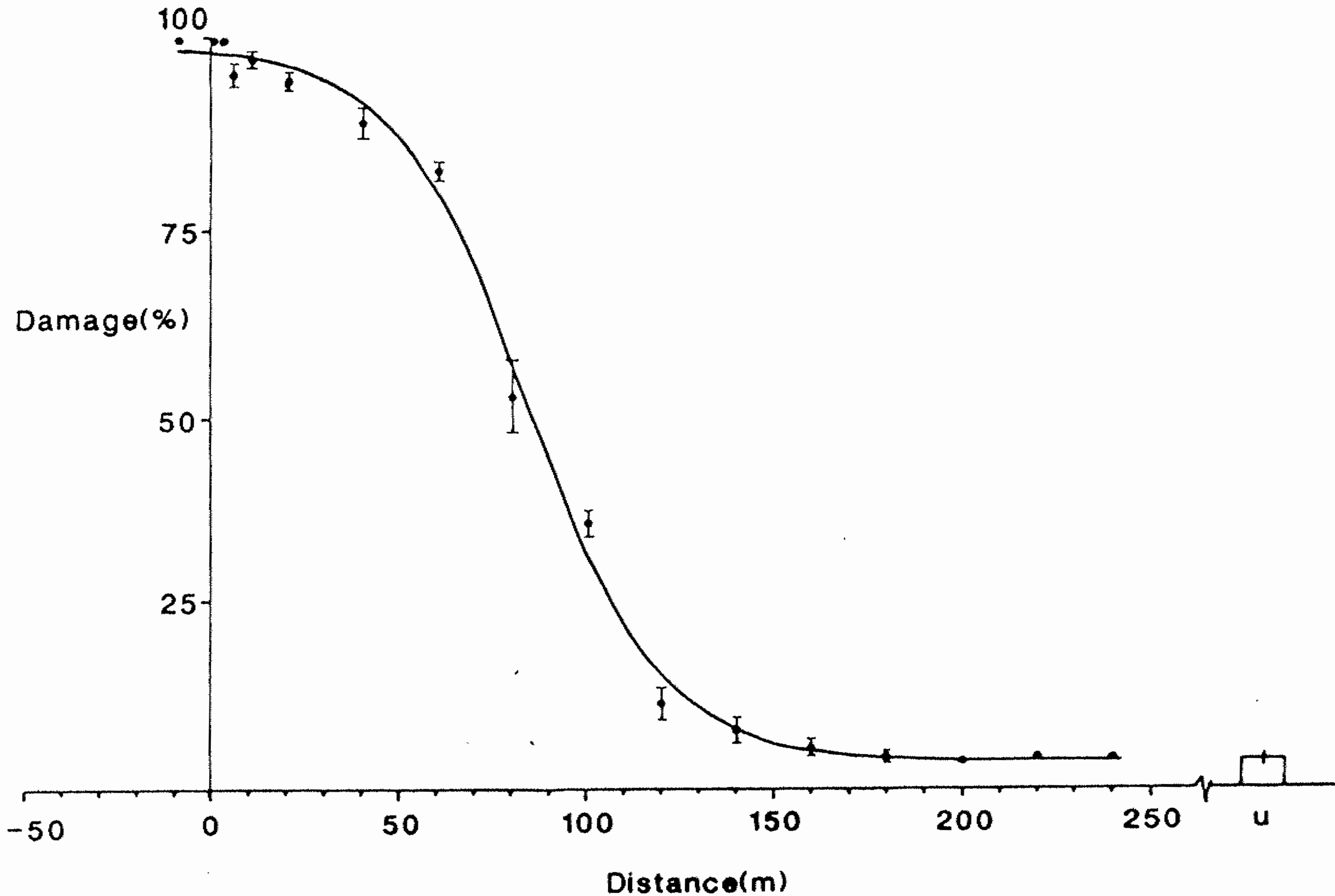

Figure 2.3. Mean values ± standard errors (n = 8) for leaf damage on test plants (<u>Rumex acetosa</u>) caused by asulam downwind of a sprayer, and a logistic curve fitted to these data, in the bioassay study at Bamford Edge, Derbyshire. The mean values ± standard errors (n = 12) for untreated controls (u) are also presented for comparison.

2.1.3 Discussion

As expected, there was a rapid fallout of large spray droplets, with few droplets detectable using water sensitive papers extending past 33 m. However, a few large droplets and smaller ones, which were not detected using our simple monitoring system, caused damage up to a predicted no-effect level of 161 m from the sprayed zone. Thus a buffer zone in the order of >160 m is required to protect sensitive upland plants from asulam spray drift, when the herbicide is applied from the air. This buffer zone requirement is much greater than for herbicide applications from ground sprayers. A buffer zone of 6-10 m was considered adequate to protect a range of established perennial species from four herbicides applied by tractor-mounted hydraulic sprayers (Marrs, Frost & Plant, 1989) and 20-30 m was suggested for the protection of fish from glyphosate applied from the air (Payne, Feng & Reynolds, 1990).

There are several additional points to make about this study. Native fern species may be more or less sensitive than the test species Rumex acetosa, but we chose this species because (1) it is very sensitive to asulam drift showing obvious symptoms of damage a few weeks after treatment, and (2) it can be propagated easily in large numbers. It would, obviously be impractical to consider collecting rare fern species from nature reserves in the numbers required for bioassay studies of this type. However, we included a small number of commercially-available ferns in this experiment, as in the pilot trial reported in the 1990 report. The results were generally similar but were much more difficult to interpret, partly because the damage takes much longer to appear (sometimes over-winter), and herbicide damage can be confounded with damage from other sources (frost, temperature control and water supply). It is of course possible that sub-lethal effects on species with extreme sensitivity to asulam extends beyond the distance detected here. Moreover, only leaf damage a few weeks after exposure has been assessed here, no account has been made of subtle damage which may influence population performance, for example fecundity and survivorship in communities where the competitive balance between species has potentially been altered by asulam drift. We did some preliminary assessments in the year after exposure and most plants appeared to survive. However, recovery occurred in a well protected environment where there was no competition from neighbours. To investigate the impact of asulam drift on native fern populations will required detailed population studies in sprayed and unsprayed situations. Moreover, any damaging effect on the ferns must be weighed up against possible negative effects brought about through bracken encroachment.

In this study only damage downwind of the sprayer was assessed. No account was taken of additional risks associated with the helicopter turning at the end of a swath. When the helicopter reaches the end of a swath the operator switches off the spray, turns, and then switches on again at the start of the next swath. An error at this point could cause the drift to start outside the target zone, and where this might occur the buffer zone may have to be extended. Alternatively, a late-switch on or early switch-off near SSSI buffer zone boundaries could help to increase the protection of these sites.

Clearly, the results obtained apply only to the test situation. The experimental site was at the upper edge of the bracken patch on a sloping plateau site with the wind speed at 6-10 m s^{-1} during spraying. The results may be less severe where the bracken edge is on steep slopes or on flatter ground. Moreover, the wind speed was higher than the limit recommended (<10 knots or <5 m s^{-1}) by MAFF/HSE (1989) for aerial spraying, but the experimental spraying was done by a commercial operator as part of a large bracken control campaign within the North Peak ESA. Thus, even if we consider our buffer zone estimate to be a 'worst case' scenario, it is one that may not be atypical in practice! If wind speeds are lower then added protection will be achieved. It is also worth noting that the >160 m zone is 90 m less than the 250 m buffer currently used in the North Peak ESA scheme for the protection of sensitive sites.

The main need for of accurately determining adequate buffer zones is because of the statutory requirement for aerial spray operators to consult the Nature Conservancy Council when spraying within three-quarters of a nautical mile of a SSSI (FEPA, 1989b). There is, therefore, an opportunity to require at this consultation stage, that a buffer zone is maintained around these sites before the spraying is done. An alternative approach may be to spray bracken patches only to the leeward of sensitive sites. Before this suggestion is implemented, however, it is essential to determine the upwind drift effects.

2.2 DEVELOPMENT OF A TEST FOR ASSESSING ASULAM DAMAGE UNDER FIELD CONDITIONS

Over the last few years there has been considerable disagreement over the policy of using aerial applications of asulam for the control of bracken in upland areas. One of the main concerns is that other ferns, which are often relatively rare, may be affected by asulam use. As most ferns are generally susceptible to asulam (Marrs & Griffiths, 1986; Horrill, Dale & Thomson, 1978), it is likely that these ferns will be damaged or killed, if they are present in sprayed areas, or if they are immediately downwind of sprayed areas. There have, however, been few attempts to assess the effects of asulam use on these ferns under field application conditions.

Within the North Peak Environmentally Sensitive Area (ESA) in Derbyshire, the problems for fern conservation is considerable. The rarer ferns are often found in cloughs, small dissected valleys that cut down from the moorland fells over the escarpments into the lower valleys. However, dense bracken often covers much of the surrounding moorland and extends down the clough sides replacing the moorland vegetation. Initial surveys of some of these cloughs have found seven fern species besides bracken including 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). Preliminary observations of the rarer ferns in the year after asulam use suggests that some of these ferns had been either badly damaged or killed.

There is, therefore, a dilemma between the conservation management required to maintain and enhance moorland communities on the one hand and the conservation requirements of these rare ferns on the other. As a balance has to be struck between these two opposing objectives, there is a need for detailed knowledge on the effects of aerial application of asulam on sensitive species in the types of habitat where these ferns are found. It is possible, for example, that individuals found under dense bracken, or protected by steep slopes or ledges, might not be affected as much as plants found in the open. Moreover, if sensitive areas are to be protected in the future there is the need to develop effective methods of checking for damage arising from aerial spraying campaigns on adjacent land. This policing may be needed for two reasons: first, to provide information to help design improved spraying methodologies, and second for prosecution purposes under the Food and Environmental Protection Act (FEPA, 1989a,b).

This paper attempts to address both of these issues by assessing the deposition of asulam and its effectiveness on bioassay plants in a range of different positions in one of the cloughs sprayed by helicopter with asulam in 1990 within the North Peak ESA. In this study the aim was not to assess asulam drift, rather the consequence of asulam use in an area where ferns were present. Bioassay plants were used in preference to observations on native populations because symptoms of herbicide damage on wild species can often be confounded with damage from other sources, especially if the herbicide damage resulted from sub-lethal doses. Use of standardized material with appropriate untreated controls ensures that effects of other environmental factors are minimized and that any symptoms found can be directly attributed to the herbicide.

2.2.1 Methods

(a) Plant propagation

Rumex acetosa (common sorrell) was the main test plant used here: propagation methods are described Section 2.1. In addition, a smaller number of the non-native fern, Adiantum pubescens was also used in this study. The ferns were obtained from a horticultural supplier in June 1990 and repotted immediately as described above for Rumex.

Seed trays containing six pots of either Rumex or Adiantum were used for bioassays in the field.

(b) Experimental layout

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 for assessment of asulam drift. The transect points were chosen to reflect different types of habitat in the clough where the rarer ferns could persist. These points were arranged from west - east (Figure 2.4) 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

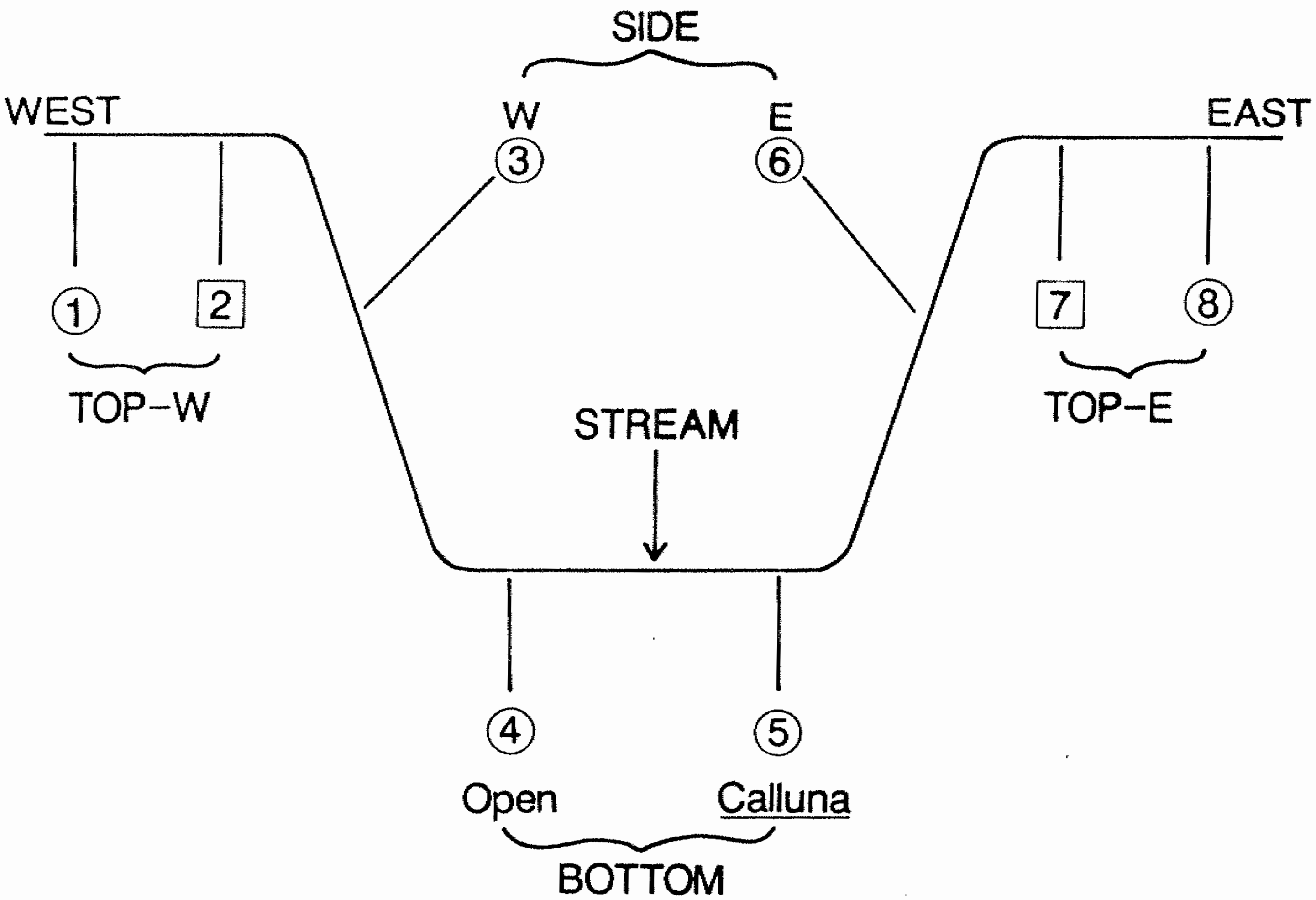

Figure 2.4. Schematic diagram of the transect across Stable Clough showing the eight sampling points. At each point water sensitive papers and trays of bioassay plants were positioned randomly. Circles denote points where there was no vegetation cover, and squared denote points under a dense bracken canopy. The helicopter applied the asulam in a series swaths in a north - south direction, ie at right angles to the transect line.

Five trays of Rumex and three trays of Adiantum, each with six plants, were randomly placed at each of these points immediately before spraying. Twelve trays of Rumex and three trays of Adiantum were kept as untreated 'controls'; these plants were treated in an identical manner to treated ones except that they were not exposed to asulam on the transects.

Four water-sensitive papers were also placed horizontally around each group of bioassay trays (combining positions 4 and 5 at the bottom of the clough) to provide a crude assessment of spray drift deposition (Sinha, Lakhani & Davis, 1990). Four additional papers were placed both inside and outside a patch of Oreopteris limbosperma adjacent to the study.

The spraying was done by a commercial operator as part of a wider bracken control/moorland restoration programme within the North Peak Environmentally Sensitive Area (ESA). Asulam was applied by a Bell 47G3B1 helicopter at a rate of 4.4 kg a.i. ha^{-1} (11 litres Asulox ha^{-1}) in 44 litres ha^{-1} spray containing a 0.1% non-ionic wetter (Agral) and a height of between 5-10 m. A 12 m boom was used fitted with 72 Raindrop nozzles and the tank pressure was 2 bar. The entire clough and its surrounding bracken was sprayed in a series of uphill and downhill swaths parallel to the clough (Figure 2.4). Wind speed and direction was continuously monitored during the spraying period at the top of the Clough using a Vector Instruments R500 recording anemometer. The wind direction was easterly with some gusts from the north-east. Wind speed varied between 2-7 m s^{-1} at a height of 2 m. There was no rain during the spraying period.

After spraying, the plants were left in situ for 2 hours to dry, before transfer 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.

After three weeks 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 percentage of leaves damaged at each transect point was then calculated from the six replicate individuals in each tray.

After six weeks the foliage of all Adiantum plants in each replicate seed tray was harvested, oven dried at 80°C and weighed.

2.2.2 Results

In the two open areas (points 1 and 8) at the top of the clough where asulam deposition should be at the full recommended dose similar amounts of deposition were detected (c. 4% of the water-sensitive paper, Table 2.1). On the downwind western half of the clough similar amounts were deposited on the clough side (point 3) and on the clough top under dense bracken (point 2). In other areas (clough bottom (points 4,5), eastern side (point 6) and under bracken on the eastern top (point 7)) the deposition was much lower, approximately 25% of the amount found at full exposure. The deposition rate within the Oreopteris limbosperma patch was intermediate at 2.7±0.6% and just outside this patch in the open 1.3±0.6%.

Damage to Rumex was severe in all six situations tested, with >50% damage found, which compared with 3.5% found in the untreated controls (Table 2.1). The mean percentage damage was highly correlated with mean deposition rates (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 is predicted even when the deposition on water-sensitive papers is 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 2.1).

Table 2.1. 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; mean values ± standard errors 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

2.2.3 Discussion

A clear result of this study has been that there were considerable differences in the amounts of herbicide deposited in the different positions within the clough. However, even where the lowest amounts of drift deposition were detected, there was still considerable damage to both species of test plant. The patch of Oreopteris limbosperma which was near our study transect also had detectable deposition and it is likely that this patch will be affected by the asulam.

That damage to test plants was detected even where deposition on water-sensitive papers was 25% of the maximum recorded is not surprising, because use of water-sensitive papers is a crude method for detecting drift deposition . Only large droplets are detected, and many of the finer droplets, which can drift further, are below the resolution of this technique. This result, however, confirms those discussed in Section 2.1 where deposition on water-sensitive papers was found up to 30-40 m downwind of an aerial spray application but leaf damage to Rumex up to 161 m. Both studies show that where drift deposition on water sensitive papers can be detected, biological damage to sensitive species is likely to be considerable.

Both deposition and plant damage show a concentration on the downwind edge of the clough, with effects being more pronounced on both the western clough side and the western top under dense bracken than on their eastern upwind counterparts. This result supports the results in Section 2.1 that spraying should only be done downwind of sensitive sites, as this would enable buffer zone distances to be reduced. Further information is required about the spray drift deposition around sensitive sites under a range of different spray application scenarios.

As this method has proved successful in three separate studies, we believe it is a suitable method both for helping to design better spray application strategies around sensitive sites, and for policing aerial applications of asulam on these sensitive sites under FEPA (1989a,b).

2.3 ACKNOWLEDGEMENTS

We would like to thank R. Starbuck, J. Taylor, N. Taylor, and F. Darwent for considerable help in planning these experiments in Derbyshire and East Midlands Region of the Nature Conservancy Council for the use of their Argocat.

2.4 REFERENCES

Clapham, A.R., Tutin, T.G. & Moore, D.M. (1987). Flora of the British Isles, 3rd edn. Cambridge University Press, Cambridge.

Davis, B.N.K. & Williams, C.T. (1990). Buffer zone widths for honeybees from ground and aerial spraying of insecticides. Environmental Pollution, 63, 247-259.

Elliott, J.G. & Wilson, B.J. (eds.) (1983). The Influence of Weather on the Efficiency and Safety of Pesticide Application: the Drift of Herbicides. BCPC occasional publication No.3, BCPC, London.

FEPA (1989a). FEPA, 1985: Control of Pesticide Regulations 1986 - Consent C(i): Use of Pesticides. The London Gazette, 20th January, 784-785.

FEPA (1989b). FEPA, 1985: Control of Pesticide Regulations 1986 - Consent C(ii): Aerial Application of Pesticides. The London Gazette, 20th January, 784-785.

Horrill, A.D., Dale, J. & Thomson, A. (1978). Asulam - its effects on selected plants, plant communities and animals. (NERC contract report to Nature Conservancy Council). Institute of Terrestrial Ecology, Grange-over-Sands.

MAFF/HSE (1989). Pesticides 1989. MAFF reference book 500. HMSO, London.

Marrs, R.H., Frost, A.J. & Plant, R.A. (1989). Assessment of the effects of herbicide spray drift on a range plant species of conservation interest. Environmental Pollution, **59**, 71-86

Marrs, R.H. & Griffiths, F.M. (1986). Terrestrial herbicides. In: The use of herbicides on nature reserves. (ed. A.S. Cooke), pp. 13-64. (Focus on Nature Conservation No. 14). Nature Conservancy Council, Peterborough.

Marrs, R.H., Frost, A.J. & Plant, R.A. (1990). Effects of herbicide drift on higher plants. In Pesticide drift and impact (ed. B.N.K. Davis), pp. 3-50. (NERC contract report to NCC/DOE). Institute of Terrestrial Ecology, Huntingdon).

Payne, N.J., Feng, J.C. & Reynolds, P.E. (1990). Off-target deposits and buffer zones required around water for aerial glyphosate applications. Pesticide Science, **30**, 183-198.

Ross, G.J.S. (1980). MLP: maximum likelihood program. Rothamsted Experimental Station, Harpenden.

Sinha, S.N., Lakhani, L.K. & Davis, B.N.K. (1990). Studies on the toxicity of insecticidal drift to the first instar larvae of the Large White butterfly (Pieris brassicae L.) (Lepidoptera: Pieridae). Annals of Applied Biology, **116**, 27-41.

Sly, J.M.A. & Neale, M.C. (1983). Aerial Spraying, Great Britain 1981. (ADAS Survey Report No. 24). MAFF, Alnwick.

Williams, C.T., Davis, B.N.K., Marrs, R.H. & Osborn, D. (1987). Impact of Pesticide Drift. NERC contract report to NCC, Institute of Terrestrial Ecology, Huntingdon.