Aerial Application of Insecticide against Pine Beauty Moth

Edited by AV Holden and D Bevan

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PREFACE

The extensive spraying of Lodgepole pine forests in northern Scotland with fenitrothion, to control outbreaks of Pine beauty moth, were first carried out in 1978. A report on the various studies made by a number of organisations into the effects of the spraying, both on the target species and on other components of the environment including man, was published by the Forestry Commission in 1979 *(Control of Pine Beauty Moth by Fenitrothion in Scotland,* edited by A.V. Holden and D. Bevan).

During 1979, further spraying operations were necessary using the ultra-low-volume technique, and the monitoring operations were undertaken partly to confirm the observations of the previous year, but also, in some instances, to provide additional information on the extent of dispersion of the insecticide spray and its effect on the non-target species.

This report, in common with that published on the 1978 operation, is assmbled from a series of individual reports written by the scientists and technicians from several organisations which participated in the monitoring operations, mostly conducted in one particular forest area (Craigellachie Forest). Particularly important were the trials at the Annabaglish section of Bareagle Forest in south-west Scotland to study the relationships between droplet size, chemical dosage, larval mortality, defoliation and drift through the crop canopy. The reports were presented at a meeting held in Edinburgh in November 1979 to discuss the results of the spraying operations and consider the necessity for any future monitoring. The various authors kindly agreed to allow these reports to be used subject to revision, and with the minimum of editing, but with an approach to uniformity of presentation, to provide as complete a record as possible of the 1979 spraying operation.

As with the previous report, it should be understood that both the acquisition of the field data and the production of the reports was achieved with severe restrictions on the time and personnel available for the operations, but it is hoped that this document will be of value to those involved in planning or implementing similar spraying operations in the future.

SUMMARY AND MAIN CONCLUSIONS

The 1978 spraying programme had demonstrated that, in most instances, a very effective control of Pine beauty moth infestation had been achieved by ultra-low-volume aerial spraying which had technical advantages over conventional LV spraying. There was no evidence of serious adverse effects on terrestrial or aquatic wildlife as far as could be demonstrated by the various studies made on non-target insects, aquatic invertebrates, fish, birds and small mammals, and no risk to humans in the spray areas. With the exception of one corner of the Strathy block of the Naver Forest, apparently due to inadequate spray coverage, satisfactory control was achieved in all eighteen blocks treated. However, new areas of high infestation were identified by pupal counts in autumn 1978 in Shin and Torrachilty Forest in northern Scotland, Craigellachie Forest in eastern Scotland and Bareagle Forest in south-west Scotland.

Limited clearance was given under the Pesticides Safety Precautions Scheme for the use of the ULV technique in 1979, subject to various restrictions and conditions. These included a minimum distance of 500 m from habitations, the temporary closure of two public roads, the monitoring of the environment and of the pilot of the plant carrying out the spraying.

The applied dosage rate of fenitrothion used in most areas was 300 g active ingredient per hectare, as in 1978, but a reduced dosage of 75 g/ha on two occasions two days apart, at an increased lane separation of 200 m, was applied on 36 ha of Bareagle Forest in an attempt to reduce spraying costs. One area of the same forest was also sprayed at 150 g/ha, again in an attempt to reduce the cost of insecticide, but both areas were found subsequently, by pupal counts, to have been less effectively controlled than areas receiving the full dosage of 300 g/ha.

The main investigations were carried out at the Elchies section of Craigellachie Forest. Here the spray drift was observed to extend up to one kilometre both laterally and downwind, but 95 per cent of the insecticide was estimated to have been deposted in the target zone. The measured droplet densities on the foliage were consistent with the finest droplet spectrum expected from the Micronair sprayers. However, the dosage on the needles decreased from tree top to tree base by factors of 20 to 300 depending on wind speeds, the tops being more strongly dosed at higher wind speeds. This variation in deposit dosage indicated that larval mortality varied with dosage. Larval mortality did not appear to result from direct impact of the droplets.

There was no evidence of any adverse effects on the human population in the spray area, or of any short-term effects in the pilot of the plane.

The measurements of ground deposition indicated that the spray was applied with considerable accuracy, and the tree foliage had trapped about 90 per cent of the spray droplets. The level of ground contamination was very low in the forest, and outside the forest boundary extended only to 50-100 m.

No effects were observed on fish in the stream studied at Elchies, and no fish were displaced. Fenitrothion was ingested in food and absorbed through the skin but was lost from the body as the concentration in the water decreased. Invertebrate drift increased by displacement rather than mortality. The aqueous concentrations of fenitrothion in the stream were low, a maximum being recorded immediately after spraying, but the concentration decreased to below 3 per cent of this within 24 hours.

There was difficulty in obtaining sufficient samples of birds for examination, but evidence was obtained to demonstrate that the principal mode of contamination was by contact with the plumage and skin. A significant depression of acetylcholine esterase activity was observed, possibly sufficient to give rise to sublethal effects although birds were seen and heard singing after the spraying. Small mammals were contaminated only on their fur, and direct effects of the insecticide on these mammals were considered unlikely.

As in the 1978 monitoring programme, the overall assessment is that the effects on humans and wildlife were insignificant or non-existent, although spraying operations of this nature require an appropriate degree of caution and the imposition of protective measures to ensure the minimum risk of exposure of the human population where this would otherwise be likely. Consultations should always take place with the appropriate wildlife authorities before spraying is undertaken.

The ULV spray technique again proved successful when the full dosage of 300 g fenitrothion per ha was applied, but a reduction to half of this dosage in either one or two stages was less effective.

INTRODUCTION

Following outbreaks of Pine beauty moth infestation of Lodgepole pine forests in northern Scotland in 1976 and 1977, it was decided to carry out aerial spraying of fenitrothion insecticide in the most seriously infested forests in 1978. The ultra-low-volume (ULV) technique was preferred as being less costly in time and materials, but aerial spraying on the required scale had not previously been employed in the United Kingdom, and the ULV technique had neither been tested nor approved for forestry use in this country.

Application to carry out the operation was made to the Pesticide Safety Precautions Scheme (PSPS) operated by the Ministry of Agriculture, Fisheries and Food and following urgent discussions, approval was given provided that monitoring was carried out to assess the possible risks to both humans and various species of wildlife. A number of organisations were approached and offered their services in the monitoring operation, despite the short notice and limited funds and staff available.

The results of the monitoring investigations, although based on a limited number of samples, suggested that no major mortalities occurred to species in the terrestrial environment other than the target organism and the sawfly caterpillars on the same trees. Most bird species were unaffected at least in the short term. In the aquatic environment, no effects were found on wild or captive fish and, although invertebrates were dislodged and the drift fauna increased, an adequate benthic fauna remained. No study was made of long-term effects on the fish, although this was considered unlikely. Concentrations of fenitrothion measured in the water were very much below the 24 hour LC_{50} for salmon fry, and the duration of the peak concentration was brief. Concentrations in the fish declined with those in the water.

Atmospheric concentrations of the insecticide in and around the forests were judged to present no risk to humans. A single brief exposure of the pilot to the chemical produced no effects considered significant by the Medical Officer in charge of the examination

The general assessment of the observed effects on wildlife was that within the limits of the investigation these were unimportant, although reservations were expressed about repeated applications to the same area if this should become necessary. The ULV treatment had certain advantages and no apparent disadvantages, and in view of this assessment it was decided that all applications in 1979 would be made using this technique.

The pupal counts of Pine beauty moth larvae made during the winter of 1978/79 indicated that while most of the previously sprayed plantations were no longer at risk, small sections of one or two areas sprayed in 1979 had probably been missed and required further treatment, while serious outbreaks were likely in several plantations not previously sprayed. Consequently the assistance of River Purification Boards, and the laboratories of the Department of Agriculture and Fisheries for Scotland and the Ministry of Agriculture, Fisheries and Food in England was sought to assist in a further monitoring programme, and the Scottish Home and Health Department and the Health and Safety Executive were requested to ensure the safety of humans and to monitor the pilot.

As the forests requiring treatment were widely scattered across Scotland on this occasion, it was decided to concentrate most of the monitoring activity in an area most convenient to the laboratories conducting the observations on the terrestrial and aquatic environments, this being the Elchies section of the Craigellachie Forest in Grampian Region. More detailed studies than those of 1978 were made on the dispersal pattern of the spray, both on the ground and in the air. Observations on the nature of contamination of fish, on its longer term effects and on the degree of toxicity to the displaced invertebrate fauna were incorporated in the 1979 programme. Unfortunately it was not possible to make detailed studies of any effects on birds, although some residue analyses were made, and small mammal collections enabled an assessment to be made of the risk to these species.

A meeting of the organisations participating in the operation was held a few weeks beforehand and the necessary arrangements made to co-ordinate the activities and provide the necessary facilities and communication links. This report describes the procedures used and observations made, based on reports discussed at a meeting of all participants held in Edinburgh in November 1979. The following representatives took part:

Professor R.J.V. Joyce Mr J.D. Parker	College of Aeronautics, Cranfield Institute of Technology, Cranfield.
Professor G.W. Schaefer	Ecological Physics Research Group, Cranfield Institute of Technology, Cranfield.
Mr A.V. Holden Mr B.R.S. Morrison	Dept. of Agriculture and Fisheries for Scotland Freshwater Fisheries Laboratory, Pitlochry.
Dr D.C. Graham Mr G.A. Hamilton Mr A.D. Ruthven	DAFSS Agricultural Scientific Services, East Craigs, Edinburgh.
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Dr P.I. Stanley	
Mr D.S. Papworth Dr B. Thomas	Pesticide Registration Dept. Harpenden Laboratory
Mr G.A. Lloyd	Operator Protection Group, Harpenden Laboratory.
Professor N.W. Moore Mr A.D. Mowle	Nature Conservancy Council
Dr A.T.B. Moir Dr G.I. Forbes) a.m. only Mr E. Reavley)	Scottish Home and Health Dept.
Dr J.D. Bell	Health and Safety Executive
Mr J.S. Coy	Solway River Purification Board
Mr J.B. Hunter	Highland River Purification Board

Mr A. Sutton *(Chairman)* — Forestry Commission
Mr D. Bevan
Mr J.T. Stoakley
Mr J.B. Teasdale
Mr I. Lumley *(Secretary)*

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Lloyds Brokers

Air BP

Civil Aviation Authority

Joint Civil/Military Air Traffic Services

Chapter 1

CONTROL OF THE PINE BEAUTY MOTH, *PANOLIS FLAMMEA* BY AERIAL APPLICATION OF FENITROTHION

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INTRODUCTION

In autumn 1977 pupal surveys were carried out in all significant areas of Lodgepole pine (LP) of susceptible age in Caithness and Sutherland, amounting to about 12,000 ha. Subsequently just under 5000 ha of plantations in that district were sprayed in June 1978 and the operation was fully reported in *Control of Pine Beauty Moth by Fenitrothion in Scotland 1978*, edited by A.V. Holden and D. Bevan.

Two unpredicted Pine beauty outbreaks occurred in 1978 and were discovered too late for control in that season; one at Torrachilty Forest in the Commission's North (Scotland) Conservancy destroyed 30 ha of plantations, the other at Bareagle Forest in the South (Scotland) Conservancy destroyed 50 ha of plantations. Also preliminary surveys at Elchies section, East (Scotland) Conservancy showed a threatening population. These events strongly suggested that LP plantations of susceptible age (i.e. over about 8 years old) in any part of Britain must be regarded as 'at risk'. However, the outbreak at Bareagle, in particular, rather strikingly confirmed earlier observations that severe outbreaks leading to complete defoliation are very largely confined to crops on deep unflushed peat, characterised by a ground vegetation of dominant *Calluna* rather than by any great proportion of *Molinia* - at least in the first year of outbreak.

THE 1979 SPRAY PROGRAMME

In autumn 1978 pupal surveys were carried out in all significant areas of LP of susceptible age in North (Scotland) and in six selected forests in East (Scotland) Conservancies. Surveys were also carried out in West (Scotland), South (Scotland), and North-West and North-East (England) Conservancies but were confined to deep unflushed peat sites - except at Bareagle where a full survey was carried out.

The surveys in North (Scotland) included all areas sprayed in 1978 and showed a satisfactory degree of control in all of the eighteen blocks which had been treated with the one exception of the Strathy block of Naver Forest. There high counts were found near the north-west boundary, counts elsewhere being at a low level and the partial failure would seem to be due simply to inadequate spray coverage.

New areas of dangerously high infestation were found in the Caplich, Inveroykel and North Dalchork blocks of Shin Forest, N(S), the Strathrannoch and Garbat blocks of Torrachilty Forest, N(S), adjacent to the 1978 outbreak; the Elchies block of Craigellachie Forest, E(S); and the Annabaglish blocks of Bareagle Forest S(S), site of the 1978 outbreak.

In 1978 the spray programme consisted of a rather large number of blocks, some comparatively small, and most were included in their entirety on the criterion of having a highest pupal count exceeding 15 per sq metre; that is to say, no account was taken of the distribution or extent of high counts within blocks. However, the North Dalchork, Inveroykel and Elchies blocks are large and it was considered necessary to include only a part of each of these in the 1979 spray programme.

AREAS INCLUDED PROVISIONALLY IN THE 1979 SPRAY PROGRAMME

In the Inveroykel block the highest count was 15 pupae per m^2 and it was included provisionally in the spray programme, for planning purposes pending the results of egg counts, which could only be done very shortly before spraying. In the event, this block was included in the final programme. Some blocks in the vicinity of Annabaglish were also included in the spray programme provisionally, because, although very few pupae had been found, it was expected that there would be oviposition by moths dispersing from Annabaglish. In the event, egg numbers were small and spraying of these blocks was not considered necessary.

The forest blocks included in the spray programme and those which were eventually treated are given in Table 1.1 (p. 13).

CLEARANCE UNDER THE PESTICIDE SAFETY PRECAUTIONS SCHEME

In view of the results of the 1978 spraying operation, application was made to PSPS for clearance for the treatment of all areas in the 1979 programme with fenitrothion at 300 gm ai diluted with butyl dioxitol to one l/ha, applied by a target specific, ULV method. Following negotiations, limited clearance was given with various restrictions and conditions. The spraying of parts of blocks within 500 m of habitations was not approved; the spraying of the parts of these blocks between 500 and 1000 m from habitations was allowed only at half the proposed dosage rate and at Caplich no part was to be treated at the 'full' dosage rate. Table 1.1 shows the areas affected by these restrictions and the means by which the lower application rate was achieved. An additional restriction on the operation was the requirement of official closure of two public roads during and after spraying. The conditions imposed referred to monitoring of the environment by various agencies and medical monitoring of the spray pilot for the 1979 programme; but further investigations in 1980 were also stipulated.

THE SPRAYING OPERATION

As in 1978 the contract for aerial application was placed with Heliscot Ltd of Inverness; they sub-contracted to Ciba-Pilatus who carried out the work with a Pilatus Porter aircraft fitted with Micronair spray units and using Agri-fix electronic track guidance equipment. The pilot, as in 1978, was Mr Noel Kinvig.

The insecticide used was supplied as 50% emulsifiable concentrate formulations of fenitrothion.

All spraying in North and East Scotland Conservancies was flown as sorties from Dalcross airfield near Inverness; for spraying at Bareagle the aircraft flew from Baldoon, a disused wartime airfield just south of Wigtown.

Two separate sets, or 'chains', of ground-based equipment for the Agrifix system, each consisting of a master and one slave station, were employed to avoid delays due to setting up time and to allow flexibility in the order of spraying blocks. One track guidance chain was set up to cover the five blocks to be sprayed in N(S), and one each for the single blocks in E(S) and S(S) Conservancies.

Forestry Commission radio networks were provided in all three Conservancies to cover all aspects of the operations and monitoring. These proved both highly effective and invaluable.

It was planned to commence spraying as soon as 90 per cent of eggs had hatched. In 1978 hatching corresponded with warm weather, took place over a short period and was virtually completed by 30th May. In 1979 the season was exceptionally cold and late and the weather was generally cool at the time of hatching. The progress of hatching was slow and although it varied somewhat between blocks it was not complete, in N(S) and E(S), until about 8th June.

The dates, timing and area covered in each spray sortie are given in Table 1.2 (p.14).

Effective ULV application requires a minimum windspeed of about 3-4 knots per hour. Whereas, in 1978, operations were greatly held up by high winds, in 1979 there were some delays due to lack of wind. In particular it was originally only possible to arrange for official closure of the A837 Lairg to Inchnadamph and A835T Dingwall to Ullapool roads in the early morning or late at night, when on a number of occasions still conditions prevailed. Finally, closure of the A835 trunk road was permitted during daytime under emergency powers. However, the restriction was not relaxed in respect of the less used A835 and the Caplich block was eventually sprayed in the late evening.

MONITORING

It was decided that monitoring of the effects of spraying on the environment should be concentrated, as far as possible, at one site. The Elchies block was chosen for investigations to be done by staff of the following organisations:

1. Freshwater Fisheries Laboratory, DAFS, Pitlochry and, associated with them, the North East River Purification Board.

2. Agricultural Scientific Services, DAFS, East Craigs and, associated with them, the Nature Conservancy Council.

3. Operator Protection Group, Harpenden.

The last also investigated possible contamination of the aircraft cockpit by fenitrothion. Fourthly, intensive medical monitoring of the pilot, including fourteen medical examinations and the taking of no less than eleven blood samples, was carried out by two local General Practitioners on behalf of the Employment Medical Advisory Service, Health and Safety Executive. All of these activities have been reported separately.

Elsewhere, possible contamination of water courses was monitored at Torrachilty and Bareagle Forests by the Highland and Solway River Purification Boards respectively.

As in 1978 the specification for spray application was provided by Professor R.J.V. Joyce, College of Aeronautics, Cranfield Institute of Technology, who with colleagues is developing the ULV application technique on behalf of the Commission. In pursuance of this the Annabaglish block was treated experimentally by the application of two 'quarter doses' separated by an interval of 48 hours and spray droplet distribution and effects on larvae were investigated.

RESULTS OF SPRAYING

Immediately after spraying had taken place its effectiveness was assessed at four sites by the method described by D.A. Barbour in *Control of Pine Beauty Moth by Fenitrothion in Scotland 1978*. Two sites were in the Elchies block of Craigellachie Forest and one each in the North Dalchork and Inveroykel blocks of Shin Forest. All sites showed larval mortality in excess of 97 per cent.

All sprayed areas were inspected for surviving larvae in the second part of June 1979. Very few larvae were found at Strathy, North Dalchork, Inveroykel, Torrachilty and Elchies and this applies also to the parts of the last three sprayed at half dose. However at Caplich (which was treated only at half dose) high larval numbers were found in places within the sprayed area. Large numbers of surviving larvae were also found at Annabaglish.

On inspection in late summer, predictably, no defoliation was found in the blocks with low larval counts and again this applies also to areas sprayed at half dose. However, there was one small patch of defoliation at Caplich, to which, probably, sawflies also contributed and, at Annabaglish, considerable extension of quite severe defoliation but little complete defoliation which would be expected to lead to death of trees.

The results of systematic pupal counts are generally the most reliable and useful indication of post-spraying population levels. A summary of counts in autumn 1978 and autumn 1979 for each of the treated blocks is given in Table 1.3 (p.14).

It will be seen that on this basis 100 per cent control was achieved in the Strathy, North Dalchork, Inveroykel and Strathrannoch and Garbat blocks and that for all practical purposes control was 100 per cent in the Elchies block also. The survey results for the parts of N. Dalchork, Inveroykel and Elchies intentionally excluded from the spray programme do not show any significant change from 1978 to 1979.

The results for Annabaglish and Caplich are clearly not satisfactory. However it should be mentioned that the highest count at Caplich was obtained by deliberately sampling within the one small area of obvious defoliation whereas sampling locations are normally chosen at random with respect to crop condition.

Table 1.1

Areas Sprayed Against Pine Beauty Moth, 1979

Forest (Conservancy)	*Block*	*Areas which Required Treatment ha*	*Areas Treated (ha)*		*Areas Excluded from PSPS Clearance ha*	*Remarks Standard Lane Separation 50m*
			At 300gm ai/ha	*At 150gm ai/ha*		
Naver, N(S)	Strathy	236	236	-	-	
Shin, N(S)	North Dalchork	552	552	-	-	
	Inveroykel	371	351	20	-	½ dose by increased lane separation
	Caplich	122	-	107	15	½ dose by spray dilution
Torrachilty, N(S)	Strathrannoch and Garbat	966	670	240	86	½ dose by spray dilution
Craigellachie, E(S)	Elchies	770	720	50	-	½ dose by increased lane separation
Bareagle, S(S)	Annabaglish	220	-	220	-	Two ¼ doses applied 48 hours apart 200m lane separation
		3267	2539	637	101	

Net Total Sprayed 3166 ha

Table 1.2

AERIAL SPRAYING SORTIES, 9th - 15th JUNE 1979

Forest (Conservancy)	*Block*	*Date*	*Spraying times Start*	*Finish*	*Area Treated ha*
Naver, N(S)	Strathy	9 June '79	1200	1245	236
Shin, N(S)	North Dalchork	10 June '79	1055	1300	552
Craigellachie, E(S)	Elchies	10 June '79	1450	1550	400
Craigellachie, E(S)	Elchies	10 June '79	1645	1800	370
Torrachilty, N(S)	Strathrannoch and Garbat	11 June '79	1130	1220	332
Shin, N(S)	Inveroykel	11 June '79	1535	1650	371
Torrachilty, N(S)	Strathrannoch and Garbat	12 June '79	1140	1225	240
Bareagle, S(S)	Annabaglish	13 June '79	1325	1400	220
Bareagle, S(S)	Annabaglish	15 June '79	1615	1640	220*
Shin, N(S)	Caplich	15 June '79	2125	2205	107

* Repeated application to area treated on 13 June '79.

Table 1.3

RESULTS OF PUPAL SURVEYS IN SPRAYED AREAS 1978 and 1979

		Autumn 1978			*Autumn 1979*		
Forest (Conservancy)	*Block*	*No of Sampling Areas*	*Pupae/m² Range*	*Mean*	*No of Sampling Areas*	*Pupae/m² Range*	*Mean*
Naver, N(S)	Strathy	8	1-48	12	8	-	0
Shin, N(S)	North Dalchork	18	0-40	9	16	-	0
	Inveroykel	10	0-16	6	14	-	0
	Caplich	5	0-30	11	8	0-23	5
Torrachilty, N(S)	Strathrannoch and Garbat	21	0-30	7	21	-	0
Craigellachie, E(S)	Elchies	32	0-52	13	24	0-1	0
Bareagle	Annabaglish	6	0-70	32*	10	5-126	38

* Includes no counts under completely defoliated trees, in outbreak year.

Chapter 2

DISTRIBUTION OF SPRAY AND ASSESSMENTS OF LARVAL MORTALITY AT ANNABAGLISH

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INTRODUCTION

In planning the 1978 aerial spraying programme against the Pine beauty moth (Joyce and Spillman, 1979), it was assumed that the feeding habits of the first and second instar larvae, which do not appear to eat foliage, dictated that maximum crop protection would be achieved if the larvae could be killed by direct contact action of an insecticide. In order to provide a high probability that each larva, (assumed to measure 10 mm x 2 mm), would be hit by at least one droplet, the design target was set at 20 droplets/cm^2, which was regarded as equivalent to about 5 droplets per centimetre of needle. Each of these droplets had to contain a lethal dose, which was assumed to be 1 µg/g. If the droplets hitting the larvae were, on the average 50 µm in diameter, weighing 70 ng, and the larvae about 25 mg, the formulation should contain 30 per cent of active ingredient. Assuming a leaf area index of 5 (in 1978 assumed the index refers to front and back silhouette areas), a total of 10^{10} droplets was considered suitable for achieving the designed droplet density, and it was found experimentally that a Micronair AU 3000, set appropriately, could produce 2.7 x 10^9 droplets per litre (with diameters in excess of 30 µm), nearly 70 per cent of them being less than 50 µm and 95 per cent less than 80 µm diameter. The spraying parameters recommended were accordingly 300 g active ingredient in one litre of spray per hectare, the carrier being butyl dioxytol, a glycol of low volatility. This was applied by the aircraft using 50 m lane separations, so as to secure an even coverage.

Analysis of the large-scale trial of this ULV rate of application over Strathy Forest, Sutherland, in 1978 (Joyce and Beaumont, 1979) revealed that the average size of the droplets collected by the needles was about 50 µm diameter and their average density 52 and 41 visible droplets per needle, each needle averaging 45 mm in length (i.e. 11.6 and 9.1 visible drops/cm of needle), at the top and middle zones of the canopy respectively. These droplets provided a mean chemical deposit on the needles in the upper third of the canopy of 229 ng/cm of needle, and the overall mortality estimated by the Forestry Commission (Barbour, 1979) was 97.5 per cent. The same high levels of mortality were achieved in the forests sprayed at LV rates where the total deposit in the upper third of the canopy was 211 ng/cm of needle, consistent with the ULV results; the average size of the droplets collected by the needles was 30 µm diameter.

The chemical collected on the ground in the ULV sprayed plot averaged 135 ng/cm^2, but over 90 per cent of this deposit was from droplets in excess of 150 µm in diameter; while that from the LV sprayed treatment was about 1150 ng/cm^2, with large droplets similarly contributing to ground contamination. The application was actually made in two half doses over two days, and larval samples taken after the first half dose showed a mortality of 94 per cent after 24 hours (Joyce and Beaumont, 1979), suggesting that a reduced ULV dosage might be as effective. A ULV spray would also minimise ground contamination.

Accordingly, a large-scale ULV trial was planned for 1979, the primary objective of which was to determine the minimum dose, both in terms of quantity of active ingredient, and droplet size and density on foliage, which was required to give an acceptable kill. The experimental method chosen to secure these objectives included:

- the use of six Micronairs so that none would be required to emit at more than 5 l/min, a procedure which sampling in a wind tunnel had shown to provide the narrowest droplet spectrum;

- applying a spray liquid at 500 ml/ha containing 15 per cent active ingredient, thus providing an application rate of 75 g active ingredient/ha;

- obtaining a gradation of deposit by employing 200 m lane separations, and

- securing an acceptable overall kill by applying a second spray 2-3 days later, using the same spray parameters but interleaving the lanes.

After consultation with the Forestry Commission, the trial was conducted on Bareagle Forest, Galloway, where 150 ha were planted to Lodgepole pine in 1966. The two sprays were applied on 13 and 15 June, and sampling confined to some 36 ha. The technical assessment of the 1979 field data which follows is based on the report by Ecological Physics Research Group (EPRG) (p.47).

THE EXPERIMENTAL SITE

The Annabaglish block of Bareagle Forest is situated on open flat moorland in Galloway, southwest Scotland, about 8 km from the coast. A scale drawing is given in Figure 2.1. An outbreak of Pine beauty moth destroyed the central portion of the forest in 1978. The experimental spraying was carried out in the section of forest south of the dead area at the main end of the larval spraying operation in June. This area measures approximately 600m by 600m, and is covered mainly by Lodgepole pine planted in 1966. The average crown height was 5.5m. The dashed lines show the wider rides, with widths of about 15m.

The positions of the 10 sampling points are also shown, at spacings of approximately 60m. The site was chosen, primarily for its flatness and uniformity of cover, to reduce the possible complications of wind flow in hilly or patchy forests.

THE METEOROLOGICAL ENVIRONMENT

A meteorological mast was raised to a height of 9m, carrying a wind vane and cup anemometer at 3.5m above mean canopy, with chart recording at ground level. On both spray days the measured wind was relatively turbulent (s.d.30 per cent), typical of low levels over a forest.

On Day 1 the wind direction was approximately northwest (Figure 2.1) and the winds were light, having an average speed of 2.5 m/s at mast top. Cumulus clouds occupied the sky to 2-3 octas at 3500 ft; convection was therefore in evidence. The day was warm, $18^{\circ}C$ in the rides at spray time, 1215 GMT.

On Day II, the wind was again approximately northwest but strong, with an average speed of 7.5 m/s. Cumulus clouds covered 3-4 octas. The wind was so strong and turbulent at flying height (20 kt, gusting to 30 kt) that the aircraft had difficulties in maintaining constant altitude. These conditions would normally be considered excessive for spraying. Temperatures were moderate at spray time, $15^{\circ}C$ at 1500 GMT.

The two days thus provided two extremes of wind speed, giving an opportunity for observing the effects of wind on spray deposit.

AIRCRAFT TRACKS AND SPRAY PARAMETERS

On both occasions the pilot was asked to fly at 12m above average canopy, but he had difficulty in keeping within 1-2m of this height on Day II. The aircraft proceeded at 50 m/s along the bearings shown in Figure 2.1. It will be seen that the wind directions were closely perpendicular to the spray lines. Taped commentary was made by EPRG field personnel during the spray sorties, allowing precise positioning of the spray lines. The lanes were in fact separated by about 200m, and those of the second day were interleaved between those of the first day to increase the uniformity of coverage.

The Ciba-Pilatus aircraft carried six Micronair sprayers, each emitting 5 litre/min, giving an average spray dosage of 0.5 litre/ha and an average active ingredient dosage of 75 g/ha each day. The carrier was butyl dioxytol, the active ingredient Fenitrothion 50EC.

SPRAY DROPLET DIAMETER SPECTRUM

Mr S. Parkin of Ciba-Geigy (AARU), Cranfield, measured the spectrum of water droplet diameters emitted by the same type of Micronair running at the same emission rate, rpm, and blade angle, using a laser droplet measuring system and a wind tunnel. We have made small corrections to his data for the differences of surface tension and viscosity between water and butyl dioxytol. The results are shown in Figure 2.2, for both the distribution of the number of droplets and the distribution of the volume emitted, in diameter classes with widths of 10 microns. The scale covers 0-100 microns; the percentages of droplet number and emitted volume contained in all larger drops are given at the right hand edge of the graph. It will be seen that the mode of the number distribution is near 15 microns, while the mode of the volume distribution is near 52 microns. The number median diameter (NMD) is 24 microns, the volume median diameter (VMD) is 77 microns, and the volume average diameter (VAD) is 45 microns. Using the latter value, there would be 10.4×10^9 drops per hectare on average, using the average dosage rate above. A 45 micron droplet would contain 7.2ng a.i.

FLUORESCENT PARTICLE TRACERS AND DEPOSITED DROP SIZES

Fluorescent particles were added to the spray mixture, using a different colour for each day. Although precautions were advised to minimise sedimentation in the unstirred spray tanks, inevitable aircraft delays occurred and the degree of suspension was disappointingly small, and beyond our control. We estimate below that the actual particle concentration was approximately one particle per volume of dioxytol equivalent roughly to a 30 micron droplet. An inspection of Figure 2.2 will show that more than half of the droplets were therefore unmarked, and the fraction was different on each spraying date. Fortunately the invisible volume associated with these smaller droplets is less than 9 per cent, so that the vast majority of the chemical may be traced.

Even though many droplets were unmarked, most of the aims could still be achieved if the visible particles could be sized, at least approximately, by the number of particles they contained. To make this connection, the volume mixing ratio of particles to dioxytol is required. It was planned to calculate this ratio by measuring droplet stain diameters and corresponding particle numbers on the Bristol cards, and then applying a stain spread factor measured previously by AARU. Unfortunately, the card supplied to us was different in surface structure from that used during the spread factor calibration, so this pathway was blocked.

Methods of analysis have been devised to largely overcome these two unfortunate circumstances, but they are mathematical and rather technical, and we felt they should be contained in a separate Report to the Forestry Commission (not reproduced here). The text below introduces the conclusions of this Report, descriptively only, where required. The one aim which has been jeopardized concerns the estimation of 'drift', and only semi-quantitative conclusions have been reached.

FIELD METHODS - DROPLET DEPOSITION

Branch tip samples were taken from the tops (5m) and bottoms (2m) of the 10 trees, for each of four aspects (west, north, east, south). The former two aspects were equally upwind, the latter two equally downwind. Samples of drops were captured near ground level by placing Bristol cards (5cm x 5cm) at three standard positions under each of the 10 trees; one card in the clearest area between the chosen tree and its nearest neighbour upwind, a second card under the tree at its upwind edge, and the third card under the tree at its downwind edge.

FIELD METHODS - LARVAL MORTALITY

The field experiments were designed to measure separately the effects of spraying directly onto larvae and the effects on larvae feeding on sprayed foliage. Before the spray run each day, 100 larvae were taken from trees at a height of 2m. 50 of these were separated into 10 groups, 5 of which were placed in small plastic tubs together with branch tips which had not yet been sprayed that particular day. Immediately after spraying the second 50 unsprayed larvae were put in similar groups in containers together with branch tips cut from the base (2m) of the recently sprayed trees. An additional 100 larvae were collected immediately after the spray period each day from a height of 2m and placed in similar tubs containing either recently unsprayed foliage (50 larvae), or recently sprayed foliage (50 larvae), in groups of 5 larvae. The 100 sprayed larvae were collected in groups of 10 near to each of the 10 trees sampled for sprayed branch tips; if the collections had been done from the very 10 trees used for foliage samples for droplet studies, stronger conclusions could have been reached in the analysis, but this did not prove to be feasible in the time available.

The containers with larvae and foliage were examined approximately every 12 hours for five days following each spray, and the number of dead larvae were noted on each occasion.

METHOD OF ANALYSIS

Five needle pairs were taken from each of the 80 branch tips; each needle was measured for length, for the number of visible drops containing fluorescent material, and for the number of droplets containing 25-39 particles, and 40 or more particles.

For each card the number of visibly marked droplets was counted, as well as sub-divisions of droplets containing 10-19, 20-39, and 40 or more particles.

RESULTS - SPRAY DISTRIBUTION

1. Needle Dimensions

Needles varied in length between extremes of 26 and 54 mm, with an average of 40.1 mm. The diameters of the needles correlated strongly with their lengths, but since the variance was relatively small we have used an average diameter, 1.52 mm. This gives an average silhouette needle area of 61 mm^2.

2. Larval Measurements

A small number of sampled larvae were measured. The average length was 9.2 mm (s.d. 2.8) and the average diameter was 1.2 mm (0.27). The measured creatures were not entirely fresh so they were not weighed, but they would have had a density close to unity, giving an estimated average weight of 10.5 mg (5÷20 mg).

3. Units for Droplet Dosages

We report all droplet dosage measurements in units of drops/cm; the number of visible droplets on each needle was divided by the length of that needle. The number of droplets counted on the 25 cm^2 of each card was converted to equivalent drops/cm by dividing by the average needle diameter (0.152 cm), and by the Leaf Area Index, taken as 3.

4. The Visibility of Drops

The measured needle droplet dosages will be presented for two classes of visible droplet sizes, those with droplets having 1+ particles (D_1 drops) and those having 25+ particles (D_{25} drops). The analysis of the Report (p. 18) shows the average diameters of droplets having 1 and 25 particles are those listed in Table 2.1 (p. 33) as D_1 and D_{25} respectively. It will be seen that the fraction of visible drops was poorer on Day I. If the tanks had been stirred continuously, this fraction would have been about 0.76, with a D_1 of about 15 microns. The table shows that over 90 per cent of the chemical was marked however.

Two sets of results are given in Table 2.1, referring to two methods of averaging measured dosages over a tree - the linear and the exponential. The explanation is as follows. Dosages were measured at only two heights on each tree, at bottom (2m) and near top, in fact at 1m from tip, at a height of about 5m. The variation of dosage distribution with height cannot be estimated accurately from two measurements only.

Our two assumptions are a 'linear' and an 'exponential' rate of decrease below the top. The tree-average dosage has been calculated under each assumption, weighting the integrand by the variation of the amount of foliage with height, which we have taken as a linear increase from tree top downwards. We consider the 'linear' assumption is more likely, and have placed the 'exponential' results in brackets. From Table 2.1 the differences are seen to be small.

It might be helpful to give a picture of the types of drops in the D_1 and D_{25} classes. Using the D_1 values of Table 2.1 in conjunction with the droplet spectrum of Figure 2.2 (p. 36), we can see that the D_1 classes consist largely of droplets with diameters between about 30 and 60 microns, which we call the 'small' drops, while the D_{25} classes contain droplets with diameters near 100 microns, the 'large' drops. We can, and will, say very little about the many 'very small' drops in the range 10 to 30 microns.

5. Spray Distribution by Tree Aspect

There was no significant difference in the deposit of D_1 droplets among the four tree aspects at tree top (5m) in the light winds of Day I, nor at tree bottom (2m) on either day. This result was expected because most of the D_1 droplets were 'small', so that they would have low needle impaction efficiencies in the light winds of Day I and in the light winds near tree bottoms, and would continue to meander through the trees downwind. Also, Lodgepole pine is open in nature, compared to Corsican pine studied earlier at Thetford Forest, and the uniformity of deposit with aspect differed from the Corsican results where there were heavier deposits in the upwind side even in the light winds of that occasion.

The same uniformity with aspect was obtained for the 'large' D_{25} droplets at tree top on Day I and at tree bottom on both days, while the deposits on the three ground cards at each tree did not vary significantly on either day either.

However, in the strong winds of Day II, the deposits at tree top differed significantly between upwind aspects (north, west) and downwind aspects (east, south), the former having some three times greater deposit in terms of D_1 droplets, and five times greater in terms of the D_{25} drops.

In the remainder of this report, the data for the four tree aspects have been combined, so that the 5m and 2m levels are each represented by 20 pairs of needles on each date.

6. Distribution of 'Small' Droplets in the Forest Canopy

The measured dosages of the D_1 class of 'small' drops are shown in Figure 2.3 for Day I and in Figure 2.4 for Day II, at tree top, tree bottom and on ground cards, at each of the 10 sites. The droplet deposit density averaged over the 10 trees is given on the right-hand side, as a function of distance above ground. These sites have an average spacing of 60m, 42m in downwind direction. The points at which the spray lines crossed the line of sampled trees are shown by the arrows at the top of each Figure.

The second set of units used in these Figures is the average chemical dosage rate (ng/cm) calculated as follows. In the emitted spectrum the volume average diameter was 45 microns, with such a drop containing 7.2 ng a.i. The plotted results refer to only the fraction (D_1 class) of the emitted drops and volume given in Table 2.1. The droplet count/cm was multiplied by 7.2 and by the D_1 volume fraction, and divided by the D_1 drop fraction.

Two main features may be noted: there is a strong decrease in dosage rate from tree top to tree bottom, possibly at an exponential rate, and there is very little on the cards.

Another feature is the very great variability from tree to tree. The first impression from Figure 2.3 (p. 37) is that there is a 'swath-width' effect, with four peaks along the experimental line; but these are not related to the spray line positions. A closer inspection of both Figures shows that three of the largest dosage rates, on trees 1, 2 and 7, are associated with trees situated on the downwind edges of wide rides, as may be seen from Figure 2.1, and have greater exposure to the spray, especially at tree bottom. Another large deposit, on tree 4, was associated with a tree in mid-forest with an unusually large amount of clear space around it. These four tree aspects we consider are quite untypical of the majority of the forest trees, represented by the other 6 trees, and they give rise to misleading conclusions.

For this reason the results have been replotted for the six 'typical' trees in Figures 2.5 and 2.6. We note the following points. There now seems to be some indication of a lane separation effect on Day I, under light wind conditions, with a peak number of droplets/cm at some 160m downwind of spray lines, at all levels. This kind of effect appears to be slightly visible in the results of Day II at the tops of trees, but is missing at tree bottom and on the ground. Also, it should be remembered that these figures refer to 'small' drops which represent an almost negligible mass of insecticide. If there is a real lane separation effect, it is surprising that the peaks are so far downwind relative to theoretical expectation, for a spraying height of 12m over a rough surface. However, this evidence for swath effects for 'small' drops is quite weak at best.

A significant and important conclusion is the large variation of dosage rate from tree top to tree bottom. It will be seen that on the occasion of very light winds (Day I) there is more uniform vertical coverage of the trees, measured in terms of 'small' droplets, relative to that on the occasion of very high wind speed: in detail, while the dosage of D_1 droplets is nearly the same at the bottom of the trees, the tops become relatively overdosed in the high wind speed.

Another noticeable feature is that with high wind speeds a relatively smaller fraction of the 'small' droplets reaches the ground as potential contamination, simply because more are impacted upon the trees.

We do not consider it is necessary to quantify further the relative distribution of these smaller droplets, since the larger drops are more important because they carry most of the chemical.

7. The Distribution of 'Large' Droplets in the Forest Canopy

Graphs similar to Figures 2.3 and 2.4 were prepared showing the spatial distribution of the 'large' droplets having 25 or more particles per drop. The results are similar to those shown in those Figures: as before, large doses occurred on exposed trees, and we have omitted these from further consideration. Once again, there was an 'exponential-like' distribution of droplets on the trees, closely parallel to those for the corresponding total droplets; we show on Figures 2.5 and 2.6, as a dashed line, the dosage of D_{25} drops averaged over the trees and cards at the six 'typical forest' sites. Note that these plotted dosages have been magnified x 10, for convenience of graphing.

As for 'small' droplet deposit, there were large variations from tree to tree, hiding any swath effect. To bring to light as clearly as possible any effects of swath on the distribution of the heavier particles, we chose a date and a measuring height for which there was least variation in dosage over all 10 trees, and we then calculated the fraction of heavy drops in the total visible droplet deposit. The best circumstances occurred at the card level on Day II (Figure 2.4). The idea is that since the heavier particles will impact more easily on needles, and so have less 'drift' relative to 'small' droplets, any swath effects should be greater for the heavier particles; and these effects should show up most clearly if the ratio of 'large' to 'small' drops is plotted, since the tree-to-tree dosage variations would then be minimised.

Figure 2.7 shows the fraction of total visible droplets with more than 10 and also more than 20 particles, the D_{10} and D_{20} droplets. There is now evidence that the heavier particles have a relative maximum dosage at a distance of about 100m from the spray lines, compared to the more uniform distribution of the 'small' droplets (Figure 2.4). A similar but less pronounced effect was found at tree bottom on both days and at the card level on Day I, for one or other of the two swaths in each case.

We may safely conclude that there is a swath effect for the heavier particles. The magnitude of the effect (Figure 2.7) is somewhat too large for good spraying practice, <u>if</u> these larger droplets are required; a single spray swath width should be reduced below 200m, or the spraying height should increase.

We may also conclude that these same heavier drops were brought down largely by turbulent diffusion, especially in the high wind condition. They could not have sedimented out where they did because the average sinking speed of these particles would be about 0.25 m/s, and falling from a height of about 10m would have required 40 seconds, equivalent on the second day to a travel of 300m, whereas the maximum deposit density was at a distance of about 100m as expected by the theory of turbulence.

8. The Average Dosage on Forest Trees

We have discussed on page 19 the 'linear' and 'exponential' weighting of droplet dosages when computing a tree-average dose, and have stated our preference for the 'linear' assumption because of the way that conical tree tops project through the canopy. We have averaged droplet dosage over tree height by integrating with this 'linear' assumption, starting at tree top 1.0m above the top measuring height, and ending at tree foliage base at above 1.5m, weighting the integrand by the amount of foliage per unit height, chosen as linearly increasing from tree tip to canopy base.

The results are 0.60 and 2.53 drops/cm for the D_1 class and 0.047 and 0.211 drops/cm for the D_{25} class, on Days I and II respectively. The values have been marked on Figures 2.5 and 2.6 as open index. To show the relative sensitivity of the results, the corresponding results for the 'exponential' assumption are 0.51, 1.61, 0.038 and 0.131 respectively.

The designed dosage of 104×10^8 drops per hectare (page 17) if they all landed within the swath width of 200m, would give an average of 104 drops/cm^2 of ground area, and using a Leaf Area Index of 3 typical of Lodgepole and other pines would give an average of 35 drops/cm^2 of needle silhouette area. Since the average diameter of needles was 1.52 mm, this is equivalent to 5.2 drops/cm of needle. Only the fraction of drops given in Table 2.1 will be visible. Multiplying 5.2 drops/cm by this visible fraction gives the 'designed visible dosage' levels marked on Figures 2.5 and 2.6.

9. Relative Deposit of Chemical at Ground Level

We were asked to report upon the fraction of chemical reaching the ground. We have used the 'small' and 'large' average drop counts from the six 'typical forest' sites, as given in Figures 2.5 and 2.6, and have calculated the ratio of the ground card average dosage to the tree average dosage for each date. In the case of the cards, the counts were based on 20 or more particles, not 25 as for the needles, but the difference this makes is small, and we are estimating the relative ground tree dosage in any case. When emitted, the D_1 class and D_{25} class contained more than 90 per cent and about 50 per cent of the chemical respectively.

The results are given in Table 2.2, as a percentage ratio.

To the extent that the ground cards give a good indication of ground dosage, it is clear that only a very small fraction of ULV spray reaches the 'ground', with less than half the fraction in stronger winds when the trees filter out more drops. It is interesting to note that the Solway River Purification Board personnel measured much less chemical run-off after Day II spraying.

The 'large' drop estimates are likely to be more accurate in assessing absolute chemical ground deposits, since the 'small' drop fractions refer to tree deposit, and this is subject to 'drift' loss (especially on Day I as we see now).

10. 'Drift'

We were asked to make estimates of the degree of spray 'drift'. What does this mean in the Annabaglish trials? In the experimental arrangement, the six 'typical forest' sampling trees had 4-5 spray lines upwind each day, reaching to some 700m, and the sampling trees extended in a line over more than one swath width (Figure 2.1). In this case 'drift' means the fraction of droplets (or of chemical) travelling more than some 700m from a spray line placed by an aircraft at 12m over this forest under the prevailing meteorological conditions.

Our estimate cannot be accurate because of the limited nature of the data. Drift is difficult to assess accurately even with good instrumentation. Large amounts of variability in the atmosphere and canopy have to be catered for. In the present case we are found to account for 'drift' by assessing the difference between emitted dosage (not accurately known) and the measured tree dosage, averaged over six trees only, and with an uncertain distribution over tree heights. Clearly, large errors are involved. On top of this the fluorescent particle mixing ratio had to be assessed indirectly.

As for the 'large D_{25} droplets, Figure 2.7 and the other similar graphs mentioned above show noticeable swath effects, and we may conclude that virtually all these drops are impacted by about 150-200m and certainly before 700m. Thus about half of the chemical was likely not to be subject to drift, but contained in only a few percent of the droplets.

The story is possibly different for the 'small' D_1 droplets, with diameters between about 30 and 60 microns. An estimate of 'drift' loss for these visible droplets may be made by comparing the forest-average dosage of D_1 drops recovered in the forest canopy (using the six 'typical forest' tree results of Figure 2.5 and 2.6; open circles), with the 'design visible droplet dosage' (calculated above and shown in the same Figures), which assumes no 'drift'. For Day I this ratio is 0.60/1.51, or 40 per cent; while for Day II it is 2.53/2.60, or 97 per cent.

Remembering the considerable uncertainties and variances on these numbers, we may conclude that in the very light winds of Day I about half of the drops with diameters between about 30 and 60 microns have 'drifted', representing possibly 12 per cent of the chemicals; while in strong winds there has apparently been negligible or little 'drift'. These results also agree qualitatively with the Solway River Purification Board results. This result for high wind speed may run counter to the 'common sense' view of 'drift', but these measurements (and theory) indicate otherwise.

When considering the importance of these longer distance droplets, the small amount of chemical is spread more dilutely the further the distance, so that when it does impact it will give very small dosage rates. It is most encouraging that our assessments of 'drift' are qualitatively in agreement with the field measurements reported by the teams working downwind of the Elchies area during spraying. A more accurate assessment of 'drift' must await further field trials.

11. Branch Tip Dosage Variations

The final type of deposit variation refers to needle-to-needle variation on a branch tip. This is of obvious importance if crawling and feeding larvae are the target. Figure 2.12, p. 46, shows a typical case of the distribution of dosage over 20 needles chosen fairly randomly for position on a branch tip on the western side of the top of Tree 1 on Day I. This was a very heavily dosed tip (Figure 2.3), providing good statistics. The mean dosage was 6.4 drops/cm, and the large 'log-normal' spread about it is clear, a factor of 20 or more. It would be easy for a tip to have a mean dosage above threshold, and yet have very few needles with doses exceeding this level.

LARVAL MORTALITY STUDIES

1. Presentation of the Data

As explained under field methods above, there are four different combinations of larvae, needles and spray on Day I. These are unsprayed larvae (SoL) on unsprayed foliage (SoF), sprayed larvae (S1L) on unsprayed foliage, unsprayed larvae on sprayed foliage (S1F), and finally sprayed larvae on sprayed foliage. A similar combination was possible for the second spray date, but the foliage used had already been sprayed once (S1F) or sprayed twice (S2F), and correspondingly the larvae were either singly sprayed larvae (S1L) still living from the first spray date, or doubly sprayed larvae (S2L).

The larvae were collected at a height of 2m in the general vicinity of each of the 10 droplet sampling trees, but at distances up to 10m or more, particularly on Day I.

The percentage mortality, assessed by inspection of the containers for dead larvae at frequent intervals over a five day period, are shown in Figure 2.8A (Day I) and Figure 2.8B (Day II), averaged over the 10 samples.

2. Larval Mortality

(a) Effects of direct spraying of larvae. Looking first at Figure 2.8A, at the upper two curves for unsprayed foliage, there would appear to be good reason for thinking that the sprayed larvae had higher mortality as a result of the spraying; but this is very likely to be only a statistical effect when the corresponding curves for Day II (2.8B) are studied, where the doubly-sprayed larvae had lower mortality. Adding to this the fact that the average mortality, obtained by taking the mean of the top two curves for each date, is the same for each day shows that the effects exhibited are likely to be attributable to statistics and handling techniques. In 1979, the containers supplied were considerably smaller than in the previous year, we understand, and certainly the mortality of the controls was greater than in the previous year. We may conclude that the effects of the spray directly applied to the larvae were very small on both days, and unmeasurable even when doubly-sprayed. The 'container effect', which amounted to about 25 per cent after a two day period in each case, does not affect this result, we believe.

(b) Effect of spray on foliage. The results are very different when larvae, both sprayed and unsprayed, were placed on sprayed foliage; this may be seen from the lower two curves of Figure 2.8 for each of the two days. There is no statistical difference between sprayed or unsprayed larvae, giving rise to the same conclusion that direct spraying gave small unmeasurable effects. It is also evident on both days that the larvae died rapidly during the first half-day, after which mortality continued at a constant rate over the next days, the rate being approximately double when using doubly-sprayed foliage on the second day. It appears from the shape of the curves during the first 12 hours that mortality is likely to be by contact with the spray on leaf surfaces. It cannot be decided whether the later mortality is due to contact or ingestion. Using the results of Figure 2.8 we calculate that by 48 hours some 65 per cent of the larvae would have died, and of the remaining 35 per cent, 75 per cent would have died by the end of the following 48 hours, giving a total spray mortality of 91 per cent.

(c) Measurements on typical forest trees. It will be remembered that some of these 10 trees were very exposed. We have therefore produced a second set of curves, given in Figure 2.9A and Figure 2.9B, based on the six trees more characteristic of continuous forest. The overall mortality at the end of the two days following the second spray is then estimated at 76 per cent.

3. Threshold Dosage for High Mortality

These estimates will not be representative of the entire forest for the following reasons. First of all the larvae were selected only from the bottoms of trees and therefore received very low dosages, while the larvae near the tops of the trees would have received much larger dosages (Figure 2.3 - 2.6) probably giving complete mortality. The distribution of larvae on trees is not yet known, and quite clearly it could have a strong effect on the control achieved. If they were to reside largely at tree top, lower emission rates could be used and windy conditions should be chosen.

We have been able to make from the results some estimate of the average dosage rate required for complete control. We have calculated separate mortality curves for each of the 10 samples each day, with larvae on sprayed foliage, and correlated the calculated mortalities at the end of 48 hours and 96 hours with the dosage rate measured on the needles at tree bottom (2m) on each of the 10 nearby droplet-sampling trees. Unfortunately, the team collecting the larvae and the sprayed branch tips for larval food was working at a distance of some 10m from the team collecting the foliage for droplet dosage studies, and therefore we do not expect to obtain such a strong correlation as we would expect from a careful application of the idea.

The Day I correlation is shown in Figure 2.10, giving the percentage mortality at 48 hours after first spray of larvae from nine stations, plotted against the average chemical dosage rate measured nearby. (Station 1 was omitted because of its extreme droplet exposure, and the uncertainty of the location of the collection of branch tips for larval food). A similar type of plot is made in Figure 2.11 at 96 hours after the first spray, 48 hours after the second spray, at the nine sites, where the chemical dosage is the sum of the two separate dosages. The mortalities include the 'container effect'.

It is seen that complete mortality was achieved at all higher dosage rates. The very wide variation in dosage rates between the nine sites makes it possible to get some estimate of the threshold for complete kill for larvae on needles; this is evidently about 12-20 ng/cm, say 16, with considerable uncertainty. Complete mortality at a few sites coincided with lower dosages, but it should be remembered that the foliage and the droplets were not taken from the same tree, as explained above, giving rise to the majority of the threshold uncertainty. This threshold, say 16 ng/cm, has been added to Figures 2.3 - 2.6, to show how it compares with the spatial variation of spray dosages. The top two-thirds of the trees are apparently adequately covered in general, for this type of larva/foliage/spray interaction.

As a comment on experimental techniques, we feel it is not necessary to spray several large forest areas at different average dosage rates to assess effectiveness of spraying strategies; it would be sufficient to monitor different parts of the three-dimensional volume of a forest in a single spray operation, whether a routine or experimental operation, and look for correlations between mortality and local dosage. We feel this could be an important time and cost saving element in future development.

4. Behaviour of Larvae at Spraying

We have noticed reactions of other species of insects in other projects to the arrival of a spray cloud, so staff members were asked to watch larvae carefully during the several minutes before and after the arrival of the spray cloud. Important reactions were observed. The majority of the larvae, all of which had been essentially motionless on the new buds, became active within several seconds and began to move to nearby needles grown the previous season. This would have brought them into contact with spray droplets still sitting on the needle surfaces. Many were seen to move as far as 10cm in the first minute, thus covering some 10 body lengths. A few larvae descended almost immediately on threads, which would expose them to spray later on, either on the thread or on foliage whilst searching for food.

We feel that this behaviour is of considerable importance in the planning of control operations. We concluded above that a negligible number of larvae sampled were hit directly with sufficient spray whilst feeding on the buds, and it is most likely that any mortality was due to subsequent contact whilst crawling, or during ingestion of needles into which the droplets had penetrated (within a few hours of impaction according to visual observation).

In our view it is now essential to reconsider whether the target should be the insect or needles, and whether the insecticide should be encouraged to remain longer on the surface of the needles for contact during crawling needs to be reconsidered.

5. Conclusions from Experimental Larval Mortality Data

It is not possible to give an accurate figure for the degree of control achieved in the forest during either of the spray trials. This is due to the large variation in dosage rate, to the unknown distribution of larvae on trees, and the unknown behaviour of the larvae after spraying relative to their behaviour in the experimental containers. A crude estimate of dosage rate has been made, for larvae feeding on sprayed needles.

OBSERVATIONS OF DEFOLIATION AND PUPAL DENSITY

In November 1979 we returned to the experimental area at Annabaglish and had the opportunity of touring the sprayed area to inspect the degree of defoliation of the 10 sampling trees, and in general, as well as of making valuable measurements of the density of pupae in the soil under our 10 trees and the associated defoliation. All that we wish to report here is the remarkably good correlation betwen the spray deposit density and percentage defoliation. Details will be presented in a future report to the Forestry Commission.

Throughout the experimental area we did not see any trees with an unacceptable degree of defoliation in the upper third, near 5m. However, in those parts of the experimental area where previous sampling over the winter of 1978/79 had shown appreciable density of pupae, the bottom third of the trees within 'typical forest' were partially or badly defoliated. These observations were in direct agreement with the data presented in Figures 2.5 and 2.6, where the deposits at the tree tops were well in excess of the threshold dosage (derived from Figures 2.10 and 2.11), while the bottoms of the trees were generally much below this threshold. Even so, the forest as a whole was not unacceptably defoliated according to Mr Stoakley of the Forestry Commission, who accompanied us on the tour of inspection.

It was noted above, and is evident in Figures 2.3 and 2.4, that the trees on the downwind side of the more open rides had significant deposits of spray at tree bottom and it was very noticeable on our tour that all the downwind exposed trees were essentially unattacked. On the other hand, immediately opposite these trees, on the upwind side of the more open rides, the bottom of the canopy was very frequently badly defoliated. Although the team did not sample spray droplets from upwind trees, aerodynamic theory would predict that the lower levels of such trees would be underdosed relative to those on the opposite side of the ride.

We have gained more confidence in the quantitative analysis carried out in this report due to the close agreement between predictions based on our calculations and the results of our defoliation and pupal density survey in November.

Although the viability of the trees was sufficiently protected, sufficient larvae escaped to produce pupal densities requiring the forest to be protected again in 1980. Speaking approximately, the resulting overall pupal density in the experimental area was comparable to that of the previous season. Since a large increase in population was possible in the absence of control measures, as witnessed by the dead area immediately to the north (Figure 2.1), a significant degree of control was exercised.

DISCUSSION

Comparison of 1978 and 1979 results

The design target dosage of 5 droplets/cm of needle and the average droplet size and mass of 50 μm (65.5 ng) and 45 μm (47.7 ng) in 1978 and 1979 respectively were similar in the two years. They differed, however, in the quantity of active ingredient they contained, each droplet in 1978 containing 19.7 ng, and in 1979, 7.2 ng, thus giving a design dosage of 98.5 ng and 36 ng/cm of needle in 1978 and 1979 respectively, if no 'drift' occurred.

Comparisons of the deposits achieved in the two years are made in Tables 2.3, 2.4 and 2.5.

The trees in Strathy Forest, growing in shallow peat on the steep sides of a burn, were morphologically very different from the more uniform and dense trees on the flat bog soil of Annabaglish, but no attempt was made to quantify these morphological differences. Even so, the normalised ground level deposits given in Table 2.5 are similar at Strathy and on Day I at Annabaglish, when the wind speeds were 5.1 (average) and 2.5 m/s respectively. On Day II at Annabaglish the wind was stronger, at 7.8 m/s, and the ground deposit half of what had been measured on the two lighter wind days.

The consistency of the measurements is best illustrated by the chemical recorded on the needles at the top of the canopy, (Table 2.4), contamination increasing with wind speed from 33.3 to 85.7 to 102.4 ng/cm, per 100g active ingredient applied, in wind speeds of 2.5, 5.1 and 7.8 m/s respectively. A linear correlation is evident, deriving probably from increase in impaction efficiency with wind speed. This shows a reverse trend of deposit with wind speed when compared with ground deposits.

The comparison of deposits on trees, in terms of visible droplets/cm given in Table 2.3, is not as meaningful as deposits in terms of chemical (Table 2.4), since the fraction of droplets made visible by dye was not measured in 1978. Applying the visible fractions for 1979, namely 29 per cent and 50 per cent for Day I and Day II respectively (Table 2.1), the visible droplet dosages at tree top of 2.2 and 11.0 of Table 2.3 would scale to total droplet dosages of 7.6 and 22 drops/cm on the two days respectively. The 1978 visible droplet dosage of 11.6 would scale up somewhat when invisible droplets were allowed for, and would probably be intermediate to the 1979 deposits, the latter obtained in both lighter and in stronger winds. The comparison can be taken no further.

We turn now to a comparison of larval mortalities in relation to chemical dosages. The overall mortality in the 1978 ULV trials, as measured on whole trees by the Forestry Commission (Barbour, 1979), was in excess of 98 per cent, and we can assume that well over 90 per cent of larvae were killed at the bottom levels of the trees; later forest surveys showed little or no tree defoliation at these levels, where the deposit is least. The ULV chemical deposit was measured in 1978 only at mid-crown and tree top (Table 2.4). However, the dosage at tree base can be estimated fairly safely by using the 1979 results of Table 2.3, where it is seen that canopy bottom dosage is more or less independent of wind speed, equalling approximately 4.5 ng/cm for an applied dosage of 75g a.i./ha. Scaling the dosage to the 300g a.i./ha applied in 1978 gives an estimated 18 ng/cm at canopy base. (A proviso for this inference is that we extrapolate measurements in a forest with flat terrain to a forest on a hillside, in a crosswind on the first spraying date, and with somewhat different tree morphology. Future investigations are called for). Our first conclusion is that an average dosage of 18 ng/cm achieves well in excess of 90 per cent mortality. The question arises as to how much the applied dosage may be reduced and yet achieve 90 per cent mortality (say) at canopy base.

The second strong piece of evidence is that the split-dosage used in the Annabaglish trial gave inadequate control at tree base level. Although there was adequate tree protection for the current season, it was insufficient to prevent survivors from representing a hazard for 1980. The total tree base dosage averaged 9.1 ng/cm (Table 2.4).

Thus the difference in control between an average of 9.1 and an average of 18 ng/cm is large and important, even though the difference is only a factor of 2.

Some light can be shed on these results by the larval mortality measurements carried out in 1979, given in Figures 2.8 - 2.11. We concluded that the threshold for virtually complete mortality corresponded to needle dosages of 16 ng/cm. There is a close correspondence of this experimental threshold with the 18 ng/cm high mortality dosage deduced from the 1978 measurements, but the 1979 data suggest that larvae were killed mainly as a result of crawling over and/or feeding on sprayed needles within the first days of spraying. This conclusion is derived from the observations (pages 24, 25) that few of the larvae sampled during the first hours after spraying and placed on unsprayed foliage died, even when larvae were collected in the vicinity of the heavily sprayed trees growing in open aspects. This contrasts with 1978 when larvae, collected from sample trees within 15 minutes of spraying the first half dose, and placed on unsprayed foliage, all died within 36 hours. In 1978, however, the average droplet contained 19.7 ng of fenitrothion compared with 7.2 ng in 1979.

Little is known about the rate of absorption of fenitrothion into pine foliage or into *flammea* larvae. Sundaram (1974) and Moody *et al.* (1977) found that fenitrothion was absorbed in the tissue of spruce needles in Canada within hours after application, but remained beneath the cuticle for days and weeks without movement from the site of application. The fact that larvae collected after Day II spraying in 1979 and placed on foliage sprayed on Day I suffered little mortality suggests that the chemical is rapidly absorbed into pine needles even when needles are removed from the trees. The experience with fluorescent dyes in 1978, which remained unaffected for weeks when sprayed onto foliage which had been removed from trees, while some disappeared within hours from foliage sprayed and removed from trees one to two hours later, suggests that absorption is a metabolic process which proceeds more rapidly on attached than on severed foliage.

Thus the 1978 chemical analysis, which measured the superficial deposits of fenitrothion obtained by washing samples collected within about two hours of spraying, probably under-estimates the spray collection on both needles and larvae; whilst the 1979 estimates of spray collection, based on droplet counts, are also subject to errors which are difficult to quantify.

On the assumption that the bottom of the canopy in 1978 was dosed to an average of 18 ng/cm of needle, larvae in this zone, whose silhouette area was about 80 mm^2 and weight about 140 mg, could have been expected to have collected chemical of which nearly 100 ng would have been recovered superficially, if the larvae were exposed as much as a needle. (In fact, the average quantity of fenitrothion measured on larvae collected from upper/mid canopy was about 180 ng in the ULV plot, 90 in the LV plot). It seems safe to assume that the LD50 of fenitrothion to *flammea* larvae is of the order of 1 µg/g, but cannot be defined more accurately from the data available. On this basis, these larvae would have received directly a dosage of some 0.7 µg/g, less than the mentioned LD50 value. In 1979, larvae, weighing 10.5 mg and with a silhouette area of 11 mm^2 could have been expected to collect from a deposit of 5.6 ng/cm of needle about 4 ng of chemical on Day I, and 2.5 ng on Day II from a deposit of 3.5 ng/cm. This equates to 0.38 and 0.24 µg/g, if fully exposed, evidently insufficient to kill by direct contact action.

If fenitrothion is absorbed into the needles of Lodgepole pine within hours after spraying, little would have been available for collection by crawling larvae 24 hours after spraying, but the chemical would still be available for ingestion if larvae fed on the sprayed foliage. Such feeding occurred in the containers in 1979 but evidently made only a modest contribution to mortality (Figure 2.8B). That such feeding occurs in the field is considered improbable by Stoakley and Heritage (1979). Nevertheless it should have been possible for most of these larvae to collect a lethal dose - say 20 ng - by crawling some 5 body lengths on the 1979 contaminated foliage soon after spraying. The mortality achieved in the field was perhaps largely due to this indirect contact action. Such crawling was in fact observed in 1979, but it was evidently insufficient to provide the same high mortality as that achieved by contact action (direct and indirect) in 1978 when droplets containing more insecticide were employed.

In 1978, larvae were killed through contact action by the application of 150 ng active ingredient per ha, each droplet containing an average of 19.7 ng. In 1979, the same quantity of active ingredient applied in two sprays separated by 48 hours as droplets containing an average of 7.2 ng active ingredient, failed to give any measurable mortality at the base of the trees by direct contact. This was because the droplets collected by the larvae contained insufficient poison and the toxic effects were not cumulative. The object of split application was to apply on two occasions a spray which was lethal to the larvae so as to increase the chances of hitting most of them. This objective was not achieved in the lower canopy as both 1979 sprays were ineffective by direct contact and gave insufficient deposit to permit larvae moving in the lower levels to accumulate toxic doses.

On both days deposits in the upper canopy from an application of 75 g active ingredient per ha were sufficient to provide a high mortality amongst the larvae at this level. The problem is to get a suitable concentration of droplets in the lower, with the minimum overdosing of the upper, levels. An alternative to split dose application for reducing the variability of deposits across the swath and within the canopy is to reduce the lane separation whilst maintaining the same spraying height. An application of 150 g fenitrothion in 1 litre spray per ha as a single spray, applied with 50 m lane separations from a height of 10-12m above the canopy, might well provide a sufficient probability that deposits in the lower canopy exceed 16-18 ng/cm of needle - a dosage level shown to result in high mortality. This expectation should be investigated in the 1980 spraying programme, with a view to removing uncertainties about terrain effects, larval size and exposure, and split dosing.

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Table 2.1

Parameters Describing Visibility of Droplets

	Average Drop Diameter 1 FP D_1	*Average Drop Diameter* 25 FP D_{25}	*Fraction of Emitted Spray with Particles* by Drops	*Fraction of Emitted Spray with Particles* by Volume
	(microns)			
Day I	34 (35)*	98 (101)	0.29 (0.27)	0.90 (0.91)
Day II	24 (28)	71 (82)	0.50 (0.40)	0.97 (0.95)

* Without brackets, linear averaging over tree foliage
With brackets, exponential averaging over tree foliage

Table 2.2

Ground/Tree Dosage Ratio (Percentage)

	'Small' Drops	*'Large' Drops*
Day I	9.5	2.1
Day II	2.1	0.8

Table 2.3

Spray droplet collection on needles of
Lodgepole pine: visible droplets/cm of needle

Canopy	*Strathy 1978* *300g a.i.: 1 l/ha*	*Annabaglish 1979* *75g a.i.: 0.5 l/ha* *Day I*	*Annabaglish 1979* *75g a.i.: 0.5 l/ha* *Day II*
Top	11.6	1.1 (2.2)	5.5 (11.0)
Middle	9.1		
Bottom		0.25 (0.5)	0.25 (0.5)
Mean	10.35	0.60 (1.20)	2.53 (5.1)

In brackets the 1979 droplet collections are normalised
for an application rate of 1 l/ha for comparison with 1978.

Table 2.4

Chemical deposits on needles of Lodgepole pine
ng/cm of needle

Canopy	*Strathy 1978* *300g/ha*	*Annabaglish 1979* *75g/ha* *Day I*	*Day II*
Top	257 (85.7)	25.0 (33.3)	76.8 (102.4)
Middle	201 (67.0)		
Bottom		5.6 (7.5)	3.5 (4.7)
Mean	229 (76.3)	13.4 (17.9)	35.3 (47.1)

In brackets the chemical deposits are normalised for an application rate of 100g (ai)/ha.

Table 2.5

Chemical deposits at ground level beneath Lodgepole pines
ng/cm^2 (x 0.1 in g/ha)

Ground	*Strathy 1978* *300g (a.i.)/ha*	*Annabaglish 1979* *75g (a.i.)/ha* *Day I*	*Day II*
ng/cm^2	135	27.6	14.8
ng/cm^2	(45)	(36.8)	(19.7)

In brackets the deposits are normalised for an application rate of 100g (ai)/ha.

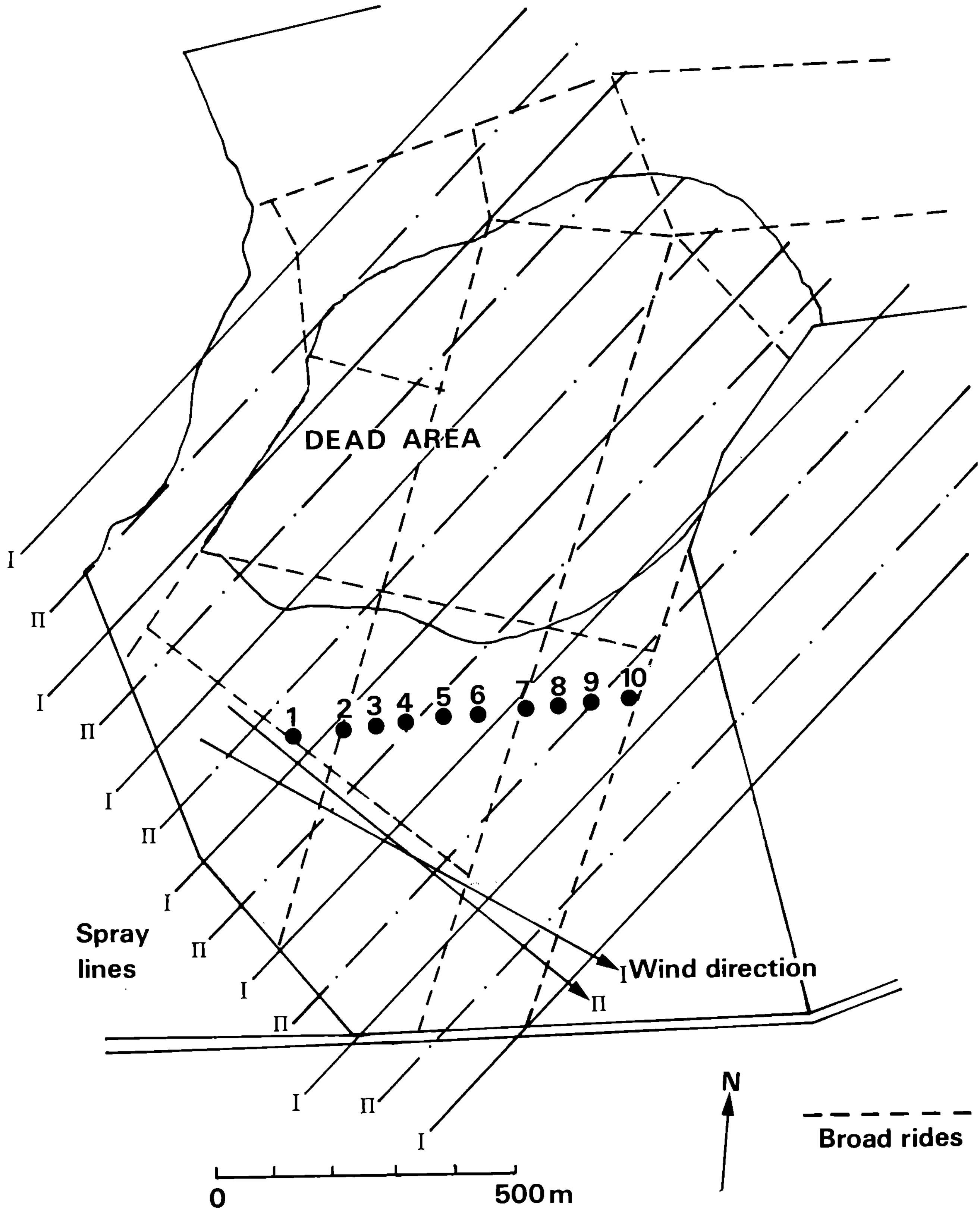

Figure 2.1. Annabaglish block of Bareagle Forest, LP/SS, P66.
Map showing spraying runs, wind direction on Days I and II of spraying and the position of sampling trees Nos 1-10.

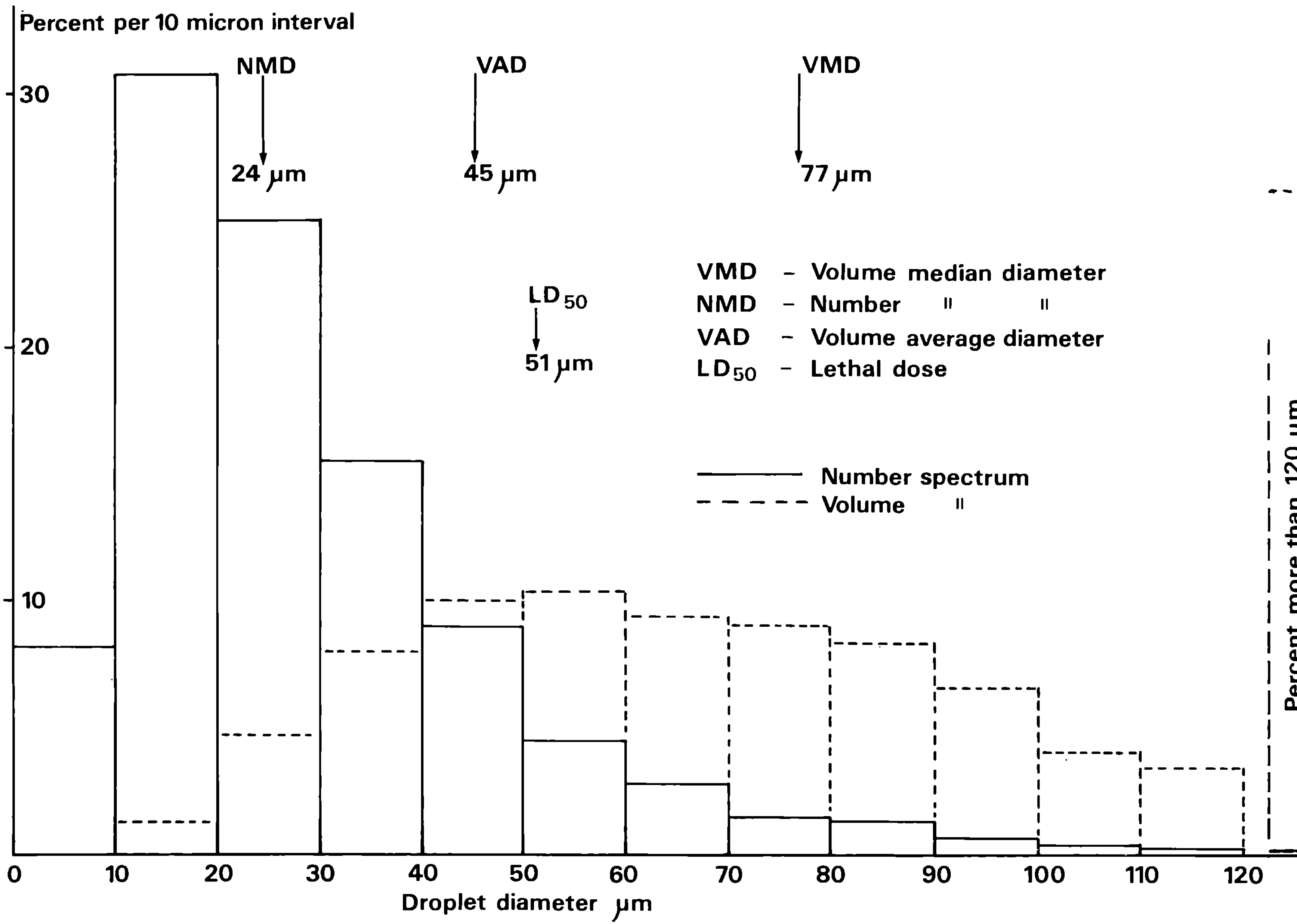

Figure 2.2 Distribution of droplets by number and volume related to droplet size.

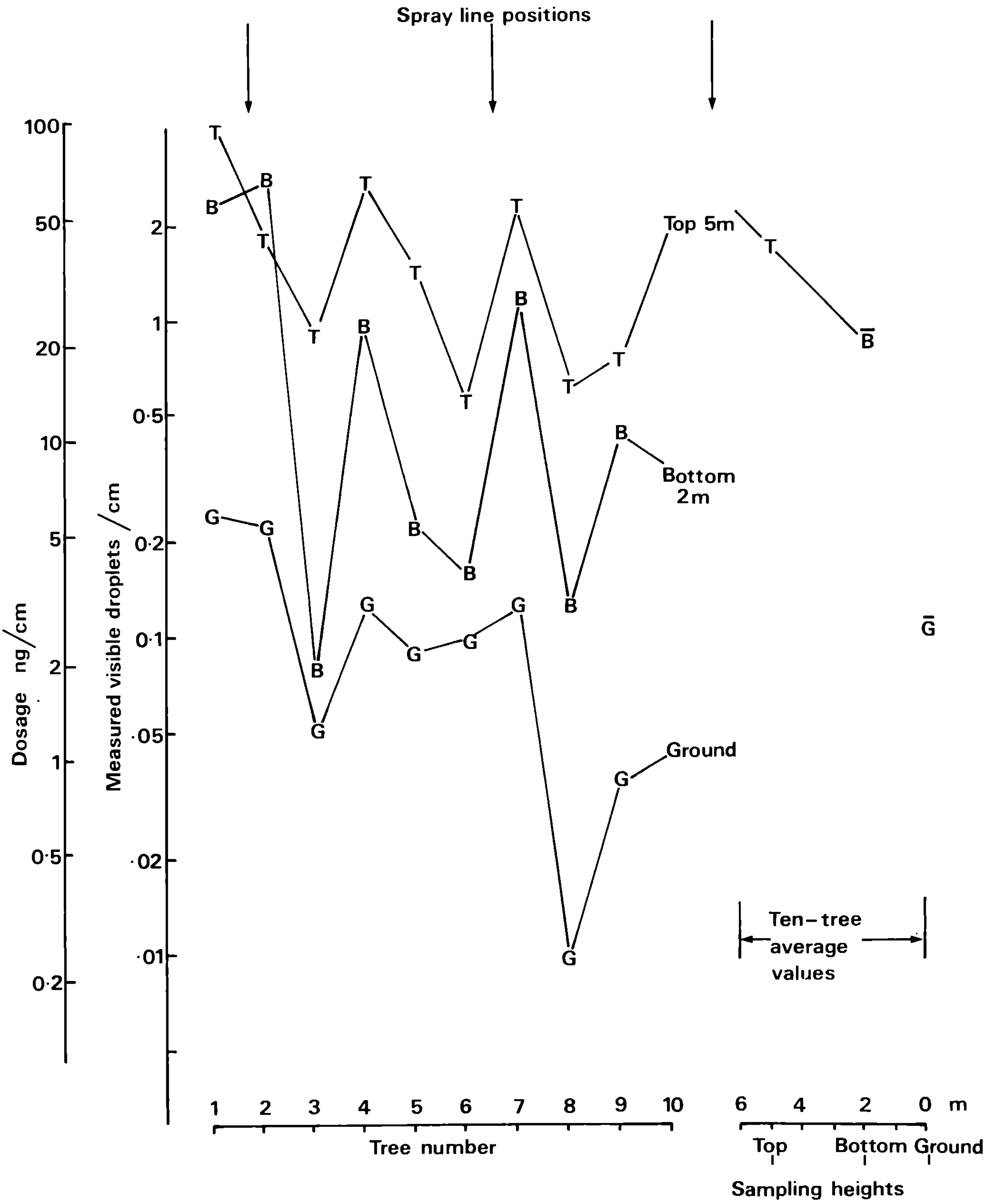

Figure 2.3. Distribution of small drops (D_1) on needles (number per cm length) at sampling heights on sample trees on Day I and equivalent dosage at ground level. Related chemical dosage (ng/cm) is shown on the left.

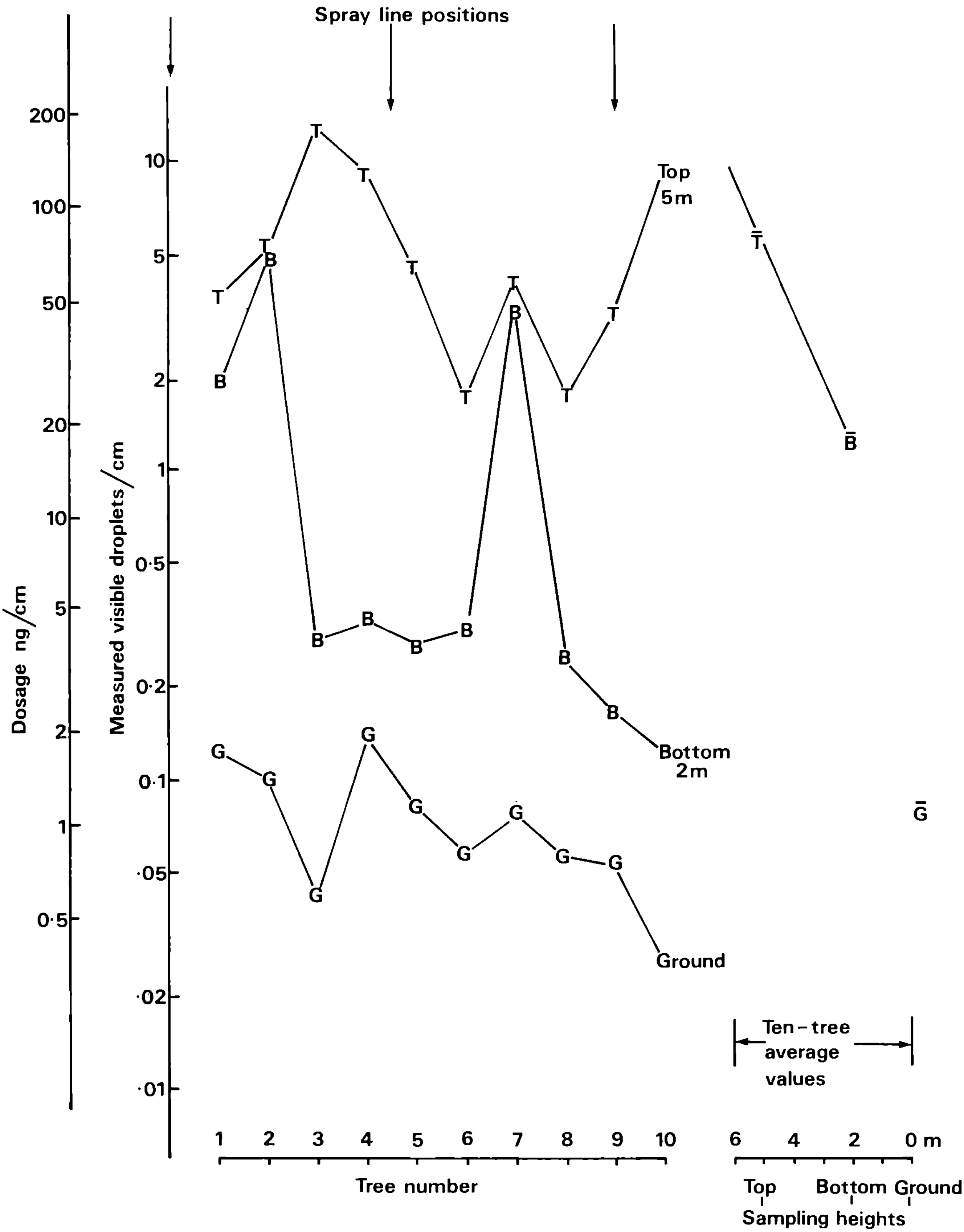

Figure 2.4 Distribution of small drops (D_1) on needles (number per cm length) at sampling heights on sample trees on Day II and equivalent dosage at ground level. Related chemical dosage (ng/cm) is shown on the left.

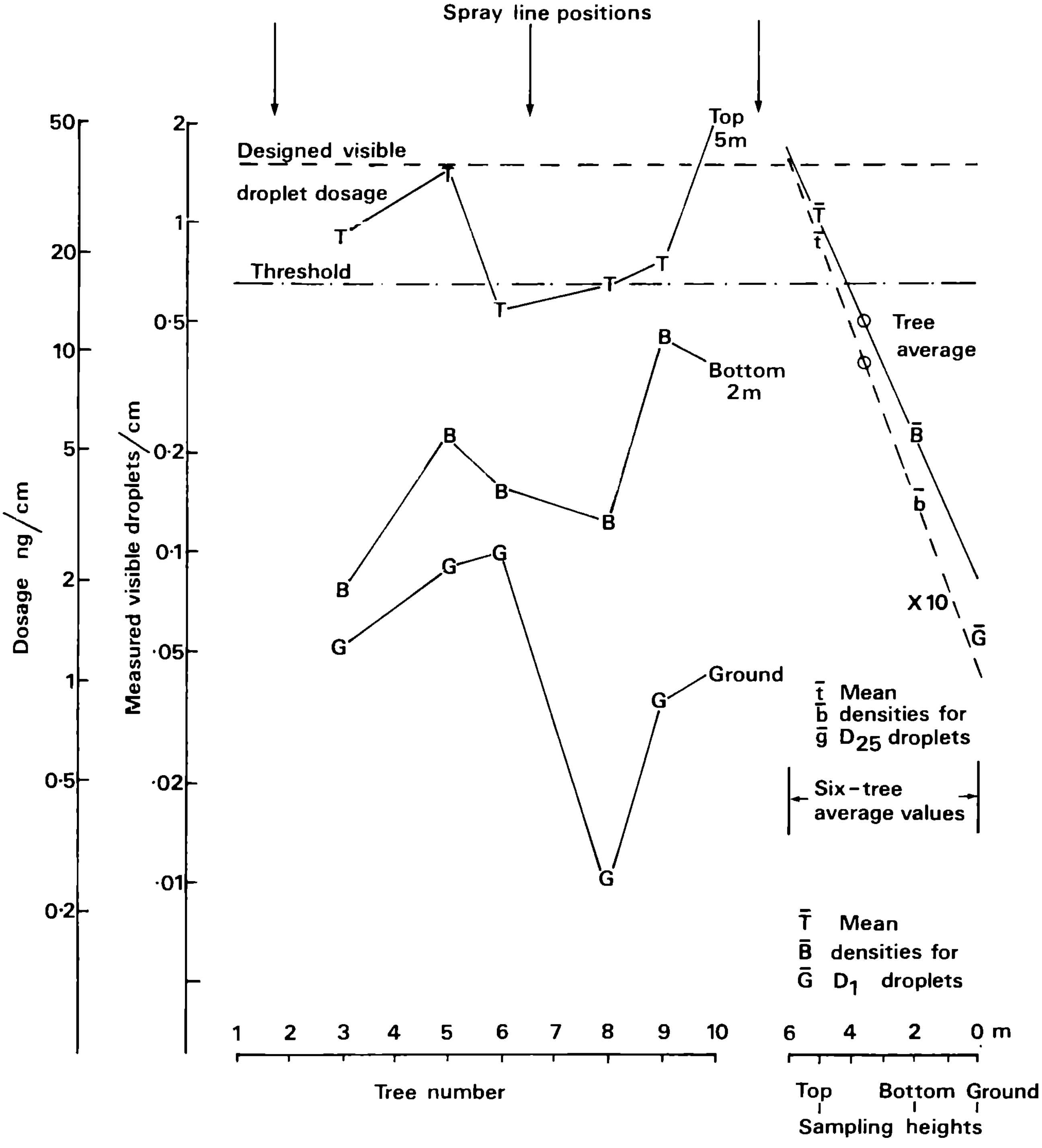

Figure 2.5 Day I dosage distribution except on trees (Nos 1, 2, 4 & 7) in open situation. Compare with Figure 2.3. Average dosage (times 10) of large D_{25} droplets is also shown.

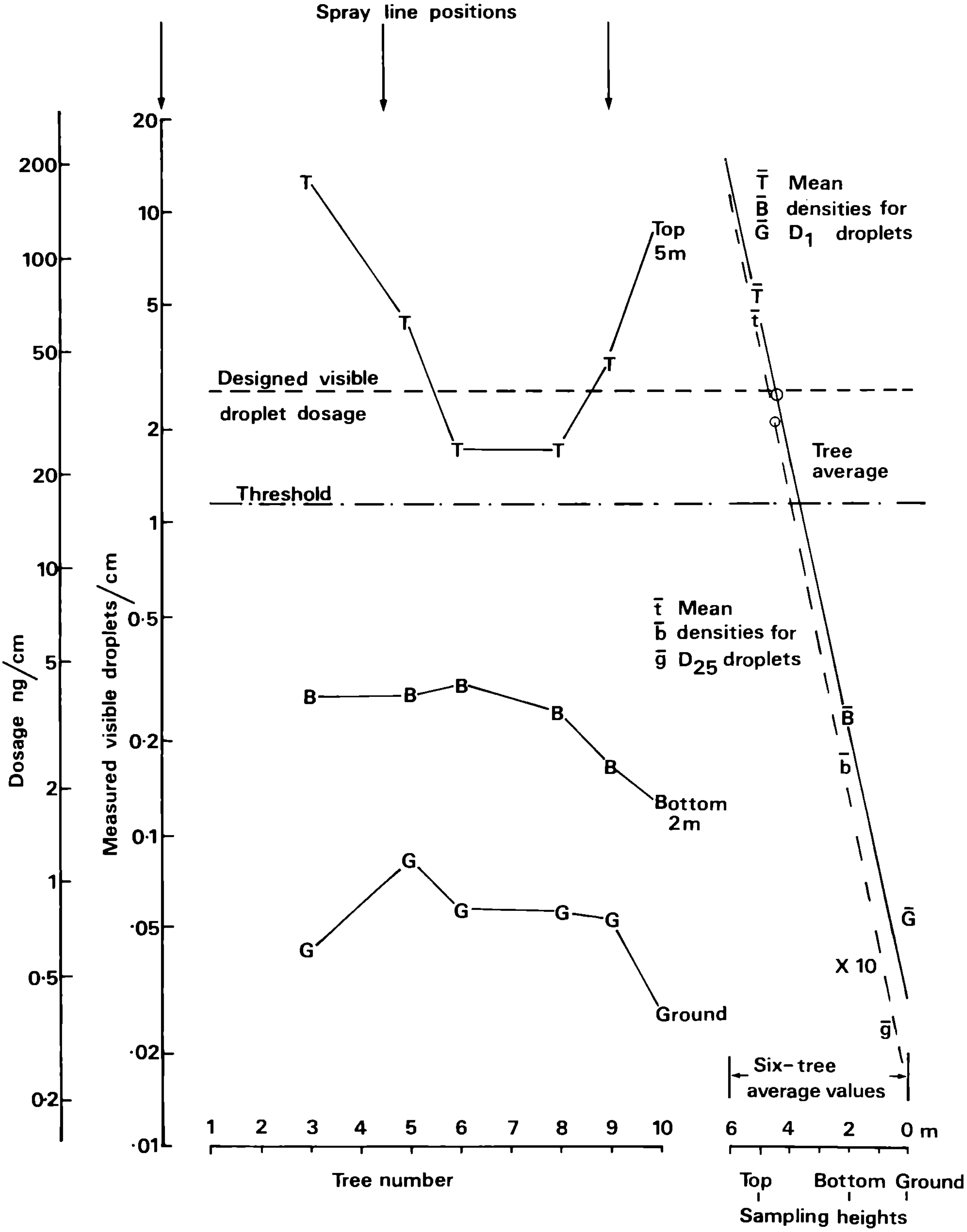

Figure 2.6 Day II dosage distribution except on trees (Nos 1, 2, 4 & 7) in open situation. Compare with Figure 2.4. Average dosage (times 10) of large D_{25} droplets also shown.

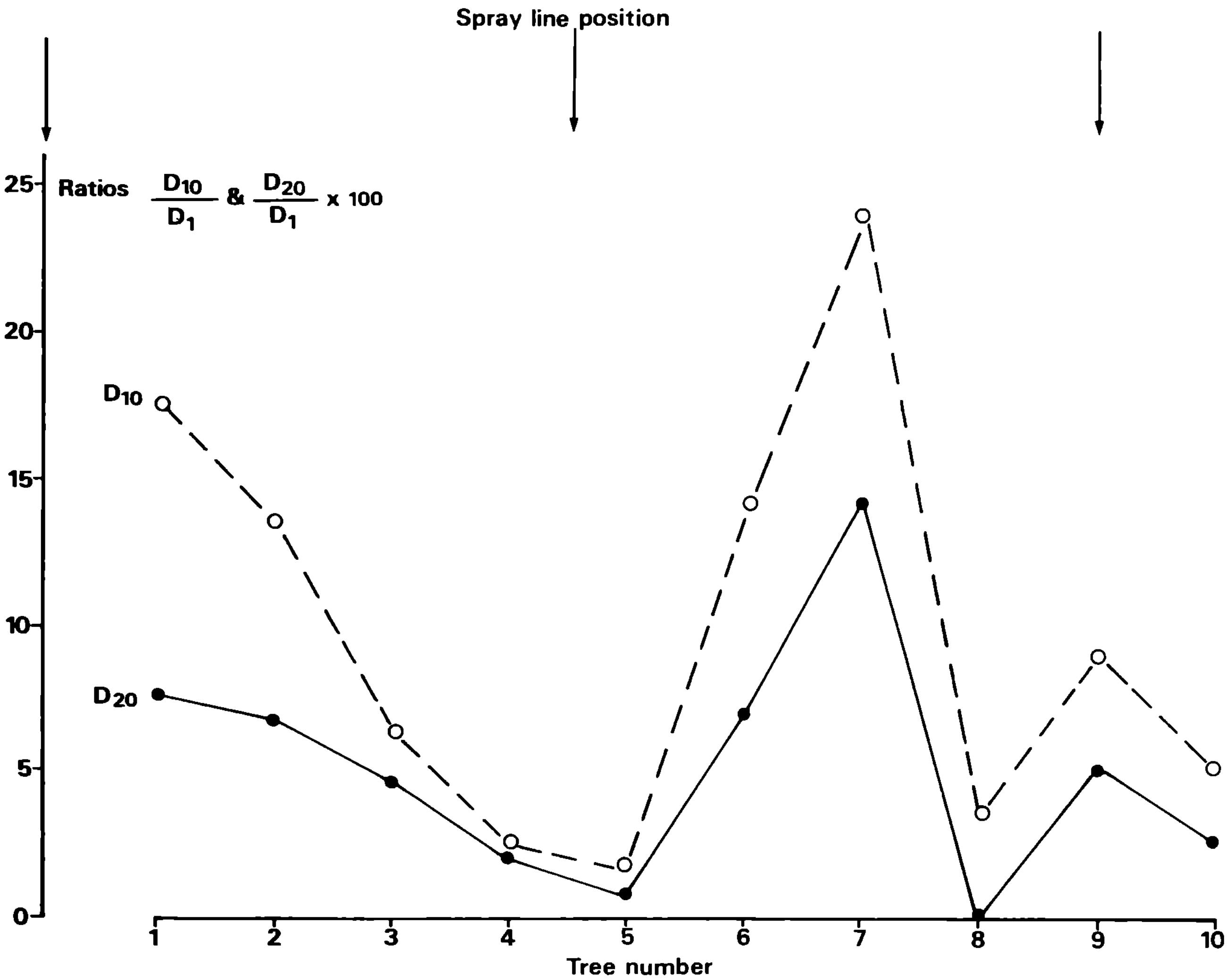

Figure 2.7 Droplet size (chemical dosage) distribution on ground levels at all sample trees. Dosage proportional to 10 (D_{10}) and 20 (D_{20}) fluorescent particles per drop.

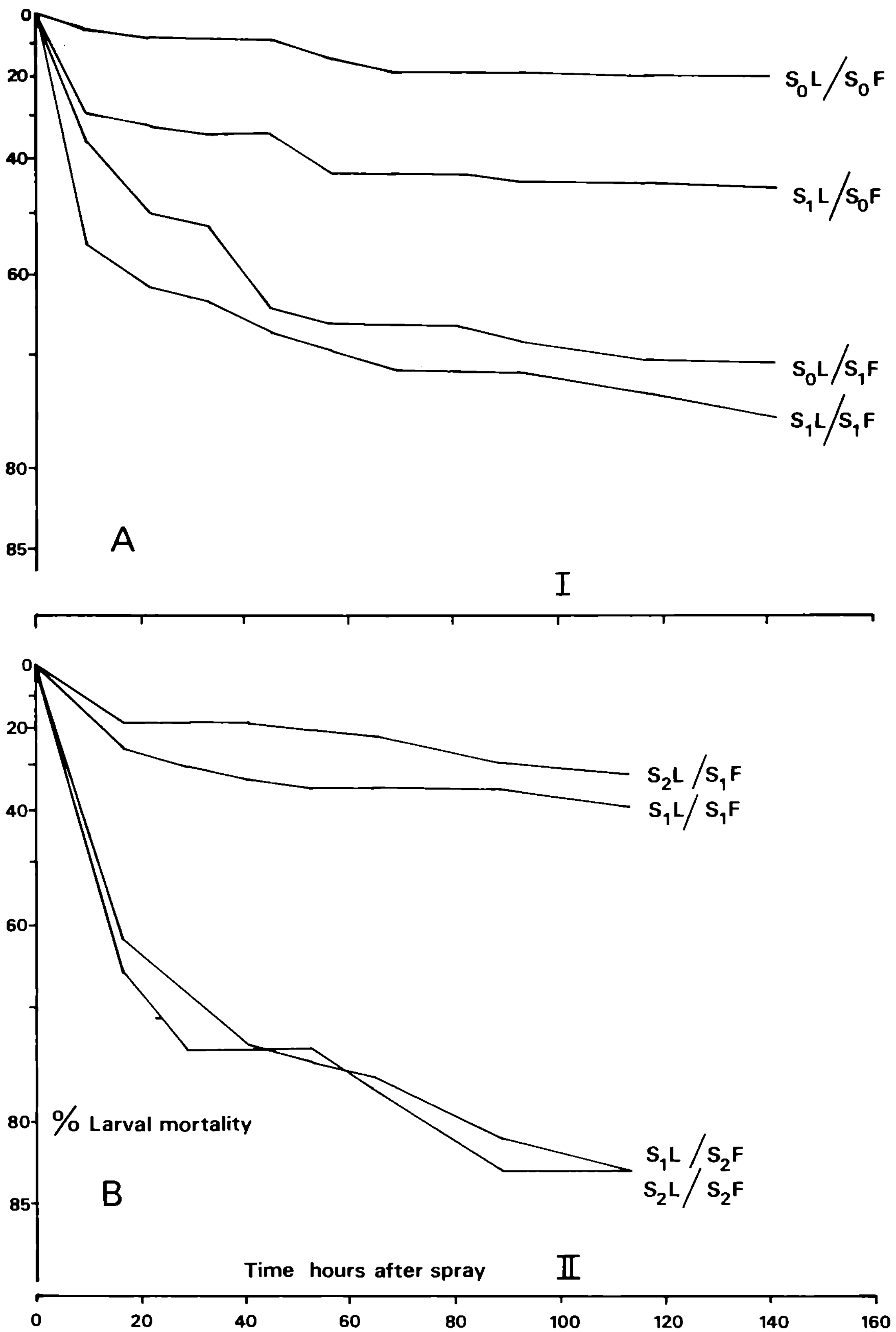

Figure 2.8 Variation in mean larval mortality over all sample trees recording to no (S_0), one (S_1) or two (S_2) sprays on larvae (L) or foliage (F)

A - assessment after Spray I

B - assessment after Spray II

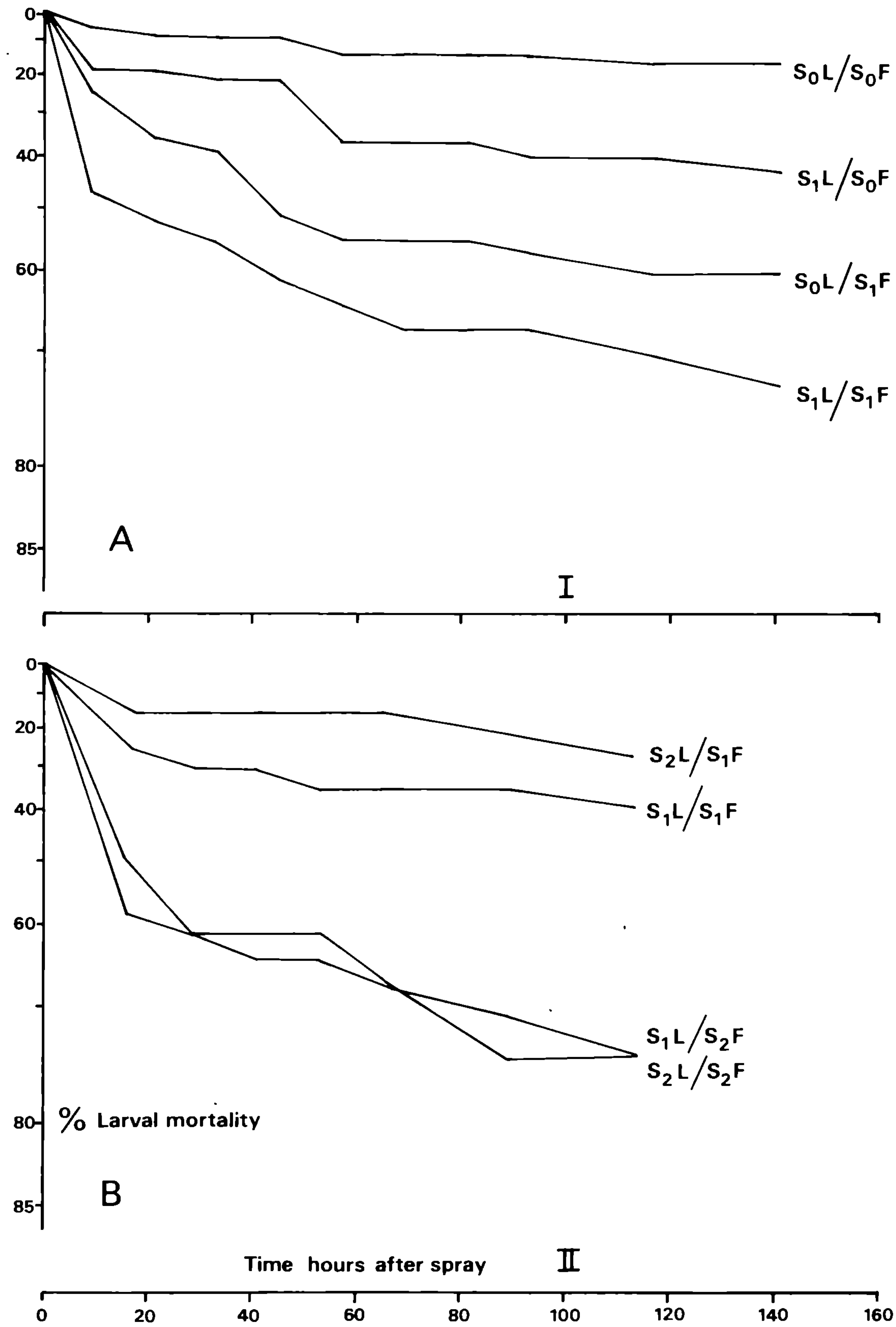

Figure 2.9 Variation in mean larval mortality over all sample trees except those (Nos 1, 2, 4 & 7) in open situations, recording to no (S_0), one (S_1) or two (S_2) sprays on larvae (L) or foliage (F).

A - assessment after Spray I
B - assessment after Spray II

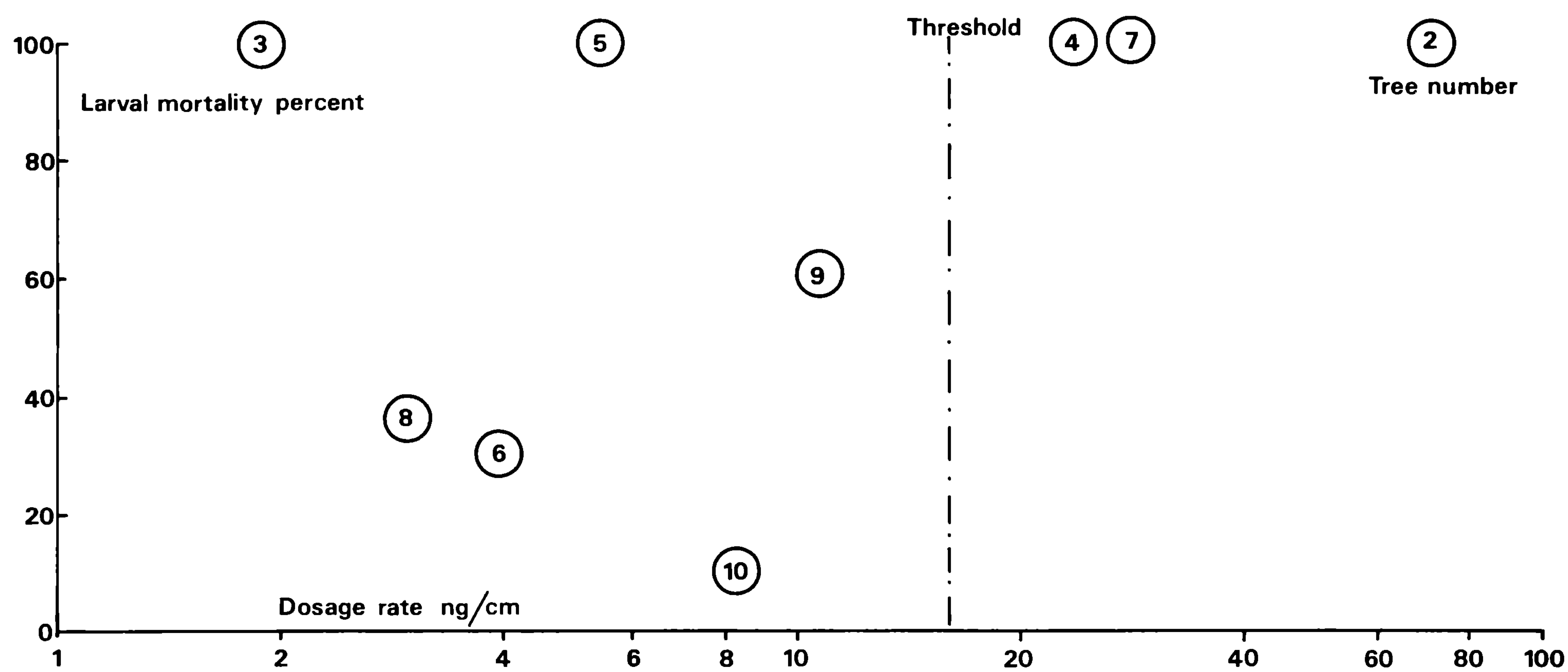

Figure 2.10 Relationship at Spray I + 48 hours between mortality and dosage rate on nine sample trees.

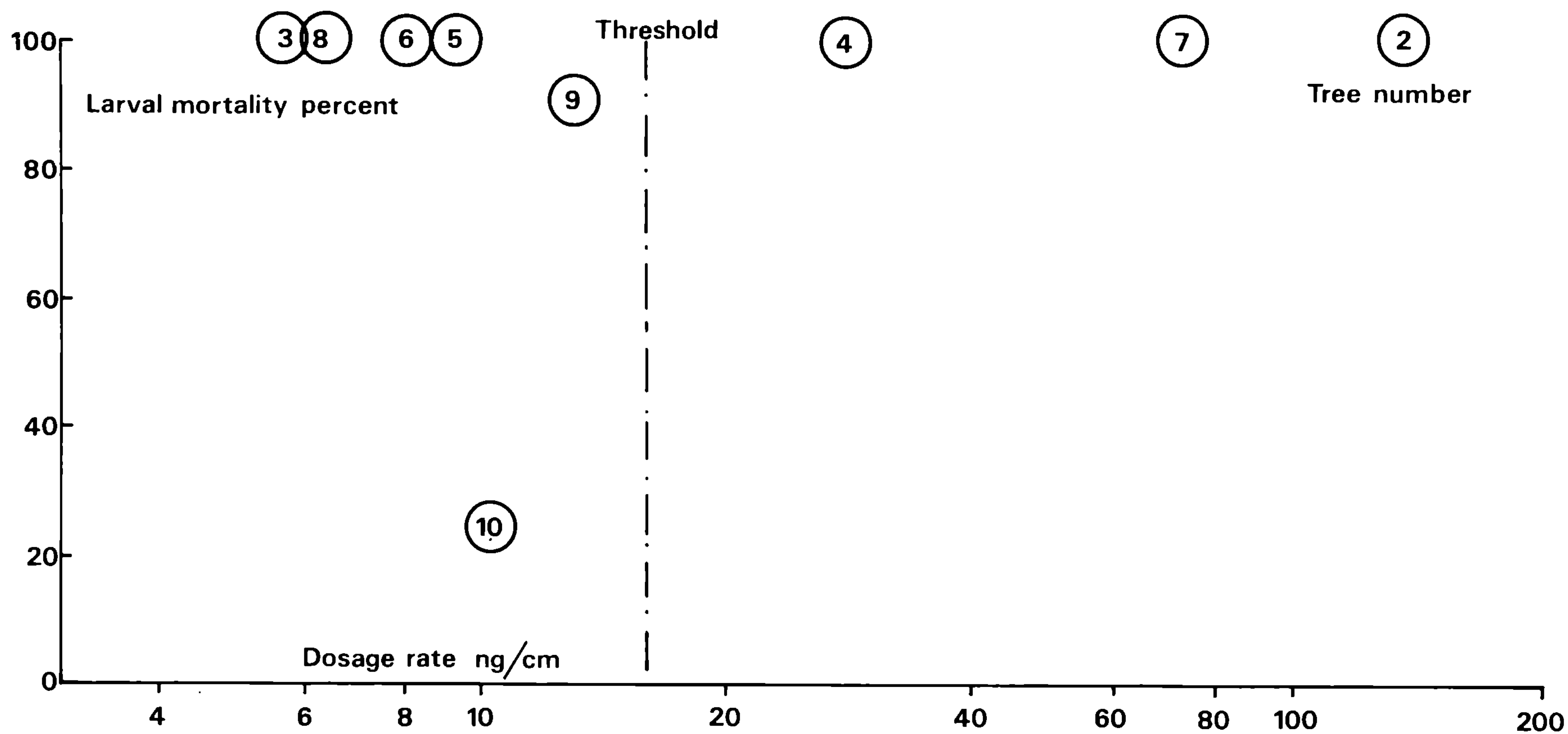

Figure 2.11 Relationship between dosage and total larval mortality on nine sample trees after Spray I + Spray II.

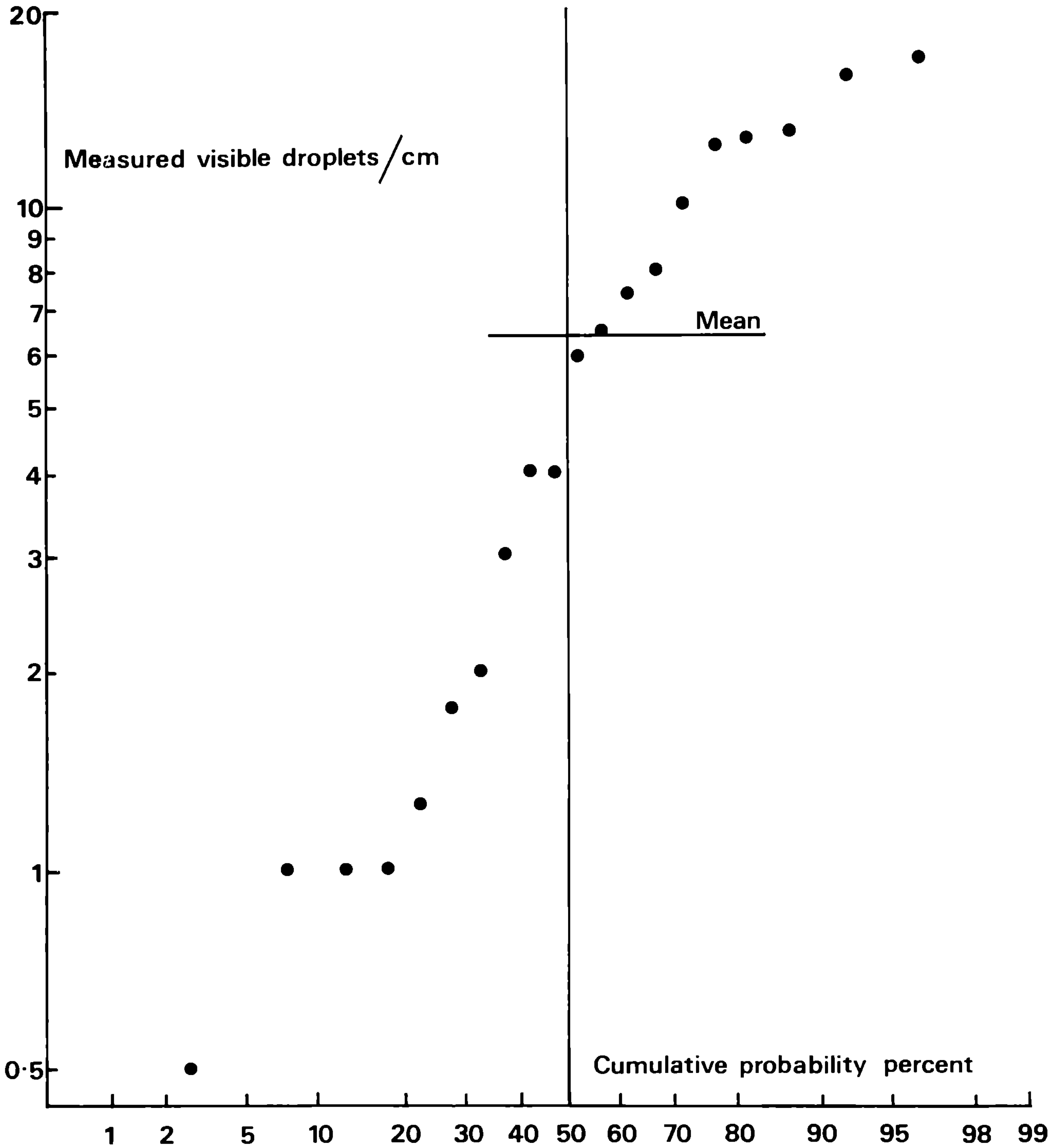

Figure 2.12 Distribution of droplets per cm of needle on 20 sample needles on a branch tip on the windward side at the top (5m level) on Tree 1.

Chapter 3

A FIELD STUDY OF THE EFFECT OF ULV SPRAYING ON SUBSEQUENT TREE DEFOLIATION AND PUPAL DENSITY AT ANNABAGLISH

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INTRODUCTION

In June 1979 experimental larval spraying was carried out in 150 ha of the Annabaglish section of Bareagle Forest, Galloway, where the Forestry Commission had planted Lodgepole pine *(Pinus contorta)* in 1966. The experiment consisted of applying two separate sprays, on 13th and 15th June (hereafter called Day I and Day II), each at a quarter of the standard dosage; 75g a.i./ha rather than 300g.

A comprehensive report by Schaefer and Allsopp was submitted to the Forestry Commission in 1979 and is reproduced here in somewhat modified form as Chapter 2. It contains a description of the forest, the spraying operation, the experimental layout, and an analysis of the distribution of spray droplets and an assessment of larval mortality. Figure 2.1, p.35 shows a plan of the forest, the spray lines and a line of 10 trees sampled intensively for spray droplets. These were sampled from branch tips taken from the four cardinal aspects at the top ($\overline{T}$) and at the base ($\underline{B}$) of each tree.

THE FIELD STUDY OF AFTER-EFFECTS; NOVEMBER 1979

The authors pointed out in Chapter 2 the probable existence of a spray dosage threshold for high mortality, and gave a rough estimate of its value, in ng/cm of needle. Some of the 10 trees were much 'underdosed', particularly at their bases, while others were 'overdosed', relative to this estimated threshold. This wide differential ought to have had large effects on subsequent tree defoliation (bases and tops) and on resulting pupal density. We felt this should be investigated after the end of the moth season and that a new understanding of how to spray a forest ought to emerge.

Five members of Ecological Physics Research Group returned to Annabaglish in the period 12-21st November 1979, to undertake defoliation and pupal surveys. Here are described the techniques used, the data collected, and the results of their analysis.

THE SURVEY FOR PUPAL DENSITY

R. Cannon was responsible for carrying out the survey. The team members were grateful for the important assistance of two Forestry Commission workers, sometimes in snow and ice.

Samples were taken from around the bases of 10 trees which had been marked out prior to spraying in June (Figure 2.1, p. 35). A standard metal frame was used to sample a 30 cm square area down to a depth of 15 cm. Samples were sorted in the field. Any pupae found were placed in tubes for closer examination in the laboratory.

Ten site maps were prepared showing the exact position of the sample sites in relation to the base of the tree bole, the perimeter of the local tree cover overhead (dashed-dotted curve), the ditches (speckled) and the planting ridge (straight dashed lines). Figure 3.1 (p. 56) gives one example, that of Site Tree No.1. (Other site maps may be obtained from the Forestry Commission).

The pupae were divided into live pupae and pupae with fungus. The data are presented in Table 3.1, which also contains the calculation of the mean number of pupae/m^2 for each tree.

DEFOLIATION SURVEY

Each of the 10 trees was assessed for defoliation damage caused by the larvae. Each tree was considered to consist of 3 sections, or height intervals, of approximately 2m extent; bottom, middle and top. Each of these sections was given a score for percentage defoliation based on a visual assessment of the proportion of green needles that had been consumed. Brown needles were ignored. The percentage data are given in Table 3.2. A short description (lodged with the Forestry Commission) of each tree section was usually made, except when there was no defoliation.

Each of these three vertical sections of the tree contains a percentage of the total foliage, which we have guessed as 50, 35 and 15 percent, ascending the tree. Multiplying the defoliation percentage figures by these proportions gives a total adjusted defoliation value for each tree, shown in the final column of Table 3.2.

MEASURED CHEMICAL DEPOSITS ON SAMPLED NEEDLES

Graphical evidence of the chemical dosage, in ng/cm of needle, for the top 5m and basal 2m of each of the 10 trees is set out in Figures 2.3 and 2.4 (pp.37 and 38) for Days I and II respectively. The sampled needles from the four cardinal aspects of each tree were pooled for this purpose. We repeat this data in numerical form in Table 3.3.

In Chapter 2 we also computed a mean tree dosage by assuming that the amount of foliage varied linearly with distance from the top of the tree, and also that the deposit was distributed linearly over the tree, passing through the top and bottom measured values. This we called the 'linear' tree mean dose. We repeat this data in numerical form at the right hand side of Table 3.3. The calculations and techniques underlying these data are given in Chapter 2.

DISCUSSION OF RESULTS

DEFOLIATION IN RELATION TO CHEMICAL DOSAGE - TREE BASES

We have plotted in Figure 3.2 the percentage defoliation (Table 3.2) for both the tops and bases of the trees, against the total dosage rate for the tops and the bases of the same trees. The 'total dosage' is the summation of the two separate doses given the trees on Day I and Day II. The points referring to the bases of the trees have the tree number underlined. Note that 3 of the tree sites (1, 2 and 7) had some parts or all parts with zero defoliation, and since the plot of

Figure 3.2 is probit, these points could not be plotted. We have taken the liberty of including them, however, on the 0.1 per cent line.

Refer first to the 10 values for the tree bases. We have chosen tree bases first because Cahpter 2 shows clearly these dosages frequently fell below what we thought was a threshold dosage for high mortality. We therefore expected a large variation in defoliation as a function of chemical dosage at tree base.

It will be seen that there is a strong linear correlation, and we have indicated a reasonable best fit by the heavy continuous line (B). On this line we have marked the 5, 50 and 95 per cent defoliation points as solid circles. This is a very satisfactory correlation, as it shows, as expected, that defoliation increases in a regular manner as the chemical dosage decreases.

We did not expect such a good correlation because the population of larvae on individual trees probably varied considerably from tree to tree, and in any case was unknown; thus the degree of defoliation should be rather variable for the same chemical dosage, particularly for the smaller dosages. The fact that wide variations about the correlation line are absent gives a slight hint that tree larval populations, at the time when most defoliation is taking place, are rather uniform. We shall have more to say about this point below.

A tentative conclusion from Chapter 2 was that there existed a threshold for 50 per cent mortality near to 16 ng/cm, judged by larval mortality measured in containers where sampled larvae were placed on sample sprayed foliage. This 'threshold' is indicated by a dashed horizontal line in Figure 3.2, labelled A. Its value is not very different from the 50 per cent point of the correlation line (labelled B), at 20 ng/cm. This suggests a common explanation.

Naturally, we would not expect a 'threshold' to be sharp or sudden, but rather it would represent an LD_{50} value, around which the mortality, and hence the defoliation, would vary more or less steeply. If we take the correlation line B literally, then the 5 per cent defoliation value occurs at a dosage of about 50 ng/cm, which is 2.5 times greater than the 50 per cent defoliation value. Speaking very approximately, this ratio would be near that expected for LD_{95}/LD_{50} ratio. We have transcribed the correlation line B onto Figure 3.3, which has been reproduced from data in the previous Chapter. The Figure 3.3 also contains the previous 'threshold', marked A. In this transcription we have used the old per cent larval mortality axis as equivalent to the new (100 - per cent defoliation) axis; obviously this is not exact, but is meant as a qualitative guide. The main point is to show the degree of steepness in the threshold region.

In conclusion, we feel we have arrived at a semi-quantitative relationship between needle chemical dosage and defoliation, which should be of some use in planning for future control programmes.

DEFOLIATION AND CHEMICAL DOSAGE - TREE TOPS

Refer now to the values for tree tops in Figure 3.2. It is clear that they do not follow the same correlation as that established for the tree bases. If they had done, the defoliation would have been negligible, considering the dosages received at the tops. But, in fact, there is noticeable, or even worrying, defoliation levels, reaching as high as 50-60 per cent. This result is quite surprising, and was not suggested in Chapter 2, where it was assumed that the tree tops would have been completely protected. (Since the top defoliation was in fact never complete, there is no alarm about the survival of that particular forest).

One way of accounting for some defoliation in the presence of heavy dosage, is to assume that the larvae which survive spraying at tree base are mobile and some reach the tree tops. (In fact, during the Chicken Dhu field experiments in June 1980 in northern Scotland, we obtained direct evidence (p. 51) of such a larval migration after spraying). We would therefore suggest that this is the explanation for these unexpected results. Presumably there are too many survivors at tree base for the available food supply, and dispersion of the older, larger larvae occurs. This conclusion is supported by the evidence below.

PUPAL DENSITY IN RELATION TO CHEMICAL DOSAGE

In Figure 3.4 we present the measured values of pupal density against total tree base dose rate. It is evident that there is a moderate degree of anti-correlation between these two variables, with less than 20 pupae/m^2 surviving the 50 per cent 'threshold' dosage of 20 ng/cm. This result is more or less expected, since possibly most survivors of spraying are from tree base levels.

This result should be compared with that shown in Figure 3.5 where pupal density is plotted against tree mean dosage (based on the 'linear' approximation as explained already). This time the anti-correlation is less clear-cut (because of the much shorter base line along the dosage axis). The comparison indicates again (as in the two preceding sections) that most of the pupae originate as larvae surviving spraying near tree bases.

If the larval populations varied greatly from tree base to tree base, we would not have expected the relatively small degree of variation in the correlation of Figure 3.4. We tentatively conclude once again that tree larval populations are in fact rather uniform throughout the forest in the older age classes.

PUPAL DENSITY IN RELATION TO DEFOLIATION

In Figures 3.6 and 3.7 we present the measured pupal densities in relation to percentage defoliation, at tree bases and for tree mean respectively. In each case we find a reasonable correlation, with pupal density increasing with percentage defoliation as expected.

Comparing these two Figures, we note that the scatter is apparently more significant in the case of tree bases. For example, defoliation can vary from 50 to 98 per cent, and yet the resulting pupal density can be the same (Figure 3.6). We have already argued that it is the larvae nearer tree bases which escape most from spraying effects, and yet the defoliation they produce is not closely correlated with pupal density (Figure 3.6). This supports again the hypothesis that many of the pupae resulting from these tree base survivors have subsequently migrated to higher tree levels for improved food supplies.

The relatively small degree of variation in Figure 3.7 hints again that there are not large variations in surviving older larvae tree-by-tree. This might be the result of fairly uniform egg laying by the female moths. It is probable that this evenness of population is not the result of competition between the surviving larvae for food supplies on a whole tree basis (since the highest tree mean defoliation is only 82 per cent) although competition is quite likely at tree base, as we have seen.

We think it is likely that as the defoliation approaches 100 per cent, the pupal density will saturate, and there is some indication of this happening already in Figure 3.7; the pupal density rises sharply as 90 per cent tree defoliation is reached. The maximum density might be expected to be near $200/m^2$, a value corresponding (within a factor of 2, say) to tree defoliation of 95 per cent (when presumably competition would be severe and pupal numbers would saturate).

COMMENT

When the field data were first inspected in December 1979, we were able to understand a few of the more obvious conclusions. As a result of recent field research in northern Scotland (late June 1980), we have reached a (slightly) deeper understanding, which we have tried to bring out in the present account. It is likely that when we have prepared our report on northern Scotland, additional meaning will be discovered, and the present data will become even more useful.

Table 3.1

A Survey of Pupal Density

	Live Pupae	*Pupae with Fungus*	*Total Pupae Found*	*Area Sampled (quadrats)*	*Mean Pupae per m^2*
Tree 1					
Sample 1	0	0	0	1	
2	1	1	2	1	
3	0	1	1	1	
4	0	0	0	1	
Total	1	2	3	4	8.4
Tree 2					
Sample 1	0	0	0	1	
2	0	0	0	1	
3	1	0	1	1	
4	1	0	1	1	
Total	2	0	2	4	5.5
Tree 3					
Sample 1	0	0	0	1	
2	3	0	3	1	
3	3	0	3	1	
4	4	1	5	1	
5	0	0	0	1	
6	3	0	3	1	
7	1	0	1	1	
8	2	0	2	1	
*(9	0	1	1	1)*	
10	4	0	4	1	
Total	20	1	21	9	26.0
Tree 4					
Sample 1	1	0	1	1	
2	3	0	3	1	
3	1	0	1	1	
4	0	0	0	1	
Total	5	0	5	4	19.0
Tree 5					
Sample 1	1	1	2	1	
2	0	1	1	1	
3	2	0	2	1	
4	4	3	7	1	
Total	7	5	12	4	33.0

Table 3.1 (contd)

A Survey of Pupal Density

	Live Pupae	*Pupae with Fungus*	*Total Pupae Found*	*Area Sampled (quadrats)*	*Mean Pupae per* m^2
Tree 6					
Sample 1	7	0	7	1	
2	7	1	8	1	
3	7	2	9	1	
4	2	0	2	1	
*(5	1	1	2	1)*	
6	7	0	7	1	
7	8	2	10	1	
8	9	1	10	1	
Total	47	6	53	7	84.0
Tree 7					
Sample 1	0	0	0	1	
2	0	0	0	1	
3	1	0	1	1	
4	2	0	2	1	
Total	3	0	3	4	8.4
Tree 8					
Sample 1	1	0	1	1	
2	2	1	3	1	
3	2	0	2	1	
4	0	0	0	1	
Total	5	1	6	4	17.0
Tree 9					
Sample 1	3	0	3	1	
2	0	1	1	1	
3	0	0	0	1	
4	2	1	3	1	
Total	5	2	7	4	19.0
Tree 10					
Sample 1	1	0	1	1	
2	1	3	4	1	
3	0	0	0	1	
4	0	1	1	1	
Total	2	4	6	4	17.0

* Omitted as not under tree canopy.

Table 3.2

Defoliation Survey (Percentage Defoliation)

Tree Site	*Tree Levels* *Lower*	*Middle*	*Upper*	*Percentage of Total Canopy Defoliated*
1	0	0	0	0
2	0	0	0	0
3	90	70	5	70.25
4	70	80	30	67.5
5	50	75	40	57.25
6	90	80	60	82.0
7	2	0	0	1.0
8	98	50	5	67.25
9	85	70	50	74.5
10	60	20	10	38.5

Table 3.3

Chemical Deposit on Sampled Needles (ng/cm)

	Day 1		*Day 2*		*Total Dose*		*Tree Mean*
Tree	*Top*	*Bottom*	*Top*	*Bottom*	*Top*	*Bottom*	*Dose*
1	97	57	52	27	149	84	113
2	44	68	73	68	117	136	128
3	22	1.95	175	4	197	5.95	91
4	65	23	127	4.5	192	27.5	101
5	34	5.4	63	3.9	97	9.3	48
6	13	3.85	24	4.3	37	8.15	21
7	56	28	58	46	114	74	92
8	15	3.0	24	3.4	39	6.4	21
9	18	10.5	44	2.3	62	12.8	35
10	48	8.2	125	1.7	173	9.9	82

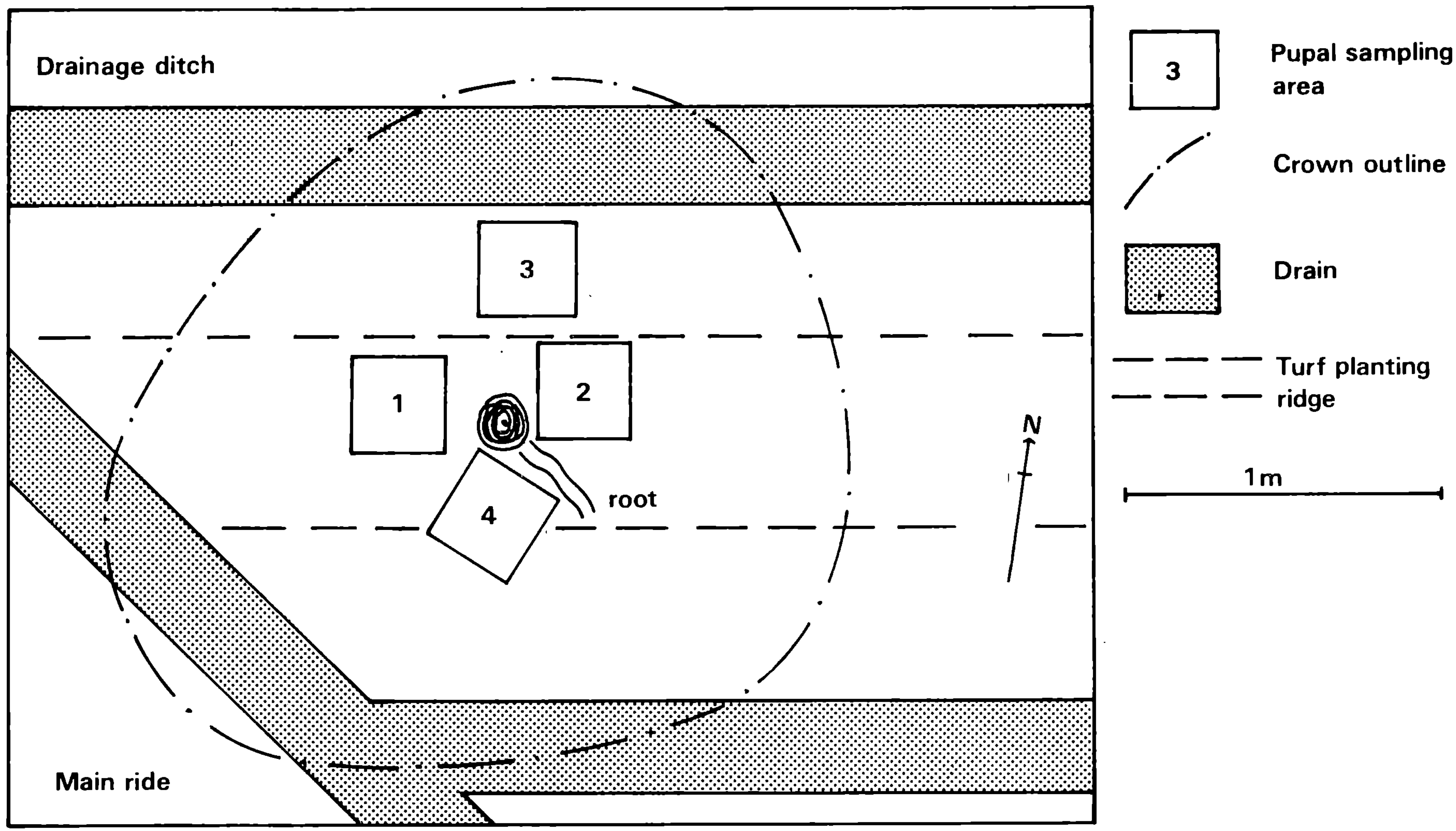

Figure 3.1 An example of sample tree survey (Tree 1) described on p.

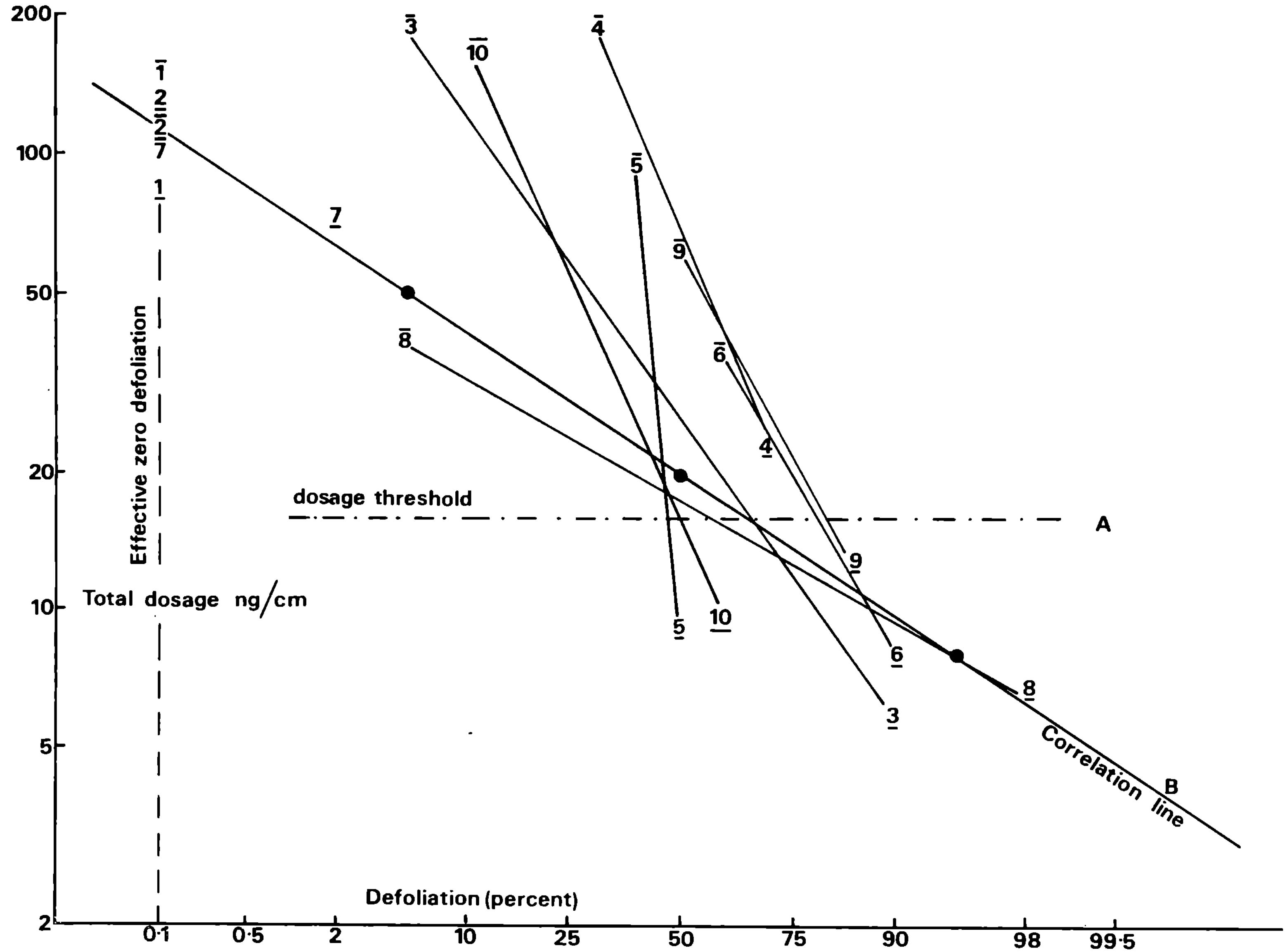

Figure 3.2 Relationship between chemical dosage and defoliation. Top (T̄) and bottom (B̲) levels of sample trees Nos 1-10.

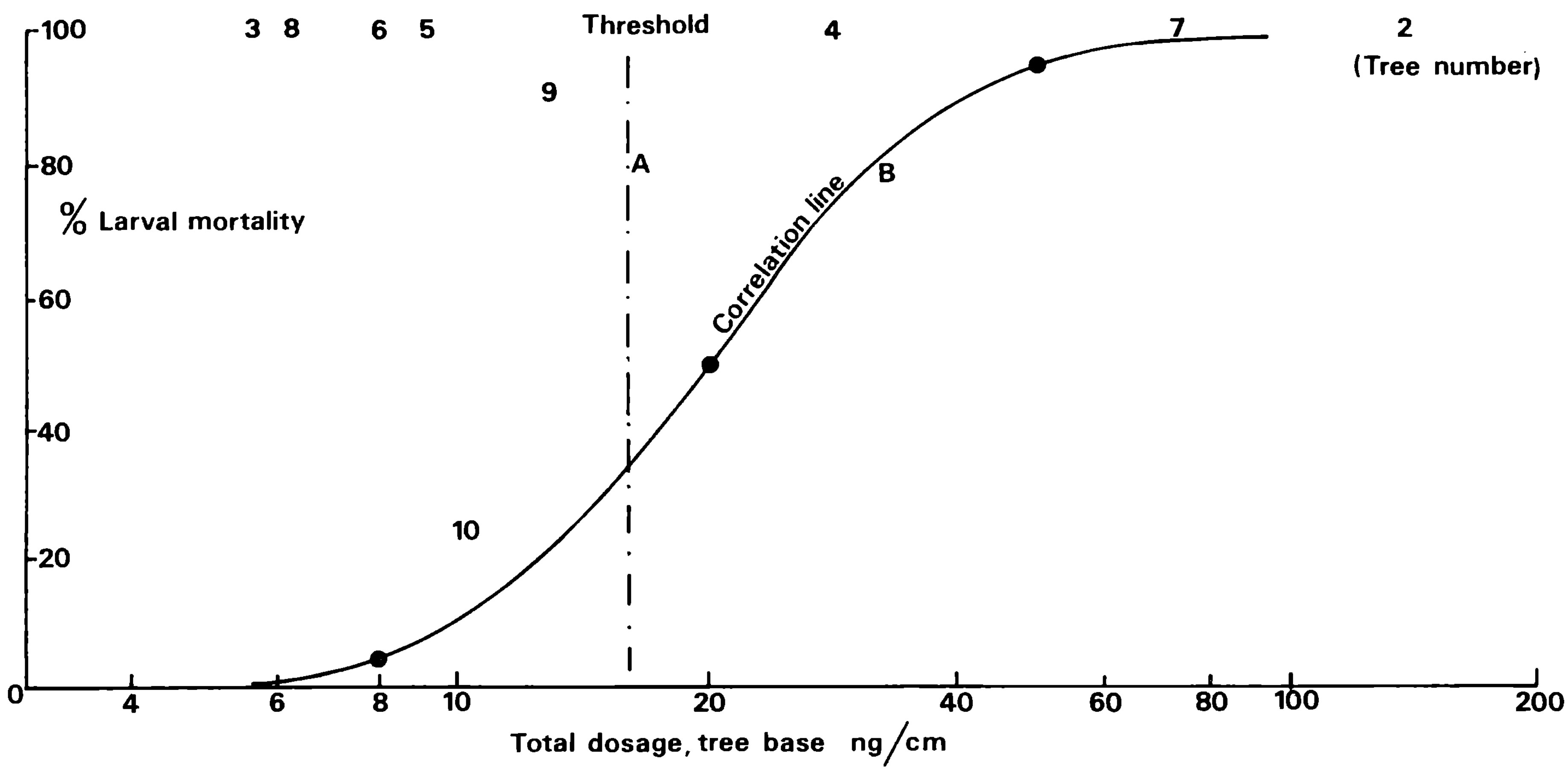

Figure 3.3 Relationship between total larval mortality at tree base from Sprays I and II and the total dosage at that level (trees 2-10 only).

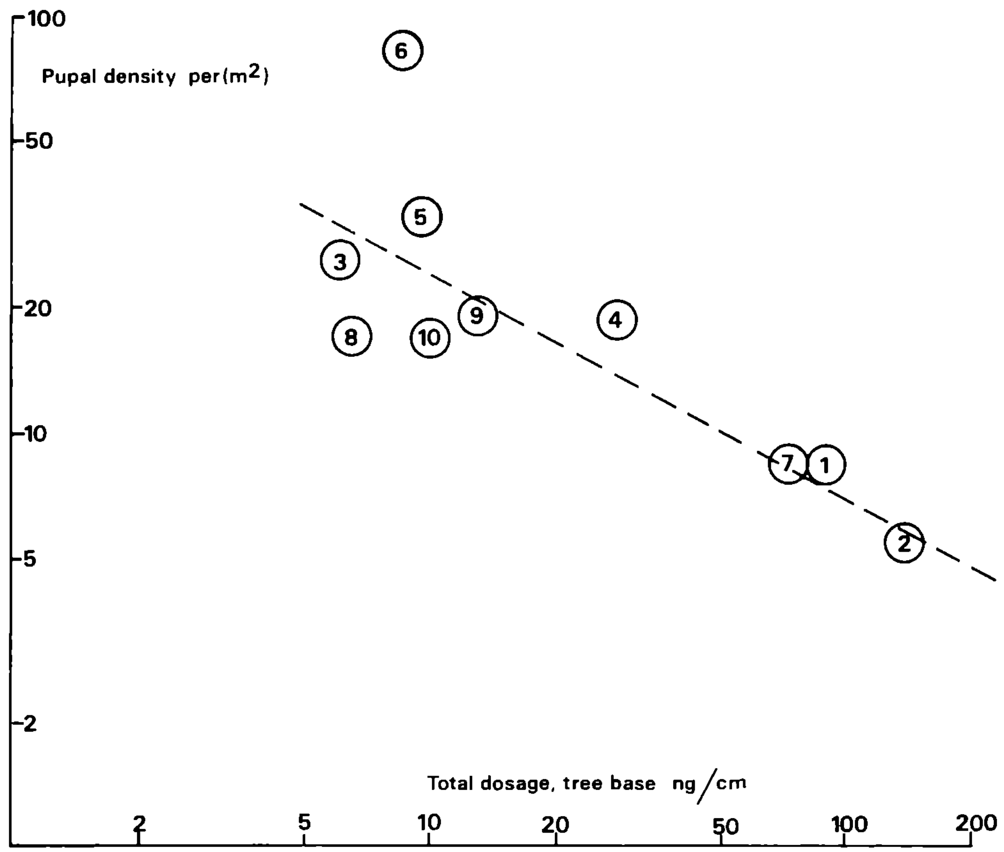

Figure 3.4 Relationship between total dosage at tree base with pupal density at all sample sites.

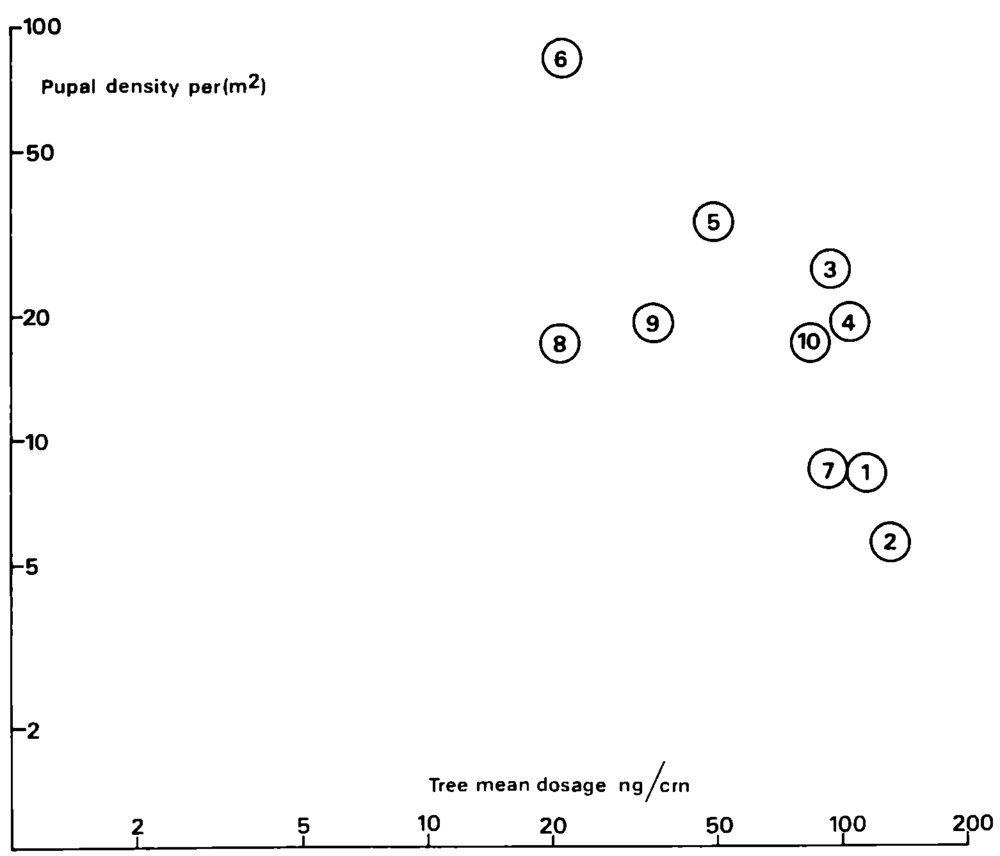

Figure 3.5 Relationship between tree mean dosage and pupal density at all sample sites.

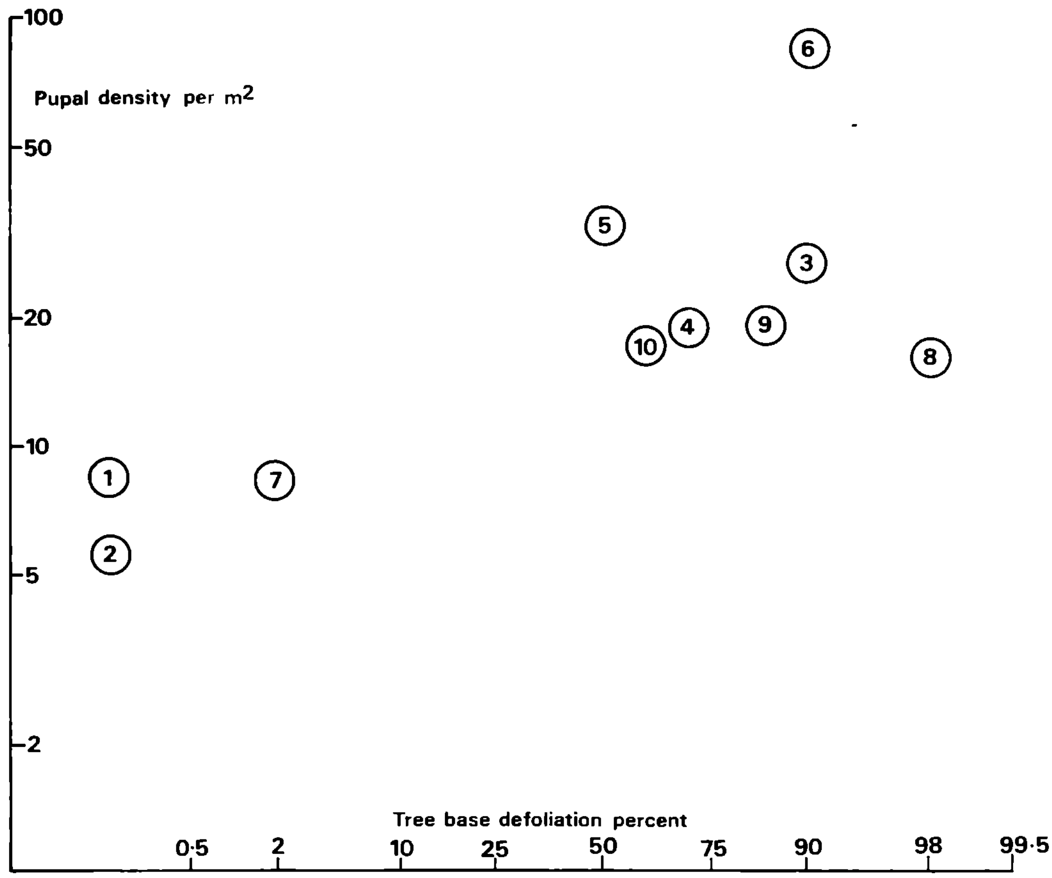

Figure 3.6 Relationship between defoliation at tree bases and pupal density at all tree sites.

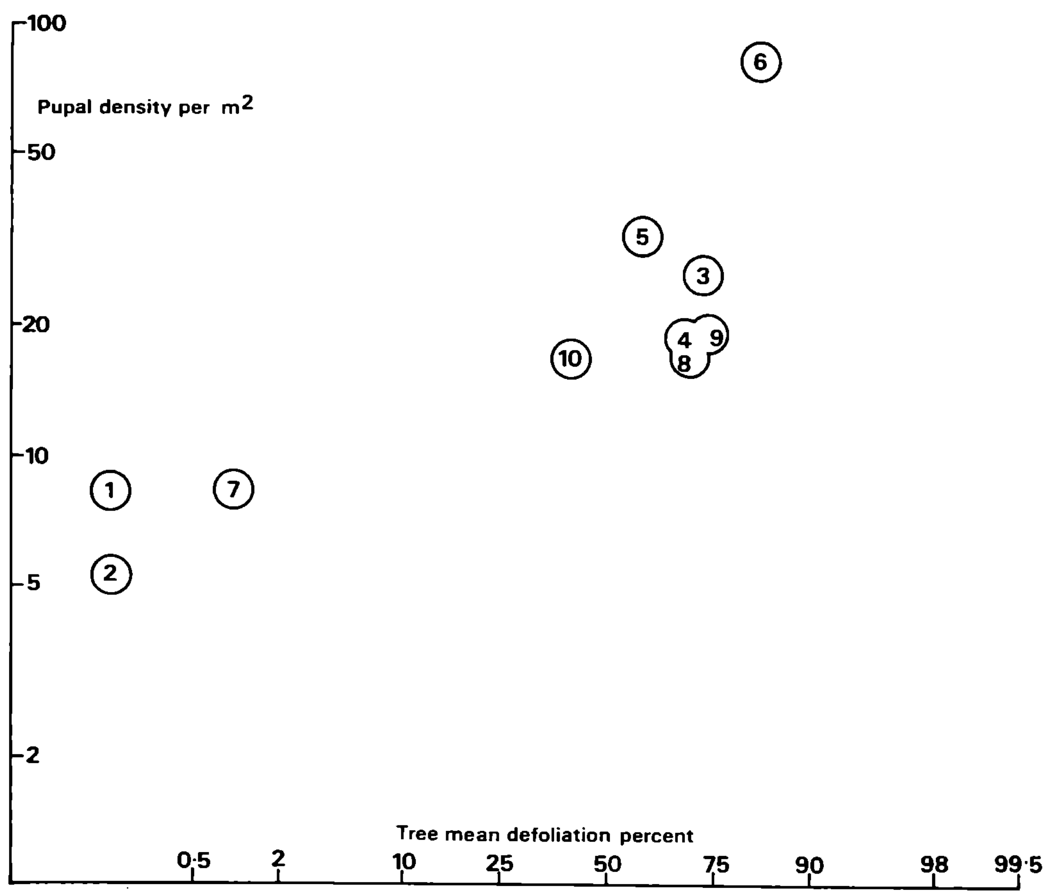

Figure 3.7 Relationship between tree mean defoliation and pupal density at all sample sites.

Chapter 4

CO-ORDINATION OF MEDICAL AND LOCAL AUTHORITY SERVICES

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Co-ordination of the medical and local authority services who were involved in the fenitrothion aerial spraying programme to control the Pine beauty moth was undertaken by the Scottish Home and Health Department. In addition, that Department acted as liaison centre with other Scottish Office Departments such as the Scottish Development Department, and non-governmental organisations including River Purification Boards.

SAFETY PRINCIPLES

The basic principles on which advice was given to medical and local authority services were as follows:

a) limitation of spraying within 500m of human habitation if this could not be evacuated for one hour before and after spraying;

b) provision of an alternative water supply for a period of 48 hours after spraying if the water supply of any property lay within the spray area;

c) closure of roads and footpaths within the spray area for one hour before and after spraying to prevent accidental entrance to the affected area by humans.

CONTROL MEASURES

Aerial spraying took place in the Highland, Grampian and Dumfries and Galloway regions and the investigation of human habitation in the proposed spray areas was undertaken by the local Director of Environmental Health, who reported to the Community Medicine Specialist (Communicable Disease and Environmental Health) who, in turn, passed on the information to the Scottish Home and Health Department. In this manner completely accurate information on occupied housing was obtained, and it was then possible to restrict spraying to a minimum in accordance with the principles given above.

The Community Medicine Specialist of the area, in addition to overseeing environmental considerations, made arrangements for the necessary first aid equipment locally, and for expert medical attention to be available in case of accident at Raigmore Hospital, Inverness, Aberdeen Royal Informary and Dumfries and Galloway Royal Infirmary. Provision was also made for an emergency ambulance service if required.

CONCLUSION

The spraying programme passed off uneventfully and there was no measurable or recorded adverse effect on the human population in the area.

Chapter 5

MEDICAL MONITORING OF THE PILOT

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Health and Safety Executive

Medical monitoring, as conducted during the 1978 operation, was similarly arranged for the extended operation in northern Scotland. Medical examinations were undertaken by Drs A.A. McLeod and C.M. Cook of Ardersier.

MEDICAL PROCEDURE

1. Pre-spraying clinical medical examination with particular reference to neurological and opthalmic state, and assessment of blood plasma cholinesterase activity provided base-line data on 6 June.

2. Repeat medical examinations, including blood plasma cholinesterase measurements, took place before and after each day's flying operations. Medical examination, without blood examination, also was undertaken in the interval between morning and afternoon operations.

3. It was not possible to arrange for medical examination during the period of the operation in south-west Scotland but medical surveillance was continued immediately before and after this part of the operations.

4. In all, 14 medical examinations and 11 blood plasma estimations were undertaken between 6 and 15 June (inclusive).

RESULTS

During the period of medical surveillance, there was no sustained, significant variation in clinical or biological criteria. This suggests absence of any short-term toxic effect as a result of exposure to fenitrothion.

These results have not been compared with electro-myographic tests undertaken by Dr Ian Perry's team from Cranfield. Comparison with the cockpit levels of fenitrothion in air and possible pilot contamination, expressed as being insignificant, suggests no lack of correlation with the findings during the full series of medical examinations conducted on the pilot.

ACKNOWLEDGEMENTS

The invaluable and efficient service provided by Dr McLeod and Dr Cook is gratefully acknowledged.

The pilot's patience and fortitude in accepting the multiplicity of medical examinations and venipuncture are also highly commendable.

Chapter 6

CONTAMINATION BY FENITROTHION OF THE AIRCRAFT PILOT, HUMANS AT GROUND LEVEL, AND NON-TARGET AREAS

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Ministry of Agriculture, Fisheries and Food

INTRODUCTION

Good control of infestations of Pine beauty moth on forest plantations in northern Scotland was achieved in 1978 by aerial application of fenitrothion apparently without serious effect on the environment, wildlife, humans in the area or the pilot of the aircraft. Further infestations appeared subsequently in new areas however and, in view of the limited nature of the environmental studies in 1978, further monitoring was thought to be required in order to check for adverse and unusual effects on the environment when the spraying operations were continued in 1979. The application of fenitrothion would be made only at ULV rates - previous work having established that LV spray applications from aircraft were likely to lead to higher levels of ground and human contamination.

This report is concerned chiefly with measurements of spray drift and human exposure (third parties and pilot) to fenitrothion in one aerial spaying operation (Craigellachie Forest - Elchies block).

ASSOCIATED STUDY - THETFORD FOREST

As in the previous year an aerial spray trial was set up in Thetford forest by research workers from the Cranfield Institute of Technology and the Forestry Commission. Again the object was to study the effects of different variables on deposition of ULV spray droplets. The trial (mid-May) was also attended by the Operator Protection Group chiefly for the purpose of evaluating drift sampling equipment which was under development at the time.

The ULV aerial application on this occasion was not typical of a normal operation in that eight spray-runs were made along the same track at two different heights. For rough comparison with other data quantitative measurements of spray deposits were therefore averaged per spray-run and expressed in equivalent amounts of fenitrothion (Table 6.1). A dye-tracer (Waxoline blue) was dissolved in the spray simulant (hexylene glycol) to facilitate analysis of spray deposits but the concentration had to be reduced so that other measurements by CIT workers could be made satisfactorily; this meant, however, a considerable loss in sensitivity in measurement of 'drift' over distances greater than 50 m downwind of the spray track; exposure levels by inhalation could not be measured at all (minimum sensitivity only equivalent to 3 mg fenitrothion/m^3 or 10 mg hexylene glycol/m^3).

The volume mean diameter (VMD) of droplets (size range collected = 12-100 microns) deposited over the sampling layout (0-400 m downwind of aircraft truck) was about 60 microns (NMD <40 microns). The VMD was expected to be >70 microns, however, as the sampling layout included the normal target area as well as the drift zone.

The combination of finer droplets and low wind speed at this trial suggested that the collection efficiencies of the vertical strings (height 10 m, diameter 5 mm) for airborne spray particles were probably variable and possibly low (<40 per cent) in general. It was decided therefore that finer strings (e.g. 1 mm diameter) would be used in the future in an attempt to improve the collection efficiency on ULV spraying operations in light winds.

SAMPLING METHODS

DIRECT MEASUREMENT OF HUMAN EXPOSURE TO FENITROTHION

The pilot. A dummy figure, complete with air sampler for monitoring concentrations of fenitrothion in air and external pads for measurement of potential body surface contamination, was strapped into the passenger seat just before each sortie. Droplet sensitive slides were also attached to the dummy figure and the interior of the cockpit for measurement of the size of droplets impinging on to exposed surfaces. These studies were made both in northern Scotland and at Craigellachie (Elchies).

Humans in the 'drift' area. The exposure of humans to fenitrothion, by inhalation and contact, in areas outside the designated target area (Figure 6.1 p. 72) was measured by six volunteers wearing modified self-breathing respirators and special suits complete with external pads. Suction-operated equipment was also used to provide additional data on atmosphere concentrations of fenitrothion. Droplet sensitive slides were also attached to the suits for measurement of droplet diameters. These studies were made only at Craigellachie (Elchies).

MEASUREMENT OF 'DRIFT'

Quantitative measurements of 'drift' of chemical from the target area were attempted by setting up twelve 10 metre masts complete with vertical strings (10 m x 1.2 mm diameter), or at the more distant sampling stations - nylon nets (10 m x 20 cm width, and individual threads 0.265 mm diameter), for the collection of airborne droplets. Three cellulose filter discs were laid on the ground around each mast for collection of 'fall-out'. Again, droplet sensitive slides (microporous cellulose acetate dyed with Waxoline Blue RS) were used for measurements of the diameter of droplets in the drift cloud.

The positions of the sampling stations (Figure 6.1) were partly governed by difficulties of access in some areas, the state of the ground, impenetrable tree plantations in the drift sampling zone and the general problem of trying to study 'drift' from such a large target area (770 ha). It was only possible to set up four sampling stations in 'open' situations (i.e. masts nos 2, 4, 5 and 12), the remainder had to be put in forest rides or narrow roadways which were usually well-shielded at least on two sides by tall trees.

Westerly winds were usual in the area and therefore the drift zone for sampling purposes was taken as a continuous band, one kilometre in depth, around the eastern and southern boundary of the target area. Sampling on the northern aspect was restricted through lack of access for vehicles and the presence of deep heather on wet peaty soil. One sampling station (No.5) was set up on the upwind side to the west for control purposes.

ANALYSES

All sampling media for quantitative analyses were extracted on site into hexane. Spiked samples were set up simultaneously to check for losses of fenitrothion on storage prior to analysis. The analyses were completed by injection into a gas chromatograph (Perkin Elmer F33 - nitrogen detector).

The operating characteristics were: 2 m column (3 mm i.d.), 5% ou-1, 1 Gas Chrom Q 80-100 mesh, column temp. 230°C; injection temp. 250°C; detector temp. 250°C; nitrogen flow 35-40 ml/min.

RESULTS

All quantitative measurements were expressed in milligrammes of fenitrothion - conversion to equivalent weights of formulation may be derived by multiplying the reported figure by 3.57. This factor originated from the analysis of a sample of the spray mix used in the operation over Craigellachie on 10 June. The nominal concentration of fenitrothion was 30 per cent w/v but only 28 per cent was found in the sample.

EXPOSURE OF THE PILOT TO FENITROTHION

Sampling in the cockpit of the aircraft was continued throughout the majority of sorties over a three-day period (9-11 June). The potential exposure to fenitrothion by contact or inhalation, in the cockpit, was found to be minimal (Table 6.2) on each occasion. Very few droplets, possibly of spray fluid, were collected on the prepared target surfaces for size analysis.

EXPOSURE OF HUMANS TO FENITROTHION IN THE DRIFT ZONE

Individual exposures of human volunteers to fenitrothion in the drift sampling zone (sampling stations A to F) were calculated (Table 6.3) from the amounts of fenitrothion found on the filters of each respirator and on the pads attached to the protective clothing. A breathing rate of 1 m^3/h was assumed for convenience in the calculations (exposure period 2.25 h).

Additional determinations (Table 6.4) were made of variations in fenitrothion concentrations in air with distance downwind by means of suction-operated equipment spaced out along the ride occupied by the human samplers 'D', 'E' and 'F'.

The concentrations of fenitrothion in air indicated by the suction-operated equipment (Table 6.4) agreed reasonably well with those found at corresponding positions where human samplers were used (Table 6.3) in the measurement of inhalation hazards. From these data the probable maximum exposure to fenitrothion would have been experienced by unprotected humans near to the boundary of the sprayed area but the degree of exposure would nevertheless have been minimum (<0.3 mg/h).

DRIFT OF FENITROTHION FROM THE TARGET AREA

On the day of the spraying operation (Craigellachie - June 10) the wind was light (1.5 - 2.5 m/sec for the area in general; 0.96 - 1.8 m/sec. measured in a fairly open position in the drift sampling area) and from the west (bearing quoted as 280°). Drift of spray therefore proceeded in an easterly direction virtually at 90° to the track of the aircraft (N-S) but nevertheless deposits of fenitrothion were found at sampling stations to the south of the sprayed area (Table 6.5).

SIZE DISTRIBUTION OF DROPLETS COLLECTED IN THE DRIFT ZONE

The parameters VMD (volume mean diameter) and NMD (numerical mean diameter) reflect the spectrum of droplets in a spray or drift cloud. In this study an overall VMD of 52 microns (NMD <30 microns) was derived from measurements on vertical targets whereas the VMD of droplets collected on the ground and human targets appeared to be 63 microns (NMD <35 microns). In general, droplets in the size range 12-100 microns were found on the target surfaces, the maximum size of droplet collected tending to decrease with distance and the results, as a whole, appeared to match up with those recorded at the Thetford trial, the wind speeds being of the same order.

Occasional droplets, apparently of 100 microns in diameter, were found however on target surfaces at distances downwind (e.g. 1000 m) where they would not normally expect to be carried by the prevailing wind (speed of only 1.5 - 2.5 m/sec). Contamination of the target surfaces by droplets of a liquid other than the spray fluid was therefore a possibility.

DISCUSSION AND CONCLUSIONS

EXPOSURE OF THE PILOT TO FENITROTHION

Measurements of the potential exposure of the pilot to fenitrothion, either by inhalation or contact (Table 6.2) throughout the sorties spread over three days (total spray time: 5.5 h) suggested that on these occasions the chemical hazard to occupants of the cockpit was probably insignificant.

Examination of the air ventilation system in the aircraft suggested that penetration of spray particles into the cockpit was possible in flight and therefore the very low levels of body surface contamination recorded in the cockpit may have originated from this source. No explanation of the high levels recorded in the previous year could be provided by the current measurements, but it was said subsequently that the sampling pump had been left switched on in the 1978 study whilst the spray tank was being filled! The loaders would appear to face the greater risk of poisoning and therefore their occupational exposure levels to the chemical should perhaps be investigated in future exercises.

EXPOSURE OF HUMANS TO FENITROTHION IN THE DRIFT ZONE

Levels of contamination of humans within the drift zone around the target area in Craigellachie forest were much lower than those found in Strathy in the previous year, possibly because the drift zone was generally well-shielded by trees and the wind speed was less than half that recorded in the 1978 trials. Exposure levels by inhalation were also lower in 1979 but the difference was less marked (Strathy 0.001 - 0.007 mg/m^3; Craigellachie 0.001 - 0.004 mg/m^3), probably because the inhalable fraction of the spray drift was less likely to be filtered out by the foliage in the area.

The total potential exposure of humans to fenitrothion at any point within the drift zone, as a result of ULV spraying operation from aircraft, appeared to be minimal and equivalent only to a maximum level of <0.3 mg of the chemical per hour (Craigellachie trial). Exposure levels in the 0-150 metre zone tended to be more variable judging from the results from the 1978 and 1979 studies but hardly measurable at distances of 500 and 1000 metres downwind.

On present evidence a minimum distance of 250 metres between areas occupied by unprotected persons and the boundary of a target area is considered to provide an extreme safety factor and should rule out any possibility of complaint by the general public about personal contamination by spray drift. Acceptance of such a limit, or indeed any other, must obviously include considerations on the effects on wild life and the environment through the drift of chemical into non-target areas.

DRIFT OF SPRAY FROM THE TARGET AREA.

Height of drift cloud. The peak height of the drift 'cloud' was probably in the region of 15 to 20 metres from the ground, although the peak concentration of fenitrothion appeared to develop at a height of about 10 to 15 metres judging from the degree of variation with height in spray deposits on vertical targets (Table 6.5). Precise interpretation of the drift deposits collected by the vertical targets used at this trial was not possible however, through cancellation of equipment essential for calibration of the various drift sampling devices.

'Lateral' drift. Notwithstanding any correction factors that may be necessary the results clearly showed that drift of spray can take place at low wind speeds into areas not immediately downwind of the target area and a small proportion may remain airborne 500 to 1000 metres away from the boundary. A small amount of drift was even collected upwind of the sprayed area (sampling station No.5) possibly through the action of eddies at the edge of the forest. The possibility of overshoot of spray could not be ruled out at this particular locality, as the aircraft was seen to fly over or near to the sampling station on several successive tracks (N-S) in the final stage of the application.

Proportion of applied chemical 'lost' through drift. Bearing in mind the possible need to apply correction factors for variations in sampling efficiency of the drift sampling equipment, and that a detailed study of 'drift' from such a large target area (770 ha, boundary approximately 13 km) was not feasible under the circumstances, extrapolation of the results (Table 6.5) for calculation of total amount of fenitrothion carried across the boundary of the sprayed area and deposited in the designated drift sampling zone can only be very approximate.

Rough calculations on this basis suggested that a maximum of about 7 kg of fenitrothion, or 3 per cent of the total amount applied (230 kg), may have been carried over the southern and eastern boundaries of the target area by the precailing wind (westerly - 1.5 - 2.5 m/sec). Of this amount about 5 kg would appear to have been deposited on the ground in the designated drift sampling area (approximately 600 ha). The corresponding amount of fenitrothion remaining airborne 1000 metres from the boundary of the target area appeared to be approximately 0.4 kg. The 'missing' 1.6 kg fenitrothion may have been deposited on foliage within the designated drift sampling zone but clearly a precise balance could not be expected for rough calculations of this nature. The possibility of lateral drift of spray over the northern boundary of Craigellachie forest could not be ruled out and, if this had occurred in the same relative proportions, then a maximum total of approximately 10 kg fenitrothion (i.e. 5 per cent of total applied) may have been 'lost' through drift from the whole of the target area. In operations (ULV) in the previous year a 1 per cent 'loss' through drift was estimated, essentially on the basis of rough calculations of deposits found in the sprayed area (see Control of Pine Beauty Moth by Fenitrothion in Scotland 1978 - edited by A.V. Holden and D. Bevan). Clearly these calculations are influenced by the methods of assessment of drift, especially when sampling stations are included just outside the boundary of a sprayed area. Here the levels of spray deposit on vertical and horizontal targets are governed by the accuracy of spraying and delineation of the boundary and in turn have a major influence therefore on calculations of 'drift'.

More precise data on percentage loss of applied chemical through drift seems to be required, therefore, and in order to make the best use of available resources, smaller areas than that faced at this trial would be preferable for this purpose.

SUMMARY

Measurements of the exposure of the pilot of a crop spraying aircraft, and humans on the ground, to fenitrothion applied at ULV rates from the air for the control of Pine beauty moth infestations at Craigellachie Forest in 1979 indicated that the risk of poisoning was insignificant under the prevailing conditions. However, drift of small amounts of spray chemical into lateral as well as downwind areas, over distances of up to one kilometre from the boundary of the target area, was observed. On the basis of rough calculations probably not more than 5 per cent of the total amount of chemical applied was 'lost' through drift from the target area and, of this amount, over 95 per cent was deposited well within a zone extending not more than one kilometre from the target area perimeter.

ACKNOWLEDGEMENTS

The chemical analyses were undertaken by Mr A.R. Paxton of the Pesticides Residues Analysis Unit at Harpenden whose services were much appreciated. Valuable assistance and co-operation was provided by Mr J.T. Stoakley (Forestry Commission), Mr A. Thompson (Chief Forester, Craigellachie) and his staff.

Table 6.1

Collection of Spray Liquid by Vertical Targets at Different Distances Downwind of the Spray Run

Sampling Station (downwind of the aircraft track)	*Pick-up of Spray Liquid on Vertical Targets at Different Heights - Calculated in Terms of Fenitrothion (ULV Mixture Assumed 30 per cent)**				
	mg/m^2 per single spray run				
Metres	*0-2 m*	*2-4 m*	*4-6 m*	*6-8 m*	*8-10 m*
1	59	34	32	9	No sample
10	<9	22	12	<9	16
50	17	<9	<9	17	20
100	<9	<9	<9	<9	<9
200	<9	<9	<9	<9	<9
400	<9	<9	<9	<9	<9

* Multiply the figures by 3.3 to give mg spray simulant (hexylene glycol).
NOTE. Wind speed was 1.5 - 2 m/sec.

Table 6.2

Potential Exposure of the Pilot to Fenitrothion

Sorties to:-	*Flying time (take-off to Touch-down)*	*Spray Time*	*Fenitrothion in air of Cockpit*	*Fenitrothion on Human Target*	*Size of Droplets Collected on Dummy Figure*
	h	*h*	*mg/m^3**	*$mg/^{2}\ m^2$*	
Strathy (June 9)	2	0.75	<0.0015	<0.1	Occasional 30 to 70 micron droplets on left leg
Craigellachie (June 10)	3.5	2.25	<0.0004	0.20	Occasional 30 to 50 micron droplets on head
Torrachility + Inveroykel (June 11)	5.0	2.33	<0.0004	0.12	Occasional 30-70 micron droplets on right leg

* Calculated on the assumption that exposure to fenitrothion was experienced only during spray time.

Table 6.3

Exposure of Humans to Fenitrothion in the Drift Sampling Zone (Craigellachie)

Distance of Human Target from boundary of target area - metres	*Fenitrothion Deposit on Whole Body Surface (in 2.25 h) mg/2 m^2*	*Concentration of Fenitrothion in Breathing Zone mg/m^3*
'C', 100 m lateral to wind	<0.10	<0.0002
'D', 0 m downwind	0.52	0.0036
'E', 50 m downwind	0.37	0.0044
'F', 150 m downwind	0.22	0.0009
'B', 500 m downwind	<0.10	<0.0003
'A', 1000 m downwind	0.10	<0.0003

Table 6.4

Variation in Concentration of Fenitrothion in Air with Distance Downwind from the Boundary of the Target Area

Sampling Position - Distance Downwind From Edge of Target Area *metres*	*Concentration of Fenitrothion in Air at Breathing Height* *mg/m^3*
0 (near human sampler D)	0.0029
4	0.0018
10	0.0017
20	0.0019
50 (near human sampler E)	0.0012
100	0.0008
150 (near human sampler F)	0.0016
500	<0.0001

Table 6.5

Drift of Fenitrothion Beyond the Target Area (Craigellachie - Elchies Block)

Distance from Edge of Target Area - Metres	*Sampling Station Reference No.*	*Degree of Tree Cover*	*Deposition of Fenitrothion on Ground and Vertical Targets: mg/m²*					
			Ground	*0-2 m Vertical*	*2-4 m Vertical*	*4-6 m Vertical*	*6-8 m Vertical*	*8-10 m Vertical*
100 m upwind	5	open	0.0025	0.125	<0.05	<0.05	<0.05	0.05
0-10 downwind	1	partial	4.3	45	76	85	117	No sample**
	6*	dense	0.55	2.5	6.0	11	14	No sample
100-125 m downwind	(2	open	0.48	11	24	29	31	39
	(3	partial	0.30	0.75	5.5	8.0	12	11
	(7	partial	5.0	6.0	9.0	11	12	10
off wind	10	dense	0.48	1.25	2.5	3.25	4.0	5.0
500 m downwind	8	partial	0.2	0.5	1.75	1.5	3.25	7.5
off wind	11	partial	0.35	0.5	4.25	3.75	5.0	7.0
1000 m downwind	(4	open	0.075	2.0	3.75	5.0	5.75	6.0
	(9	dense	0.175	0.5	1.0	2.0	4.0	4.5
off wind	12	open	0.175	0.5	0.75	1.25	1.5	2.0

* Near to half-dose area

** These masts were shorter as they were close to the track of the aircraft

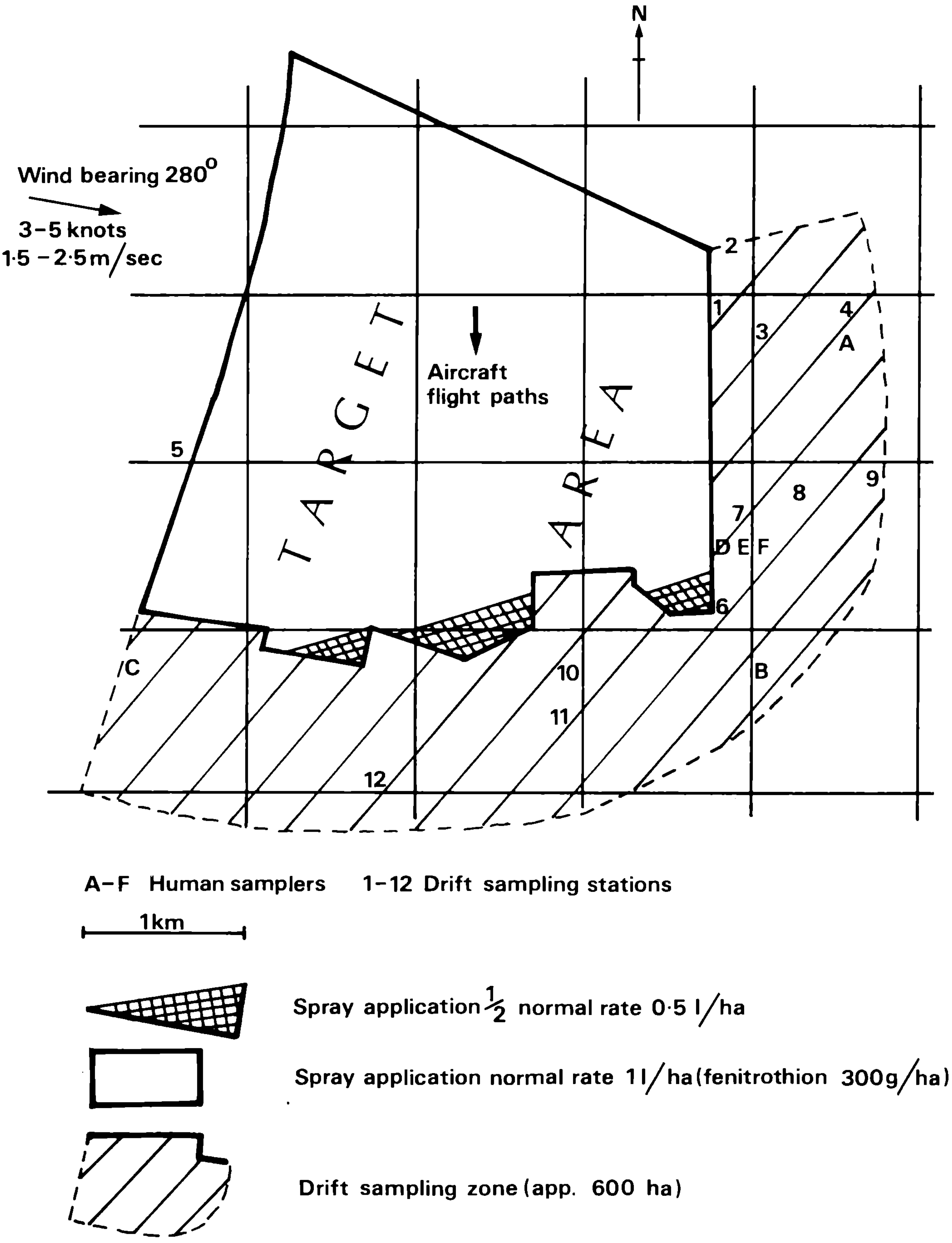

Figure 6.1 Drift sampling positions at Elchies block, Craigellachie Forest.

Chapter 7

FENITROTHION RESIDUES IN PANOLIS FLAMMEA LARVAE

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In response to a request by the Forestry Commission, analyses were made of residues of fenitrothion in *Panolis flammea* larvae following the aerial spraying at Elchies section of Craigellachie Forest.

SAMPLING AND ANALYSIS

The results of larvae analysis from the 1978 spraying operation indicated that analyses could be done on samples comprising 10 *P. flammea* larvae and arrangements were made for 30 samples, each comprising about 10 larvae, to be collected immediately following the spraying. The samples were collected in clean glass tubes and stored in a deep freeze within a few hours of the completion of spraying. It was evident that the larvae were at a much earlier stage of their development than was the case during the 1978 spraying operation and thus they were very much smaller. For this reason, three samples were pooled to give samples comprising approximately 30 larvae for each analysis.

The larvae were ground together with anhydrous sodium sulphate to give a dry powder and this was extracted with acetone. The extracts were filtered and the acetone solutions were analysed for residues of fenitrothion by gas chromatography using a phosphorus-specific flame photometric detector.

RESULTS

The results of the analyses of eight samples each containing about 30 larvae are given in Table 7.1.

DISCUSSION

Each larva weighed only approximately 2 mg compared with a mean weight of 16 mg for samples analysed after the 1978 spraying. Every batch of larvae analysed was found to contain residues of fenitrothion but the amount of these residues varied greatly. The mean residue found was 2.73 µg/g which is greater than twice the residue found on the larger larvae subjected to ULV spraying in 1978.

Table 7.1

Fenitrothion Residues in Panolis Flammea Larvae

Sample	*No of Larvae in Sample*	*Total wt. of Sample (mg)*	*Total Fenitrothion in Sample (ng)*	*Equivalent Residue (ng/larva)*	*Equivalent Residue (ppm)*
A	29	58.43	54.9	1.9	0.94
B	29	59.81	72.9	2.5	1.22
C	35	74.37	357.7	10.2	4.81
D	33	68.51	64.3	1.9	0.94
E	38	79.05	703.6	18.5	8.90
F	30	63.40	35.1	1.2	0.55
G	36	75.27	314.6	8.7	4.18
H	29	63.88	18.1	0.6	0.28
Mean	32.4	67.84	202.7	5.7	2.73
				S.D $\pm$ 5.9	S.D $\pm$ 2.83

Chapter 8

DEPOSITION OF FENITROTHION AT GROUND LEVEL

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SAMPLING PROGRAMME

Part of the monitoring programme conducted during aerial spraying of forests in 1978 included a comparison of the amount of fenitrothion reaching ground level as a result of the LV and ULV spraying techniques used on different areas. A limited amount of information was also gained on the extent of the contamination of ground surrounding the sprayed areas. Since the 1979 spraying operation was to be done almost entirely by the ULV method of application, a sampling programme was designed to measure the extent of ground contamination both inside and outside the target area. This programme would also indicate the uniformity of the application over several spray swathes and the extent to which the fenitrothion was trapped by the tree foliage.

Elchies section of Craigellachie Forest was used for this sampling programme, and it was decided to measure the fenitrothion reaching the ground by placing sampling plates on the ground at previously selected sites within and outside the forest. There were a total of 120 sites within the forest and 95 outside.

Within the forest there were two lines of sampling sites 300 m long, both at right angles to the flight path of the aircraft so that they extended across six of the 50 m spray swathes. Plates were placed at 10 m intervals both on open ground and under trees. One line was located along part of the forest road and this was used as the open situation while the paired sample was approximately 5 m under the forest canopy. The latter plates were placed strictly at the 10 m intervals regardless of whether or not they were covered by foliage. The other sampling line was a repeat of the above, except that a forest ride was used instead of the road. No record was made of the degree of foliage cover over the plates as in 1978.

The sample sites outside the forest were chosen on lines extending at right angles out from the edges of the sprayed area (Figure 8.1). Sampling plates were laid out in lines on the west, north and east sides of the sprayed area. Samples were taken at intervals up to a distance of 100 m on the west side and 500 m on the north and east sides. No samples were taken on the south side since the boundary of the sprayed area was very irregular and some spraying at half the dose rate was to take place within this boundary. Sampling on the west side was limited to a distance of 100 m because this side of the forest was expected to be upwind of the target area.

SAMPLING AND ANALYSIS

The methods of sampling and analysis were very similar to those used during the 1978 monitoring programme. Glass plates, 100 cm^2 in area, coated on the upper surface with a thin layer of silica gel absorbent, were placed at each site some 2-3 hours prior to the spraying. Immediately following the completion of the spraying the plates were recovered and within a few hours all the silica gel layers had been transferred into acetone solution. The amount of fenitrothion in each solution was subsequently determined by gas chromatography. Control plates were spiked with amounts from 10 to 500 µg of fenitrothion at the same time as the spraying began. One set of control plates were left exposed to the sun and another set kept in shade. These plates were recovered and analysed in an identical manner to the sample plates.

RESULTS

The recovery of fenitrothion from the spiked plates varied from 8 per cent to 95 per cent, with a mean of 90.5 per cent. The higher recoveries were obtained from plates remaining in the shade. These figures are much higher than those determined during the 1978 experiments and probably reflect the much shorter exposure time of the silica gel layers and the lower air temperatures during the 1979 treatment. All the results from the sample plates have been corrected for a recovery of 90 per cent.

The fenitrothion depositions at all the sampling positions within the sprayed area are shown in Table 8.1 and the depositions from sites outside the sprayed area are shown in Table 8.2.

DISCUSSION

Fenitrothion was found at every sample site inside the forest. However, there is considerable variation in the results along each sampling line, particularly in the samples taken under trees. The results tend to fall into groups where several adjacent results are similar but these are then fairly distinct from the next group. This suggests that the amount of fenitrothion reaching the ground varied from swathe to swathe. The grouping of the results obtained under the trees may also reflect the variation in the density of the tree cover as well as the difference due to the spray swathes. A mean of 12 per cent of the theoretical applied dose reached the ground under the trees and 25 per cent of the dose reached the ground in the open. At only seven of the 120 samples sites did the deposit exceed 50 per cent of the theoretical deposit of 300 g/ha and only at one position did the deposit exceed 300 g/ha.

The results from the samples sited outside the forest show that considerable amounts of fenitrothion reached the ground in the area up to 20 m from the forest edge and in some places this extended to 100 m. The samples taken along the west edge show the least distance of contamination and this was the upwind side of the forest during the period of application. There were higher results on lines A and E but these were probably the result of some direct overspraying due to the shape of the forest on the west side, where part of these sampling lines were within the likely flight paths of the aircraft. Large deposits of fenitrothion occurred at many of the sites up to 100 m from the north edge of the forest and these almost certainly resulted from direct overspraying of this area. During the spraying operation it was observed that on some occasions spraying started before the plane reached the forest and on others spraying continued after the plane left the forest. Assuming an aircraft speed of 180 km/hour, then 100 m only represents 2 sec. flying time, therefore to ensure complete cover of the target area with outside contamination limited to this distance illustrates a considerable degree of pilot accuracy.

The east edge of the target area was almost directly downwind during much of the spraying operation, but was well inside the forest and was not clearly delineated, being only marked by flags at intervals. The results from the sample lines on this side show that heavy contamination was limited to a distance of 50 to 100 m from the edge of the target area. However, fenitrothion was found at every sample point, even to a distance of 500 m, despite the fact that this was not an area of open ground but was within the forest. The sample lines were all located on the forest roadway or in rides.

CONCLUSION

The results show that for this size of operation the spraying was done with considerable accuracy and almost the entire dose of fenitrothion was placed within the target area. Assuming little loss, other than onto the ground, the tree foliage appears to have trapped almost 90 per cent of the spray droplets, resulting in a low level of contamination of the ground within the sprayed area. Some contamination of the surrounding area occurred, but this was generally limited to a distance of 50 to 100 m from the target boundary. However, low levels of contamination did occur over a much wider area even where this was within the forest.

Table 8.1

Deposition of Fenitrothion at Ground Level Inside the Forest

	Sample Line K'			*Sample Line M'*	
Distance into Forest (m)	*Fenitrothion Deposit Under Trees (g/ha)*	*Fenitrothion Deposit in Open Ground (g/ha)*	*Distance into Forest (m)*	*Fenitrothion Deposit Under Trees (g/ha)*	*Fenitrothion Deposit in Open Ground (g/ha)*
10	52	47	10	10	37
20	3	41	20	18	32
30	4	23	30	14	40
40	2	24	40	32	52
50	8	21	50	23	53
60	4	30	60	23	53
70	4	34	70	19	94
80	10	32	80	30	61
90	6	33	90	70	119
100	34	31	100	146	71
110	43	54	110	21	100
120	18	107	120	24	53
130	11	70	130	42	60
140	12	54	140	16	172
150	6	62	150	27	239
160	44	86	160	404	79
170	18	90	170	11	14
180	18	56	180	9	17
190	23	79	190	20	21
200	27	49	200	8	31
210	27	81	210	36	38
220	30	81	220	47	54
230	76	80	230	96	147
240	28	140	240	67	164
250	49	160	250	48	96
260	50	189	260	71	88
270	17	88	270	59	99
280	40	50	280	70	204
290	3	58	290	19	90
300	2	4	300	-	108
Mean	22	65		51	83

Table 8.2

Deposition of Fenitrothion at Ground Level Outside the Forest (g/ha)

1. West Edge of Forest

Sample line	*Distance from Forest Edge (m)*				
	0	*10*	*20*	*50*	*100*
A	69	130	80	14	0.09
B	17	8.6	2.6	0.22	0.26
C	0.27	0.11	0.24	0.10	0.39
D	0.01	0.03	0.12	0.02	0.02
E	41	316	0.75	0.26	0.02
Mean	25	91	17	2.9	0.16

2. North Edge of Forest

Sample line	*Distance from Forest Edge (m)*						
	0	*10*	*20*	*50*	*100*	*200*	*500*
F	2.7	1.9	1.2	0.82	0.61	0.59	0.40
G	38	60	78	23	2.0	0.22	0.26
H	23	28	19	27	30	2.6	0.76
I	36	38	11	18	30	11	0.50
J	13	7.1	6.1	17	4.0	2.2	0.17
Mean	23	27	23	17	13	3.3	0.42

3. East Edge of Forest

Sample line	*0*	*10*	*20*	*50*	*100*	*200*	*500*
K	57	17	52	17	13	6.2	4.7
L	13	5.7	11.3	8.6	11.0	1.9	3.7
M	29	13	6.7	6.7	4.1	5.2	4.6
N	16	21	13	12	5.8	3.8	2.4
O	26	18	22	16	11	6.0	0.50
Mean	28	15	21	12	9.0	4.6	3.2

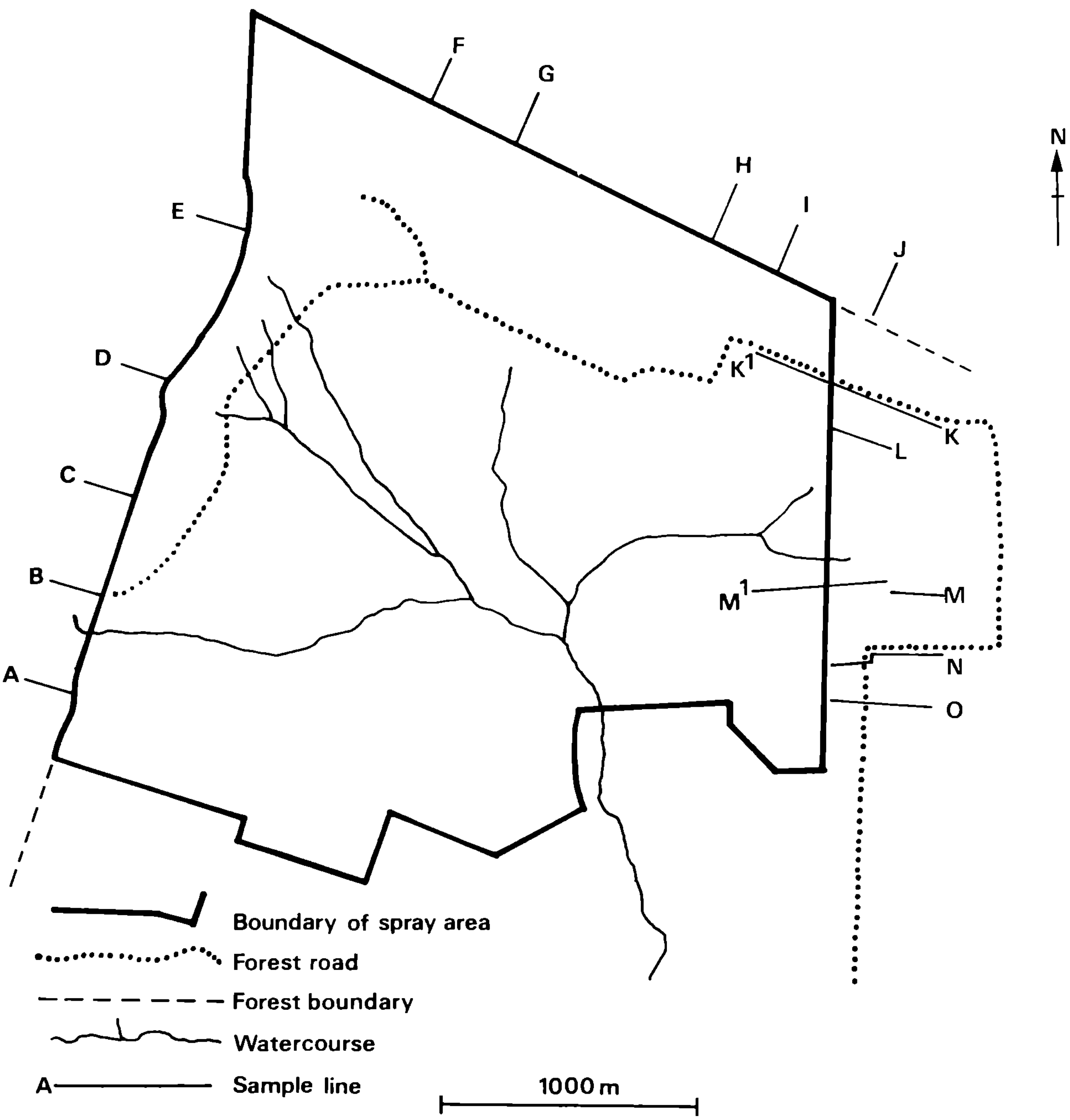

Figure 8.1 Position of ground sampling sites at Elchies section of Craigellachie Forest.

Chapter 9

ASSESSMENT OF THE EFFECT ON THE AQUATIC ENVIRONMENT OF AERIAL SPRAYING WITH FENITROTHION

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INTRODUCTION

Following the investigation into the effects on the aquatic environment of the aerial spraying of fenitrothion in Sutherland in 1978, it was considered that the level of contamination which resulted did not present a significant risk to fish populations in the short term. Consequently a further extensive monitoring was not considered justified, but the 1979 spraying afforded an opportunity to carry out experiments to answer the following questions raised by the 1978 investigation.

1. Are stream invertebrates killed as well as displayed by fenitrothion in the water ?

2. How significant is the downstream drift of invertebrates in relation to the size of the total population ?

3. Are fish displaced by the fenitrothion treatment ?

4. Is the fenitrothion absorbed into the tissues of the fish or does it simply adhere to the surface of the skin ?

5. Are significant amounts of fenitrothion adsorbed/absorbed by the flora and sediments in the stream ?

SITE

Several of the forests in the 1979 programme were considered for the experiments, and of the various sites inspected the Ballintomb Burn at Elchies section of Craigellachie Forest, had most of the characteristics required. The head waters and a section of the main stream were almost entirely within the treatment area, and there was a 3 km stretch downstream of the forest with no major tributaries (Figure 9.1). The stream varied in width from 2 - 4 m and, although over much of its length the bed consisted predominantly of large stones 20 cm or more across, there were areas of smaller stones suitable for quantitative bottom fauna sampling. The aquatic moss *Fontinalis antipyretica* was very common in most areas and was used in the studies on fenitrothion uptake by plants.

The sampling sites for different aspects of the work are marked on the map. Water samples were taken by an automatic sampler, invertebrate drift fauna in fine-meshed $0.3mm^2$ drift nets and benthic invertebrates by a Hess type sampler. Fish were obtained by electrofishing, and both fish and invertebrates were held in cages in the streams. A fish trap was used to investigate fish migration.

RESULTS OF INVESTIGATION

FENITROTHION CONCENTRATION IN STREAM

The flow rate in the burn was high the day before spraying took place (580 l/sec at 12.00 on 9 June), but fell to 150 l/sec at the start of the treatment at 14.55 on 10 June. It fluctuated between 90 and 150 l/sec in the course of the following 4 days.

The spraying was carried out between 14.55 and 17.55 on 10 June with an hour's break between 15.48 and 16.47.

The concentration of fenitrothion in the water rose to a maximum of 18.8 g/l at site 1. an hour after the start of spraying, then fell rapidly to 3-5 µg/l at 18.00 - 20.00 and was below 0.5 µg/l after 24 hours. The highest concentration measured at sites 2 and 3 was 4-5 µg/l approximately 2 hours after the peak at site 1. This concentration also declined to below 0.5 µg/l after 24 hours.

EFFECT ON STREAM INVERTEBRATES

In 1978, fine-meshed drift nets set in streams within the treated areas of forest collected significantly greater numbers of insects immediately after spraying than had been collected before spraying started. Similar results were obtained at the three stations on the Ballintomb Burn (Figure 9.2). The nets were the same as those used in the 1978 work. Examination of the drift net samples prior to preserving them in formalin showed that a very high proportion of the animals were alive and very active at the time of capture.

In order to make a closer examination of the effect of treated water on individual insects, specimens representing a range of species in the burn were confined in groups within plastic cages in the stream for several days before and after spraying. Throughout this period several of the stonefly and mayfly nymphs in the cages changed to the winged stage, and when this happened before spraying the insects were released and replaced by more nymphs. After spraying the winged insects were released but were not replaced by fresh nymphs. No mortalities which could be attributed to the fenitrothion were found. Occasionally an insect was found crushed between the lid and the wall of the cage. Mayfly and stonefly nymphs, caddis larvae and adult water beetles were used in these tests.

Quantitative sampling of bottom fauna was done on 9, 10 and 18 June, i.e. before and after spraying. There was no general decrease, or increase, in the numbers of animals in each taxonomic group following spraying but, of the 28 groups investigated, significant differences were found in two at site A (one increase, one decrease), two at site C (both increases), and three at site B (all showing a decrease in numbers after spraying). This drop in numbers at site B produced a significant decrease in the overall total for that site only, and overall totals for sites A and C showed no significant difference before and after spraying.

EFFECTS ON FISH IN THE STREAM

Juvenile trout and salmon of 15-20 cm in length were held in cages at the three main sampling stations and observed for several days before and after treatment. Heavy rain and high water levels resulted in two of the cages being overturned prior to treatment and some fish had to be replaced. No mortalities were observed in the caged fish five days after spraying and subsequently these fish were removed to fibre glass ponds where they were kept and fed on pelleted food for three months. Four fish were found dead on the ground beside the ponds shortly after being introduced and of the remaining 26 fish about half showed signs of malnutrition. Since the rest were in good condition, it is probable that the sick fish had not become adapted to eating pelleted food. Attempts by laboratory staff to feed wild trout on pelleted food have often failed.

An Inscale trap was set at station 2 to catch any fish which might move downstream following application of the fenitrothion. Only four fish, three trout and one salmon parr were taken in the trap and all of them prior to spraying. The salmon parr may have escaped from the cage which was overturned immediately upstream of the trap during the spate on 9 June. Electro-fishing in the burn upstream of the trap site on 18 June showed that trout were regularly distributed in the area sampled, indicating that they had probably not been disturbed by the fenitrothion.

FENITROTHION RESIDUES IN THE FISH

During and after the spraying operation in 1978, fish taken from the streams were found to contain fenitrothion residues which decreased in amount as the concentration of fenitrothion in the water decreased. The analyses were carried out on samples of whole fish. In 1979 a more detailed analysis was undertaken and results were obtained from individual tissues - skin, liver, muscle and stomach (with contents). The highest levels of fenitrothion were found in the skin (0.25 mg/kg), followed by the stomach and its contents (0.22 mg/kg), muscle (0.16 mg/kg) and liver (0.08 mg/kg). Fenitrothion concentrations in the skin, stomach and muscle followed the profile of the fenitrothion concentrations in the water, but the maximum concentration in the liver was not reached until some six hours after the peak concentration in the water. The concentration in each of the four tissues fell to 0.02 mg/kg after 24 hours. (All measurements refer to wet weight of tissue). These results confirm the figures obtained in 1978 in that they show that the uptake and loss of fenitrothion by the fish is linked closely to the concentration in the water and that the chemical does not persist in the fish tissue (half-life = 0.6 day).

FENITROTHION IN FLORA AND SEDIMENT

Analyses of the leaves of *Fontinalis antipyretica* (Willow moss) showed that little or no retention of fenitrothion had occurred. The maximum concentration was 0.139 mg/kg (wet weight) falling to 0.003 mg/kg after 48 hours. Fenitrothion was not detected (minimum detectable concentration = 0.001 mg/kg) in the sediment but this may be a reflection of the nature of the substratum. The particle size of the samples taken ranged from 2 - 5 mm to 10 - 15 mm giving a very low surface area to weight ratio.

SUMMARY

Tha aims of the 1979 programme were achieved. The concentration of fenitrothion in the water within the treated area was greatest immediately after spraying but decreased to less than 3 per cent of its maximum value within 24 hours.

The information on invertebrate drift indicated that the majority of animals caught in the nets were displaced rather than killed. Caged invertebrates were not killed by the fenitrothion.

Trout were apparently not displaced or killed during the treatment. Fenitrothion was ingested as well as absorbed through the skin of the trout but it was lost from skin, muscle and stomach tissues at approximately the same rate as the concentration in the water decreased. It was taken up more slowly by the liver but within 24 hours had reached a low level similar to that found in the other tissues.

There was little uptake of fenitrothion by the moss *Fontinalis antipyretica* and it was completely lost after 48 hours. No fenitrothion was found in the sediment samples.

CONCLUSIONS

It is felt that most of the short-term effects on fish and aquatic invertebrates subjected to concentrations of fenitrothion of the order resulting from forestry spraying can be predicted and that no further work along these lines need be undertaken. No further work is planned for 1980. A paper describing the work done during 1979 will be prepared as soon as all the analyses have been completed.

We were greatly helped by staff of the North East River Purification Board, who undertook the hydrological work and shared in the routine sampling and some of the subsequent (chemical) analysis.

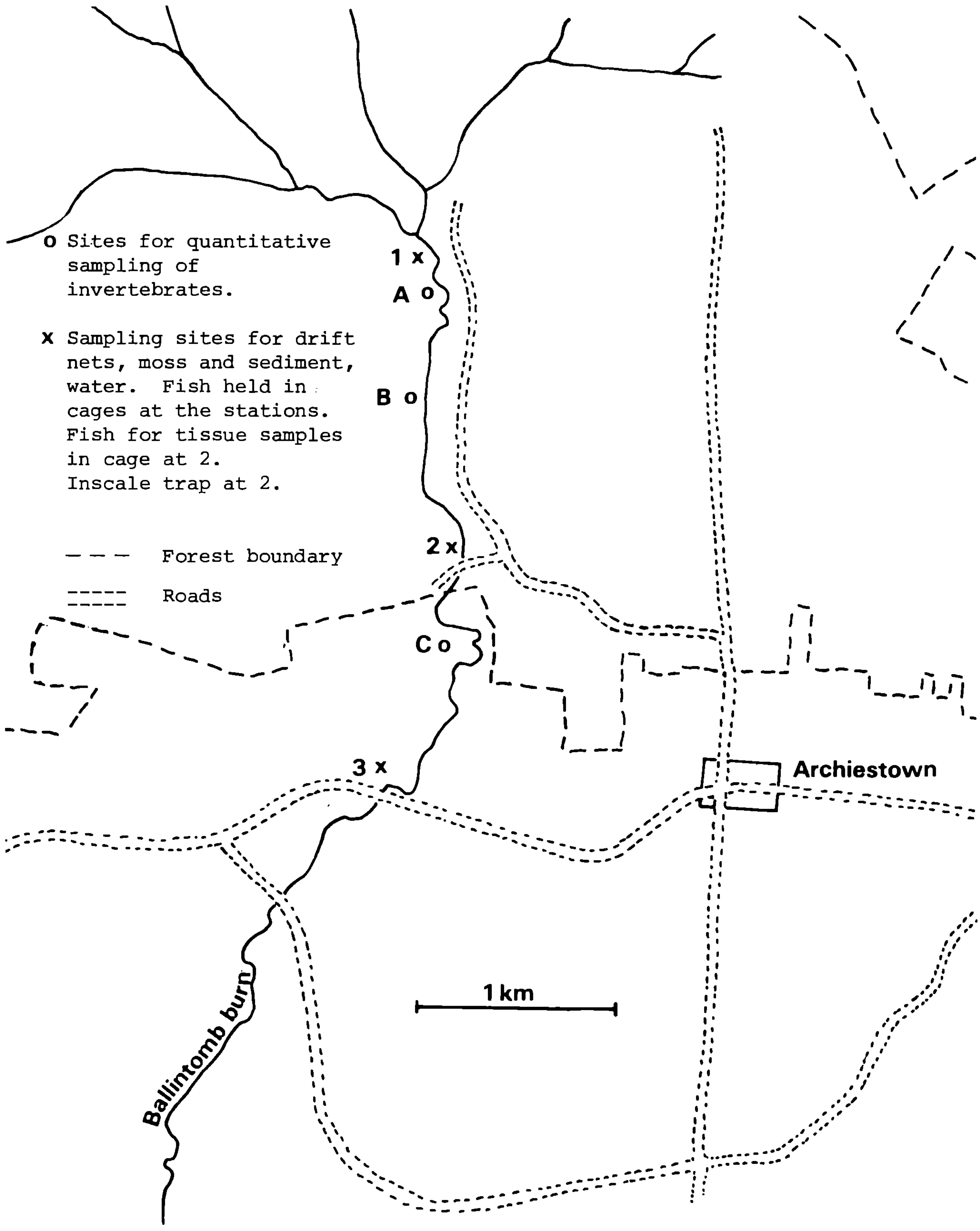

Figure 9.1   Position of sampling sites in Ballintomb Burn catchment.

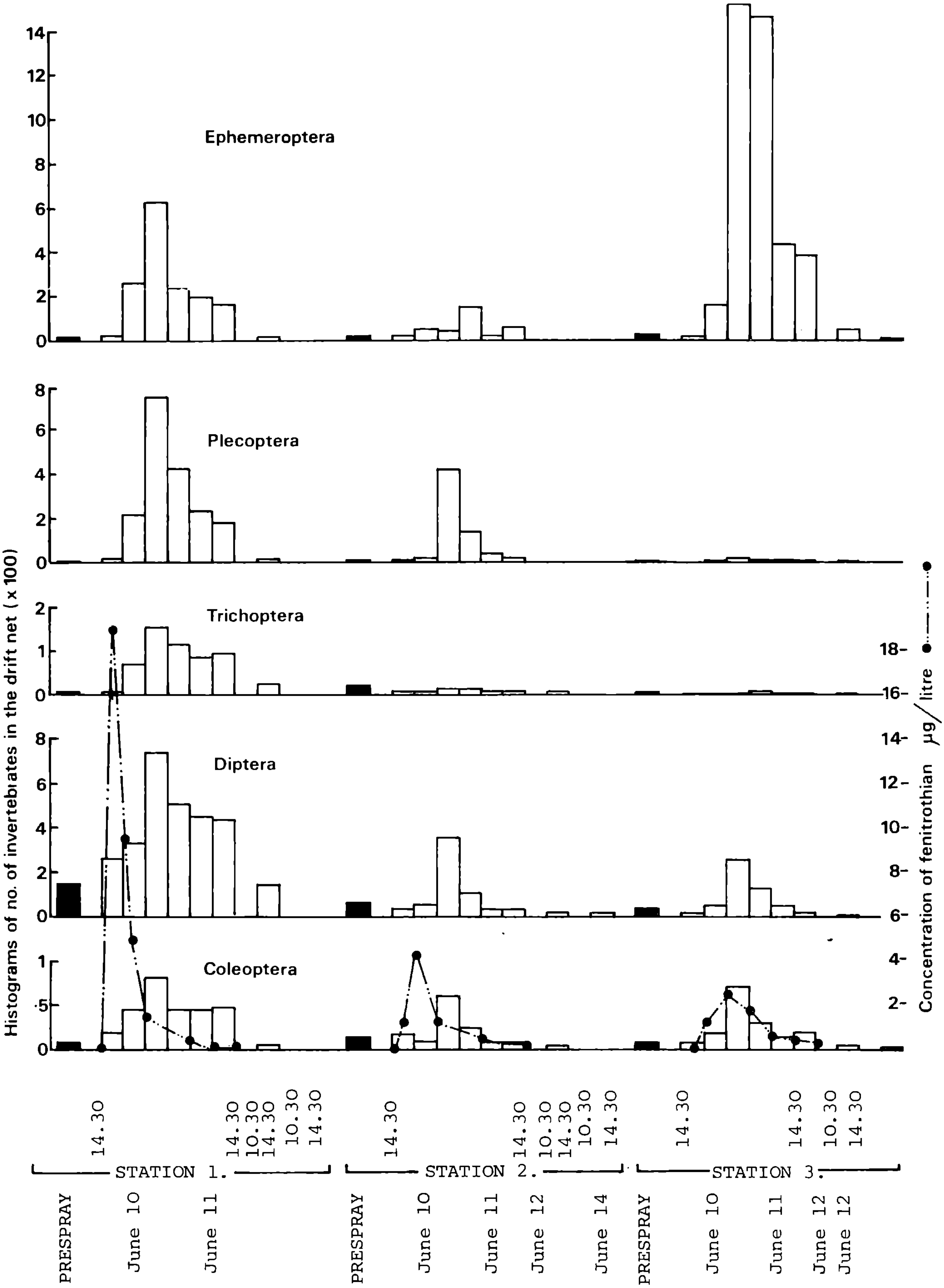

Figure 9.2 Number of insects taken in drift net samples at Stations 1, 2 and 3 in Ballintomb Burn. An indication is given of the fenitrothion concentration in the water.

Chapter 10

THE EFFECTS OF FENITROTHION ON SOME TERRESTRIAL WILDLIFE

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INTRODUCTION

The work done in 1979 was basically a continuation of the studies carried out during the 1978 spraying operations. Due to the lack of time following the submission of the 1978 report to PSPS, and in particular to the Wildlife Panel, a full wildlife trial could not be undertaken before 1980. However, it was felt that much useful information could be gained by continuing to study some effects on wildlife, even in a limited manner, in the interim period. Benefit would also be gained from further experience in trapping animals in a forest environment for subsequent analyses. Several difficulties had been encountered in 1978 and it was felt that some modifications of methods of sampling birds and small mammals were desirable, and changes should also be made in methods of sample preparation for analysis. This work would be helpful in the conduct of any large trial planned for 1980.

SAMPLING AND ANALYSIS

BIRDS

It was proposed to examine birds in some detail, and this would be achieved by limiting the sampling to two species which were relatively abundant in the forest. Chaffinches and Coal tits were chosen for sampling, firstly because of their relative abundance, and also for the difference in their choice of food. In 1978, the few birds that were shot were only analysed for total body burden of fenitrothion. These samples gave little useful information since they did not identify the distribution of the residue, and they could have been substantially affected by falling down through the sprayed foliage and thus increasing their total residue. Little published information on residue distribution within the birds had been found, so it was decided to sample birds on three occasions after spraying and to analyse these birds, after removal of the head and feet, in three portions - skin and plumage, viscera, remainder of the carcase. Whole brain acetylcholinesterase activity would be measured on each bird and six birds from each species would be obtained before the spraying for use as controls for these measurements.

The sampling would be done by the Nature Conservancy Council (NCC) and several methods of live trapping were considered and discussed, but shooting was decided to be likely to be the most effective method of sampling.

MAMMALS

Analyses were to be done on small mammals trapped at three intervals after the spraying. These would be dissected so that separate analyses could be done on skin and fur, viscera, and the remainder of the carcase. Whole brain acetycholinesterase activities would also be measured. Again these samples would be collected by staff from NCC.

It was decided that a large number of Longworth traps would be placed in suitable areas of the forest prior to the spraying and these would be used in the subsequent trapping periods. In 1978, the setting of the traps had been timed so that probably all the mammals which were obtained were caught almost immediately on leaving their burrows following the spraying. In 1979, the first trapping would be delayed until 24 hours after the completion of spraying. In 1978, a high degree of success was achieved with the trapping in one forest and no animals were trapped in another, so many more traps were to be used on this occasion.

INVERTEBRATES

No formal sampling plan was proposed except for *Panolis flammea* larvae, and it was decided to analyse only those insects which might be found dead or affected following the spraying. The analyses of *P. flammea* larvae are reported on separately.

CASUALTY SEARCHES

Several man-miles would be walked either inside or just outside the sprayed area by East Craigs staff during the collection of ground deposition sampling plates, and also by Freshwater Fisheries Laboratory staff and Forestry Commission staff during the course of their work, and those involved were asked to look out for and recover any casualties found. A deliberate systematic search of three distinct areas of the forest would be done by East Craigs staff as soon as possible after the completion of the spraying.

RESULTS

BIRDS

Five Chaffinches and six Coal tits were shot prior to the spraying and placed in deep freeze for use as controls. The sample birds were shot at intervals of one, four and eleven days after spraying. While the third sampling was one day earlier than previously planned this should have had little effect on the results. The original sampling plan had already been modified to include extra Coal tits and omit a third possible species. The results of the sampling were as follows (planned numbers in brackets).

	Pre-spray	1 Day	4 Days	11 Days
Chaffinches	5 (6)	12 (12)	7 (12)	11 (12)
Coal tits	6 (6)	12 (12)	11 (12)	2 (12)

The results of the analyses of chaffinches are shown in Table 10.1 and the results of analyses of Coal tits are shown in Table 10.2.

MAMMALS

Pre-spray trial sampling of small mammals with the Longworth traps showed that this was likely to be unsuccessful. However, adequate numbers of shrews had been found by Forestry Commission staff in plastic bowls placed under trees to catch falling *Panolis* larvae as part of the pre-spray larvae assessment, and it was decided to rely on this source. In practice this was not completely satisfactory, only five shrews being caught in three attempts before the fifth day after spraying when eleven shrews were caught. The animals were too small to allow separate brain acetylcholinesterase measurements and too few were available to do combined measurements, so only fenitrothion analyses were done on these samples. The animals were skinned, and separate analyses done on skin with fur and the remainder of the carcase. The viscera was not removed for separate analysis. The results of the small mammal analyses are shown in Table 10.3.

INVERTEBRATES

Few dead or affected insects were found. The largest find was eleven *Carabus glabratus* found six days after spraying in a feeble condition which suggested possible fenitrothion poisoning. The results of the invertebrate analyses are shown in Table 10.4.

CASUALTY SEARCHES

This did not produce any samples except for the insects mentioned above.

DISCUSSION

There was a marked reduction in whole-brain acetylcholinesterase activities in several chaffinches and Coal tits, and this was still evident in the birds shot 11 days after the spraying. Unfortunately in the batch of twelve Coal tits shot after one day, it was only possible to recover the brains from four of these because the others were badly damaged by shooting. A total of 20 brains from the 54 birds shot were not usable. In many of the birds fragments of feather and skin had been impacted into the carcase by the force of the shot. This made dissection of many of these birds very difficult, and in some instances it was almost impossible to remove all the feathers and skin from the carcase or from the viscera. This may have affected some of the carcase and viscera analyses so that these results should be interpreted with caution.

There does appear to be a general correlation between the inhibition of brain acetylcholinesterase activity and whole-body residue levels despite the fact that these are made up almost entirely from skin and feather residues. It was hoped that the brain acetylcholinesterase measurements would give some indication of any sub-lethal effects of the spraying. Reductions in activity of more than two standard deviations are considered to be significant (MAFF data), and reductions to less than 50 per cent of the control value are considered to be highly significant (US data) and may lead to behavioural changes. The results given in Table 10.1 show that 13 out of 21 chaffinches had a reduction in brain acetylcholinesterase activity of at least twice the standard deviation, but none of these birds gave a reduction of more than 50 per cent of the control value. The results for Coal tits, Table 10.2, show that nine out of 13 birds gave levels which were reduced by more than two standard deviations and three birds had an esterase inhibition of more than 50 per cent. Wide variations were found in the amounts of fenitrothion in the whole bodies, these ranging from 1.7 μg to 106 μg in chaffinches shot after one day, and from 1.3 μg to 89.7 μg in Coal tits shot on the same day. Most of the fenitrothion was on the skin and plumage but the relationship between the whole-body residue and the inhibition of brain acetylcholinesterase indicates some degree of absorption or ingestion following the initial contact.

Small mammal trapping in forests such as this trial area has been shown to be very unpredictable, and the planned sampling programmme was not followed with any degree of success. The levels of fenitrothion found in the shrews which were obtained were all very low and entirely confined to the fur and skin. These results do not show any evidence of possible adverse effects on shrews as a result of the spraying.

The diptera and lepidoptera found dead on the day of the spraying had substantial residues of fenitrothion and they must be considered likely victims of the spraying. Most of the insects found on subsequent days did not have any detectable residues despite the fact that they exhibited symptoms which were consistent with fenitrothion poisoning.

CONCLUSIONS

The work described in this report demonstrates the difficulties in obtaining a predetermined number of birds for analysis from a forest environment. The bird populations were too small and generally inaccessible for trapping techniques to be successful. Shooting small birds often resulted in such severe damage that the sample was spoiled for some analytical purposes. Nevertheless, sufficient birds were obtained to demonstrate that the principal mode of contamination of birds following aerial spraying with fenitrothion is by contact with the plumage and skin. This contact does seem to have resulted in a significant depression of brain acetylcholinesterase activity in many of the samples giving rise to the possible occurrence of sub-lethal effects. Trapping of small mammals was also difficult to achieve with any certainty. The analyses of the shrews showed only slight contamination of their fur, and it seems unlikely that the spraying would have had any direct effect on the small mammal population. As might be expected, insects other than *P. flammea* were affected to some extent by the fenitrothion spraying. No attempt to define the extent of this effect has been made, but only a small number of insect casualties were found.

Searching for wildlife casualties was very difficult to do with any prospect of success, since the density of tree planting made it impossible to penetrate any distance into the forest, and the ground cover in the rides was largely deep heather. No casualties were found other than a few insects, despite the intense human activity in the sprayed area in the period following the application. There was abundant evidence of normal wildlife activity in the sprayed area, especially on the day after the spraying when the weather was warm and sunny. Birds were seen and heard singing and moths and bees were flying above the heather in an apparently normal manner. Sightings were also made of roe deer, field mice, lizards and frogs.

The fenitrothion spraying does not appear to have any substantial effect on the wildlife populations present in this forest. The data obtained from the bird samples does indicate the possibility that some sub-lethal effects on birds may have occurred.

ACKNOWLEDGEMENTS

The assistance of many individuals and organisations is gratefully acknowledged: in particular, staff of NCC for obtaining most of the samples, staff of the FC for facilities and help, staff of MAFF for advice and discussion and staff of DAFS for much of the analytical work.

Table 10.1

Fenitrothion Residues and Acetylcholinesterase Levels in Chaffinches

Sample No	Body Weight (g)	Sex	Fenitrothion Residue (μg) Skin + Plumage	Viscera	Carcase	Whole Body	Brain AChE (m. Moles/hr/g)	Brain AChE % of Control
A. Control Birds Taken Several Days Before Spraying								
1	22.9	M	-	-	-		2.86)	
2	19.4	F	ND	-	-		2.29)	
3	22.8	M	ND	-	-		2.63)	Mean control
4	22.6	M	-	-	-		2.61)	level = 2.54
5	22.8	M	-	-	-		2.50)	S.D. ± 0.20
B. Birds Taken 1 Day After Spraying								
6	19.8	M	2.9	0.3	0.3	3.5 = 0.18 mg/kg	-	
7	19.0	F	30.0	0.3	0.7	31.0 = 1.63 "	-	
8	18.2	M	69.3	0.1	1.1	70.5 = 3.87 "	-	
9	21.3	F	10.0	0.5	0.8	11.3 = 0.53 "	2.71	106.7
10	21.3	M	19.2	0.3	0.8	20.3 = 0.95 "	1.93	76.0
11	21.3	M	38.4	0.3	0.4	39.1 = 1.84 "	1.37	53.9
12	22.5	M	7.8	0.1	0.3	8.2 = 0.36 "	1.95	76.8
13	18.1	F	103.9	1.6	0.6	106.1 = 5.86 "	-	
14	21.8	M	1.7	ND	Trace	1.7 = 0.08 "	3.01	118.5
15	19.2	M	2.1	Trace	ND	2.1 = 0.11 "	2.27	89.4
16	22.2	M	37.5	ND	0.3	37.8 = 1.70 "	1.42	55.9
17	19.1	F	15.4	0.4	ND	15.9 = 0.83 "	-	

- continued overleaf

Table 10.1 (contd)

Sample No	Body Weight (g)	Sex	Fenitrothion Residue (µg) Skin + Plumage	Viscera	Carcase	Whole Body	Brain AChE (m. Moles/hr/g)	Brain AChE % of Control
C. Birds Taken 4 Days After Spraying								
18	21.7	M	6.5	Trace	ND	6.5 = 0.30 mg/kg	-	
19	19.4	M	11.0	ND	0.5	11.5 = 0.59 "	-	
20	21.9	M	9.2	ND	Trace	9.2 = 0.42 "	1.96	77.2
21	21.7	M	7.7	Trace	ND	7.7 = 0.35 "	-	
22	23.8	M	16.7	ND	ND	16.7 = 0.70 "	1.81	71.3
23	19.8	M	0.6	ND	ND	0.6 = 0.03 "	2.19	86.2
24	19.7	M	2.9	ND	ND	2.9 = 0.15 "	2.48	97.6
D. Birds Taken 11 Days After Spraying								
25	22.3	M	3.1	ND	ND	3.1 = 0.14 "	1.43	56.3
26	22.1	M	Trace	ND	ND	<0.01 "	2.12	83.5
27	21.0	M	1.1	ND	ND	1.1 = 0.05 "	1.95	76.8
28	21.6	M	2.8	ND	ND	2.8 = 0.13 "	2.41	94.9
29	22.6	M	3.4	ND	ND	3.4 = 0.15 "	1.45	57.1
30	22.0	M	2.0	ND	ND	2.0 = 0.09 "	2.07	81.5
31	19.0	M	ND	-	-	ND	-	
32	20.6	M	7.1	-	-	7.1 = 0.34 "	1.53	60.2
33	20.5	M	1.3	-	-	1.3 = 0.06 "	2.11	83.1
34	21.3	M	1.4	-	-	1.4 = 0.07 "	1.51	59.4
35	20.9	M	1.5	-	-	1.5 = 0.07 "	3.02	118.9

Notes:
1. Limit of detection = 0.05 µg
2. Trace = 0.05 - 0.1 µg
3. ND = Nil detected
4. - = Not analysed

Table 10.2

Fenitrothion Residues and Acetylcholinesterase Levels in Coal Tits

Sample No	*Body Weight (g)*	*Sex*	*Fenitrothion Residue (µg)* *Skin + Plumage*	*Viscera*	*Carcase*	*Whole Body*	*Brain AChE (m. Moles/hr/g)*	*Brain AChE % of Control*
A. Control Birds Taken Several Days Before Spraying								
36	8.7	M	ND	-	-		2.60)	
37	8.8	?	-	-	-		2.15)	
38	8.5	?	ND	-	-		2.22)	Mean control
39	7.9	M	-	-	-		2.74)	level = 2.51
40	7.8	?	-	-	-		2.73)	S.D. ± 0.23
41	8.5	?	-	-	-		2.59)	
B. Birds Taken 1 Day After Spraying								
42	7.8	M	13.3	0.2	0.2	13.7 = =.76 mg/kg	-	
43	6.2	?	18.0	0.3	0.7	19.0 = 3.06 "	-	
44	8.2	M	86.0	3.0	0.7	89.7 =10.94 "	1.03	41.0
45	8.3	M	33.5	0.6	1.2	35.3 = 4.25 "	-	
46	8.7	M	78.0	0.1	0.1	78.2 = 8.99 "	1.33	53.0
47	6.0	?	6.7	0.2	0.7	7.6 = 1.27 "	-	
48	7.6	F	55.8	0.2	1.0	57.0 = 7.50 "	-	
49	8.5	?	61.3	0.2	0.3	61.8 = 7.27 "	1.49	59.4
50	7.8	M	1.0	ND	0.3	1.3 = 0.17 "	-	
51	6.1	?	1.0	0.6	0.4	2.0 = 0.33 "	-	
52	5.7	?	11.7	Trace	0.5	12.2 = 2.14 "	-	
53	7.1	?	17.5	0.2	0.6	18.3 = 2.58 "	1.46	58.2

- Continued overleaf

Table 10.2 (contd)

Sample No	*Body Weight (g)*	*Sex*	*Fenitrothion Residue (µg)* *Skin + Plumage*	*Viscera*	*Carcase*	*Whole Body*	*Brain AChE (m. Moles/hr/g)*	*Brain AChE % of Control*
C. Birds Taken 4 Days After Spraying								
54	7.5	M	1.2	ND	ND	1.2 = 0.16 mg/kg	-	
55	8.7	F	19.3	Trace	0.2	19.5 = 2.24 "	1.13	45.0
56	6.4	?	0.3	Trace	ND	0.3 = 0.05 "	2.10	83.7
57	8.3	?	1.0	0.2	Trace	1.2 = 0.14 "	2.70	107.6
58	8.2	F	15.3	ND	0.1	15.4 = 1.88 "	1.38	55.0
59	7.6	M	1.5	ND	Trace	1.5 = 0.20 "	-	
60	7.4	F	2.7	0.2	Trace	2.9 = 0.39 "	3.61	143.8
61	8.2	M	3.1	0.8	Trace	3.9 = 0.48 "	-	
62	8.4	?	7.5	Trace	ND	7.5 = 0.89 "	0.99	39.4
63	4.7	?	19.2	0.5	0.6	20.3 = 4.32 "	-	
64	7.9	?	1.1	Trace	ND	1.1 = 0.14 "	1.91	76.1
D. Birds Taken 11 Days After Spraying								
65	8.6	M	1.3	-	-	1.3 = 0.15 "	1.63	64.9
66	8.7	F	0.4	-	-	0.4 = 0.05 "	2.78	110.8

Notes:
1. Limit of detection = 0.05 µg
2. Trace = 0.05 - 0.1 µg
3. ND = Nil detected
4. - = Not analysed

Table 10.3

Fenitrothion Residues in Shrews

Sample No	*Species*	*Body weight (g)*	*Time from Spray to Capture (Days)*	*Fenitrothion in Skin + Fur (µg)*	*Fenitrothion in Carcase (µg)*	*Fenitrothion in Whole Body (mg/kg)*
67	Common	10.7	Pre-spray	ND	-	
68	Common	6.5	Pre-spray	ND	-	
69	Common	5.3	1	1.0	ND	0.19
70	Common	11.8	2	0.4	-	0.03
71	Common	8.3	2	0.4	-	0.05
72	Common	6.8	4	0.2	-	0.03
73	Common	5.8	4	0.4	-	0.07
74	Common	10.5	5	0.6	ND	0.06
75	Pygmy	3.1	5	Trace	-	<0.03
76	Common	5.7	5	Trace	ND	<0.03
77	Pygmy	3.6	5	Trace	ND	<0.05
78	Common	7.0	5	Trace	ND	<0.03
79	Common	5.5	5	0.2	-	0.04
80	Common	7.4	5	1.5	-	0.20
81	Common	12.2	5	0.4	-	0.03
82	Common	10.8	5	0.5	-	0.05
83	Common	10.2	5	Trace	-	<0.02
84	Pygmy	2.4	5	0.2	-	0.08

Notes:
1. Limit of detection = 0.1 µg
2. Trace = 0.1 - 0.2 µg
3. ND = Nil detected
4. - = Not analysed

Table 10.4

Fenitrothion Residues in Some Invertebrates Found Within 3 Days Following Application

	Type	*No of Insects*	*Total Weight of Sample*	*Total Residue of Fenitrothion*	*Residue (ppm)*
1.	Diptera	2	15.98 mg	0.395 µg	24.7
2.	Lepidoptera	3	34.83 mg	0.468 µg	13.4
3.	Arachnida	2	9.85 mg	0.015 µg	1.5
4.	Hymenoptera	3	411 mg	0.196 µg	0.48
5.	Coleoptera-Carabidae	2	1,246 mg	1.974 µg	1.58
6.	Nebria (Brevicollis)	2	91.78 mg	0.015 g	0.16
7.	Elateridae	2	130.88 mg	ND	(Limit of detection 0.01 µg)
8.	Diptera	1	20.35 mg	ND	" " "
9.	Hymenoptera	1	5.87 mg	ND	" " "
10.	*Carabus violaceus*	1	311.06 mg	ND	" " "
11.	*Carabus glabratus*	11	6,264 mg	ND	" " "
12.	Hymenoptera	2	409.80 mg	ND	
13.	Carabus	6	3,080 mg	ND	(Limit of detection 0.03 µg)

Notes:
1-4. Collected by D. Bevan, Forestry Commission, 10.6.79.
5. Collected by A.D. Ruthven, DAFS, 11.6.79 (Found alive, but in a feeble condition)
6-11. Collected by B. Morrison, DAFS, 13.6.79 (Found alive, but in a feeble condition)
12-13. Collected by B. Morrison, DAFS, 12.6.79 (Found alive, but in a feeble condition)

Chapter 11

STUDY OF WATER QUALITY AND STREAM FAUNA AT ANNABAGLISH

J.S. Coy
Solway River Purification Board

INTRODUCTION

Although the bulk of the treatment in 1979 was scheduled for forests in north and north east Scotland, a small plantation of Lodgepole pine at Annabaglish (Bareagle Forest) Wigtownshire was also included. At a meeting in March it was agreed that the Solway River Purification Board would examine the chemical effects of this spraying on surface water run-off and later, despite a lack of expertise in limnology, it was also agreed to undertake some elementary biological studies under the direction of the Freshwater Fisheries Laboratory, Pitlochry.

SPRAYING AREA - AFFECTED WATERCOURSES

The Annabaglish Plantation (Figure 11.1) lies to the south and west of Kirkcowan in an area of peat overlying Silurian greywacke and shales. It is drained by two watercourses: the Drumdow burn which flows north into the River Tarf, and the Gillespie burn which flows south into Luce Bay. Because of its confluence with the Tarf, at one time a salmon river of some repute, the Drumdow is perhaps the more significant. It also drains the larger part of the plantation so, with limited resources and taking account of accessibility, the monitoring effort centred on this stream,

PRE-SPRAY WORK

CHEMICAL

Two sampling stations were selected - one immediately below the plantation (A), the other about 1.5 km downstream, just above the River Tarf (B), the purpose of the downstream site being to measure the effects of dilution and possible degradation on the level of pesticide entering the main river. At (A) the burn is about 1.5m wide and 60cm deep. It has a bed of a clay/peat amalgam, though some larger stones are present. The flow here is sluggish, but shortly after the plantation the gradient stiffens with a consequent increase in velocity.

By the time (B) is reached, the flow has swollen considerably and here the burn is about 2m wide; has a depth of 30cm and the bottom consists of gravel and large stones. Due to recent draining and planting in other parts of the catchment, heavy deposits of scoured peat covered the stream bed, which was later to prove a handicap with the biological monitoring.

BIOLOGICAL

The equipment for this work was kindly loaned by the Freshwater Fisheries Laboratory, Pitlochry.

Drift Nets

To collect displaced invertebrates carried downstream, drift nets were placed at both sites. On reflection, (A) was not ideally suited to this particular exercise because of the sluggish flow. A slight excavation was needed at (B) to ensure that the mouth of the net was under water.

Fish Cages

A fish cage (black polythene with chicken wire top) was anchored at each station. It was hoped to use solely trout from the Drumdow burn for this monitoring but electrofishing an 800m stretch provided only four fish. Additional wild brown trout were later obtained from another burn on Forestry Commission land and these, together with the Drumdow trout, were introduced to the cages on 6 June: 10 trout of 10-15 cm length to a cage. Gradual acclimatisation prevented any mortalities due to changes in water quality and all the fish were alive and healthy at the onset of spraying.

Invertebrate Cages

A basket containing six cylindrical, plastic 'cages' was positioned at station (B). It was intended to collect all the specimens for the cages from Drumdow burn, but heavy deposits of peat on the stream bed proved a hindrance and only caddis larvae were taken from this course. Mayfly and stonefly nymphs were therefore gathered from the parent river Tarf where there appeared to be an abundance of both species.

Each cage was allocated five specimens:- two contained five caddis larvae each, two contained stonefly nymphs (five large and five small respectively) and two contained mayfly nymphs - again five large and five small.

The first batch of the smaller mayfly and stonefly escaped through the cage mesh, but further losses were prevented by covering these particular cylinders in a nylon sleeve.

SPRAYING

There was a late change in the programme when the area was selected for experimental spraying. It was learned that the purpose of this was to see if an effective 'kill' of the Pine beauty moth could be achieved using half the normal dose of pesticide. Instead of a single ULV treatment of 300g active ingredient/hectare, the plantation received two applications each at a quarter of the normal dosage rate (75g/hectare) separated by a period of 48 hours. This naturally extended the time over which fenitrothion would be present in the water and the initial sampling programme had to be modified accordingly.

Spraying commenced at 13.15 on 13 June 1979, a fairly calm dry day. This was followed by the second application on 15 June at 16.30 hours; it was a day of strong gusting winds.

WATER SAMPLING

Samples (1 litre acidified bottle) for fenitrothion determination only were taken every 2h from both stations over a 24h period commencing just before spraying. An automatic sampler was employed at (A), while those from (B) were taken manually. Additional samples were obtained at intervals for the Board's normal, full analysis to determine the overall quality.

BIOLOGICAL MONITORING

To assess any pre-spray drifting of invertebrates the nets were first set on 12 June; the contents being emptied and preserved in a formalin solution the following morning. Thereafter the nets were emptied and reset every four hours, except for the spell in between applications. All these samples were sent to the Freshwater Fisheries Laboratory for evaluation, and the results of the invertebrate analyses are given in an Appendix to this report.

Post-spray checks on the trout were made at four-hourly intervals. Because of the peat-stained water and dark colouration of the cages this was initially done by lifting the containers out of the burn. However, it was felt that this routine subjected the fish to unnatural stress, so after the first two inspections a check was simply made on whether there had been any mortalities.

RESULTS AND DISCUSSION

Water quality, rainfall and flow data are given in Table 11.1, and results of the water analyses for fenitrothion in Table 11.2. Flows were not actually gauged, but observation suggested there was little change in water level throughout the period of monitoring - if anything, levels would have fallen slightly. The rainfall figures are from a gauge some 11 km away from the sampling site.

Chemical

The overall water quality is somewhat richer and harder than would have been anticipated from a catchment of this nature - greywacke overlain by deep peat. Applications of mineral fertiliser, primarily within the afforested areas, readily accounts for the phosphate concentration being five times greater than considered normal for the Galloway region as a whole. However, the calcium figures are not so easy to explain. Geological maps have been examined but they do not show any strata likely to contain calcium in quantity. Nevertheless, from the water analysis it must be assumed that there are such deposits.

The very low dissolved oxygen saturation below the plantation on 13 and 14 June can be attributed to a combination of three factors. Firstly, the stream is canalised at this point; secondly it is shielded from the prevailing westerly wind and, thirdly, it supports very little in the way of oxygenating plants.

The behaviour of the fenitrothion at Station (A) is shown graphically in Figure 11.2. It rose quite sharply to a maximum of 3 μg/l 6½h after the primary spraying. A steady fall, punctuated by three peaks associated with rain showers, was then recorded and at the close of the first 24h sampling programme the level had fallen to 0.9 μg/l.

When sampling began again on 15 June before the secondary treatment, the concentration had dropped further to 0.3 μg/l and, somewhat surprisingly, despite spraying at 16.30, it continued to fall until around 03.00 hours on the 16th; some 12h after the second application. A maximum of 0.8 μg/l was registered between 13 and 17 hours after spraying.

At the downstream station (B), excluding one result which must be treated as bogus, the fenitrothion concentration never exceeded 0.1 μg/l. Dilution alone would account for a reduction, at the peak concentration, to a value of approximately 0.8 μg/l and it is therefore assumed that the fenitrothion molecule broke down during transit downstream.

That the second application did not produce a higher peak through an accumulative effect must, it is felt, be related to the strong, gusting wind on 15 June. There is no doubt that the fine ULV spray would have been distributed over a much broader area than just the plantation and it is conceivable that a fair proportion eventually came to earth beyond the Drumdow burn catchment. This spread over a wider area could also account for the longer time taken for the second treatment to show a peak in the watercourse.

Biological

The caged trout at both stations appeared to behave normally throughout the survey and no mortalities occurred, irrespective of the low dissolved oxygen at (A). The use of stones to anchor the cages tended to shield the fish from view, and in future it would be better to incorporate the weighting in the cage design.

In common with the trout, all the caged invertebrates survived, although none actually hatched into the adult fly. Drift net samples were analysed by the Freshwater Fisheries Laboratory (see Appendix) but again it is emphasised that Station (A) was, in retrospect, not thought ideally suited to this particular exercise because of the low current velocity.

One final comment on the insect life: pondskaters in reasonable numbers were seen at (A) over the whole monitoring period.

CONCLUSIONS

The maximum recorded level of fenitrothion in the Drumdow burn immediately below the plantation was 3 µg/l, 6½h after the first treatment. 24 and 48 hours after spraying the level had dropped to 0.8 and 0.3 µg/l respectively.

The second treatment did not produce the expected, accumulative response i.e. the second peak was not higher than the first. But it must be stressed that weather conditions were not considered anything like suitable for aerial spraying and other factors determined the decision to proceed. At the station 1.5 km downstream of the spraying area the concentration of pesticide was negligible.

From the basic biological surveillance it seems that the effect on the stream fauna was insignificant. However, the results of the drift net sampling have still to be taken into account, though they are not expected to detract from this view.

Finally, thanks are due in large measure to the Freshwater Fisheries Laboratory both for their help in arranging a manageable sampling programme and for the loan of equipment used in the biological monitoring; also to Mr Alec Marshall of the Forestry Commission for obtaining the trout and to others on the Forestry Commission staff who gave advice freely when approached.

APPENDIX

B.R.S. Morrison
Freshwater Fisheries Laboratory, Pitlochry

The analysis of the drift net samples was done at the Freshwater Fisheries Laboratory, Pitlochry, and the results are summarised in Figure 11.2. It had not been possible to sample at regular intervals and consequently the histograms are based on the number of animals taken in each sample, divided by the duration of that sampling period. At Station (A) 73 per cent of the animals in the net were larval Chironomidae, and this group of insects formed 90 per cent of the catch at Station (B).

Although it is not known when the animals entered the drift nets during the long sampling period prior to treatment, the fact that this period extended over the hours of darkness as well as daylight enabled the effects of nocturnal drifting of invertebrates to be taken into account. Catches indicate that this must have been at a relatively low level. At first sight the increase in the catches over the period 13/14 June would appear to be due to the effects of the fenitrothion, but it is more likely that this was the result of the rain which fell at this time (see Table 11.1). Similar increases in numbers were noted at both stations despite the fact that the level of fenitrothion at Station (A) was 30 times that at (B). Evidence from 1978 work (Holden and Bevan, 1979) suggests that levels below 1 μg/l have no effect on the rate of drift. There was no second peak at (B) when fenitrothion levels reached 0.1 μg/l for a second time, on 14 June. Further evidence suggesting that increases in catches were not related to fenitrothion concentrations is shown in the analysis of data for the second treatment. In this case peak levels at Station (A) were obtained before the fenitrothion level in the water rose.

Table 11.1

Water Quality, Stream Flow and Rainfall Data

	Drumdow Burn*							River* Tarf
	Station A				Station B			
	Below Plantation				Above River Tarf			
1979 *Date*	*13/6*	*14/6*	*15/6*	*16/6*	*13/6*	*15/6*	*16/6*	*11/7*
pH	6.6	6.9	6.9	7.1	6.8	6.9	6.9	6.3
Conductivity (μS/cm)	135	122	126	130	137	141	148	109
Temperature °C	15	13	15	16	16	16	18	15
Dissolved Oxygen	6.1	5.8	8.7	7.7	7.6	8.2	6.9	9.5
Dissolved Oxygen - % saturation	62	55	88	78	75	81	73	94
Suspended solids	8	4	4	4	4	2	3	9
4-hour Permanganate value	25	26.4	27.4	26.6	17.2	36.4	17.4	9.6
Biochemical Oxygen Demand	1.2	1.1	1.1	1.1	1.0	1.0	0.9	2.1
Free and Saline Ammonia	0.18	0.14	0.10	0.11	0.11	0.15	0.1	0.18
Nitrite	0.02	0.02	0.02	0.02	0.04	0.03	0.03	0.01
Nitrate	0.16	0.13	0.06	0.1	0.64	0.74	0.12	0.54
Soluble Orthophosphate	0.047	0.047	0.042	0.041	0.023	0.021	0.024	0.072
Chloride	17	24	16	16	16	16	18	16
Total Alkalinity	27	37	34	34	37	36	36	32
Total Hardness	56	-	53	51	23	47	51	35
Calcium Hardness	29	-	31	33	18	36	43	23
Silicate	2.2	2.0	1.9	1.8	1.2	1.3	1.2	0.3

* All figures mg/l unless otherwise stated

Estimated Stream Flows

Station (A) - 8 litres/sec)
Station (B) - 31 litres/sec) approximately 60 percentile flow

Rainfall Figures		mm
June 12	-	4
" 13	-	1.4
" 14	-	1.1
" 15	-	trace
" 16	-	trace

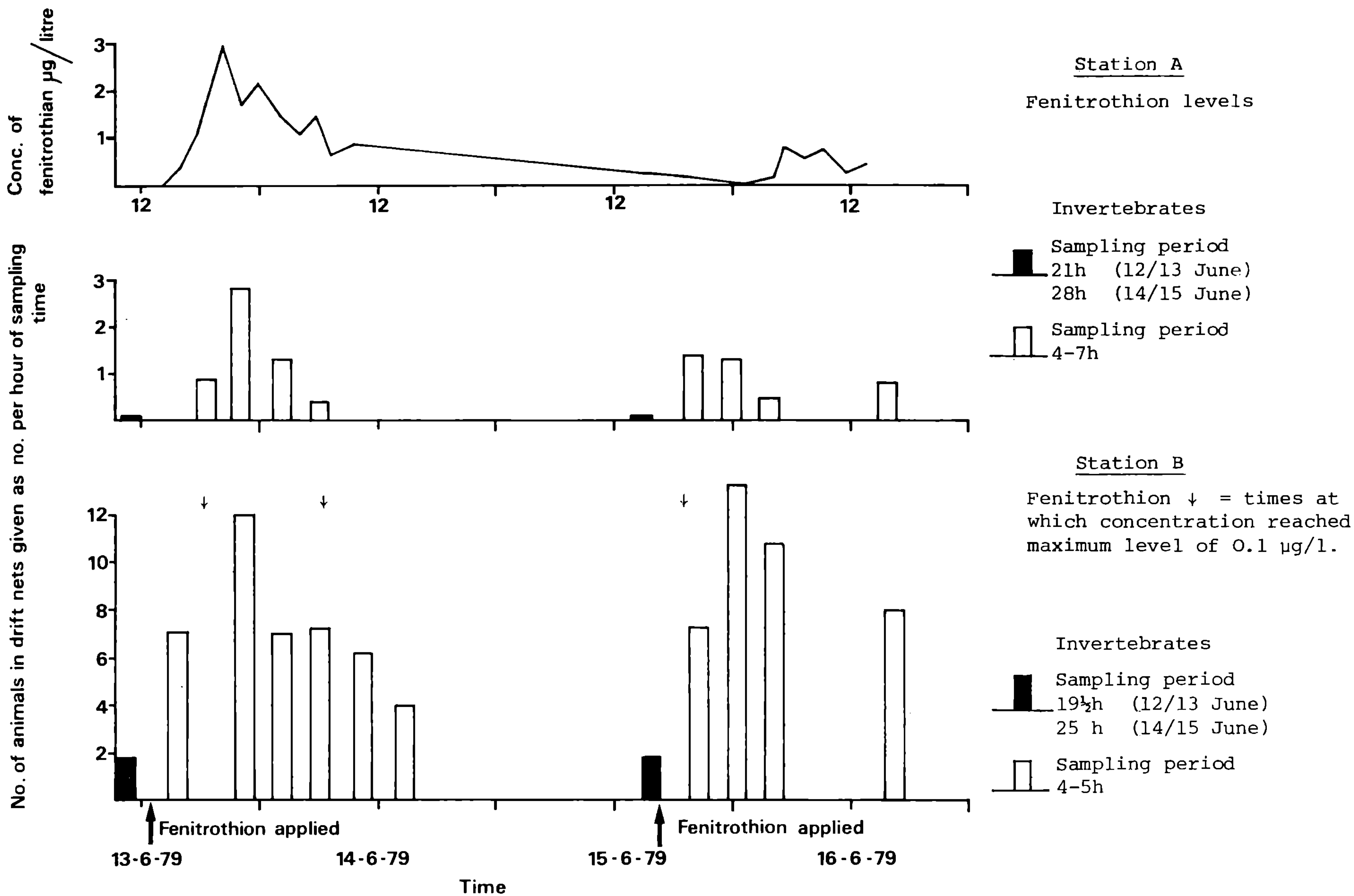

Figure 11.2 Relationship between fenitrothion concentrations and drift net catches in the Drumdow Burn.

Chapter 12

1979/1980 SPRAYING FORECAST AND PROGRAMME COMPLETED

J.T. Stoakley
Forestry Commission

3166 hectares were sprayed during 1979 at Naver Forest (Strathy) - 236 ha, Shin Forest (N. Dalchork) - 552 ha, (Caplich Wood) - 107 ha, Inveroykel - 371 ha, Torrachilty Forest (Strathrannoch and Garbat) - 996 ha, Craigellachie Forest (Elchies) - 770 ha and Bareagle Forest (Annabaglish) - 220 ha. At Caplich Wood and Torrachilty, 15 and 86 ha respectively were excluded by the terms of the PSPS clearance. Good control was obtained with mortality ranging from 97 to 100 per cent.

Following pupal counts in September and October 1979 in all Forestry Commission plantations considered to be substantially at risk, the areas which should be sprayed during 1980 are given below, together with a record of the programme completed.

	Programme	
	Forecast	*Completed*
North (Scotland) Conservancy		
Naver Forest		
*Truderscaig (N)	166	166
*Rosal (S)	125	361
Altnaharra small blocks		
*Barren Ridge	22	22
*Chicken Dhu	56	56
Mudale	20	20
Poles 1 and 2	102	102
Garvel	20	20
Grumbeg	20	274
Cnoc Dubh	13	13
*Syre	420	166
Shin Forest		
†Caplich	122	-
South (Scotland) Conservancy		
Bareagle Forest		
†Annabaglish	220	220
N. Annabaglish	37	27
	1343	1447

* Sprayed 1978

† Sprayed 1979

The changes in programme were based on later assessments of pupal populations.

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