Control of Pine Beauty Moth by Fenitrothion in Scotland 1978

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Forestry Commission

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PREFACE

This document is assembled from a series of individual reports written by scientists and technicians from a number of organisations which took part in an operation carried out at short notice, to monitor the spraying of forests in northern Scotland to control the outbreaks of Pine beauty moth. The operation was achieved with a limited number of available personnel and equipment for sampling, and with little opportunity for preliminary tests of experimental procedures. The unavoidable delay in commencing the spraying on the scheduled date resulted in additional difficulties for some organisations and, in view of the short notice given that spraying was to be carried out, it was not possible for adequate pre-spray observations to be made, such as would have provided the desired reference basis for the subsequent measurements.

Notwithstanding these limitations, it has been suggested that the publication of the following reports in one volume will be of value to those who have the responsibility for authorising future aerial spraying operations in the United Kingdom, to control pests over relatively large areas. The experience gained by the various organisations involved has enabled them to reach certain conclusions regarding both the use of aerial spraying techniques and the environmental risks involved, and also to plan future monitoring operations, if necessary, with a greater ability to provide data which will give more confidence in assessing the environmental impact.

The reports are presented with the minimum of editing, although duplication of essentially descriptive material has been avoided as far as possible, and an approach has been made to uniformity in the presentation of the data. The respective authors have presented all the information obtained during their investigations in the interest of providing as complete a record as possible, but it should be understood that both the acquisition of the field data and the provision of the reports were achieved with severe restrictions on the time available for planning and preparation, and with the minimum of staff for their accomplishment. It is to be hoped, however, that this document will be of value in planning future operations of a similar nature.

SUMMARY AND MAIN CONCLUSIONS

The course of the current outbreak of Pine beauty, *Panolis flammea*, is described, and the failure to control it with *Bacillus thuringiensis* in 1977 is recorded.

The technical advantages of a target-specific ultra low volume aerial spraying over conventional low volume technique is considered. A comparative trial of the ULV and LV techniques is described and the results of assessments of deposits upon the ground, on the pine needles and on larvae are given for both the trial and the later spraying operation itself. It was clear that more insecticide arrived on the target larvae and needles in ULV applications and less upon the ground.

The results of environmental monitoring are reported and are largely based on a limited number of samples and insufficient time for adequate pre-spray studies. Nevertheless it seems evident that in the terrestrial environment no major mortalities occurred during the period of study in species other than those of the primary target (Pine beauty moth) and the sawfly caterpillars on the same trees. Many other flying insects were seen among the trees some hours after spraying, and most bird species in the forests were unaffected, at least in the short term. No effects were found among the small mammals, although the time interval between spraying and sampling was too short to demonstrate any longer term effects.

In the aquatic environment, while a significant effect was observed on many species of invertebrates, adequate representation of many of them was found in subsequent kick samples a month later. No effects were found on either wild or captive fish, and the residues found in them were much lower than were likely to be lethal. Concentrations in the water were mostly below 18 µg/litre, and even the maximum observed (48 µg/litre) was only about 1 per cent of the 24-hour LC_{50} for salmon fry, although the duration of this peak was very brief. The aqueous concentrations decreased more rapidly after the ULV technique than after the LV spraying, but otherwise there was little difference between the methods. The possibility of long-term effects on the fish populations resulting from a decrease in the invertebrate food supply has not been investigated, although the likelihood of this is small.

The concentrations of fenitrothion measured in the atmosphere in the vicinity of sprayed plantations were judged, by those responsible for the measurements, to present no risk to humans in the area. The pilot showed no evidence of cholinesterase reduction, although on one occasion some influence on pupil dilation was observed when the plane was forced to fly down wind into a previously sprayed area. This effect was not considered by the Medical Officer to be significant. Measurements were also made of the levels of fenitrothion in the cockpit atmosphere; on only one occasion were levels recorded high enough to cause concern, that is if threshold limit values for the very much more toxic methyl parathion are accepted as datum.

The general assessment of the effects of the spraying on wildlife is that, within the limits of the observations made, these were small or unimportant. However, it is anticipated that in any future treatments some more detailed studies may be made to examine whether any more subtle effects, particularly those of a longer term nature, can be detected. If single treatments are made at long intervals, it seems unlikely that serious damage would be caused to non-target species. The Group, who have only had the opportunity to study single treatments, expressed some reservations on repeated applications on the same area. Where the fresh waters are used for commercial purposes, as in fish farms, contamination could be less acceptable.

Despite the small measure of reported adverse environmental effects of this use of fenitrothion, as a single treatment over a large area, it is considered that caution over such operations should continue. The presence of rare species of birds or insects, for instance, might require special consideration, and consultations should take place with the appropriate wildlife authorities before spraying takes place.

The ULV treatment would appear to have certain advantages and no disadvantages over the LV treatment, particularly those arising from the shorter period required to apply the required dose of insecticide, and the decreased risk of ground contamination.

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INTRODUCTION

In 1976, outbreaks of Pine beauty moth were recorded on Lodgepole pine plantations in northern Scotland, and by 1977 it was found, following pupal surveys in a large number of plantations, that chemical control was urgently required if serious damage to large areas of Lodgepole pine forests was to be avoided. Aerial insecticide spraying on the scale required had not previously been employed in the United Kingdom, and the preferred ULV technique, which was less costly in both time and materials, had neither been tested nor approved for forestry use in this country.

The first approach for permission to use fenitrothion spraying was made by the Forestry Commission to the Pesticides Safety Precautions Scheme (operated by the Ministry of Agriculture, Fisheries and Food) in March 1978, and following urgent discussions qualified approval was given, provided that the operation was monitored to assess the possible risks both to humans and to various wildlife species. Co-operation was sought from several organisations and laboratories, which had the responsibility for protecting human health or the environment, or had the necessary expertise and equipment to obtain information on the environmental concentrations of the pesticide, and to assess the hazards which these might present.

Fenitrothion was selected as the most appropriate insecticide on the basis of preliminary screening tests. It has been used on a large scale in North America for some years, and Canadian reports on usage in forests were available to those responsible for monitoring the Scottish project, giving a valuable indication of the effects which might be anticipated in the Scottish situation.

The monitoring operation was organised at relatively short notice, but was designed to obtain information on the degree of exposure to humans inhaling air in the spray zone, the concentrations of insecticide and their effects in streams and on various aquatic and terrestrial wildlife species, the rate of deposition on the trees and the ground, and the efficiency of destruction of the Pine beauty moth. In addition, an assessment was made of the extent to which the pilot of the spray aircraft was exposed to the insecticide, the pilot himself being under medical supervision. Information on these observations is presented on the following pages, based on reports which were submitted and discussed at a meeting of the various organisations in Edinburgh in October 1978.

Forestry Commission

Ministry of Agriculture, Fisheries and Food

Department of Agriculture and Fisheries for Scotland

Nature Conservancy Council

Highland River Purification Board

College of Aeronautics, Cranfield

Institute of Occupational Medicine

Health and Safety Executive (Scotland)

In addition, the assistance of the following organisations enabling the spraying operation to be carried out is gratefully acknowledged:

Department of Trade and Industry

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Environmental Health Department, Highland Regional Council

Heliscot Limited

Lloyds Brokers

Air BP

Civil Aviation Authority

Joint Civil/Military Air Traffic Services

Chapter 1

THE PINE BEAUTY MOTH - ITS DISTRIBUTION, LIFE CYCLE AND IMPORTANCE AS A PEST IN SCOTTISH FORESTS

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The Pine beauty moth *(Panolis flammea* D&S, family *Noctuidae)* is an indigenous species reported as occurring on Scots pine throughout Britain except in Caithness and Sutherland (South 1961). Outbreaks have never occurred on the native host in this country although in Central Europe it is an important pest of Scots pine and there have been several major outbreaks in this century. However, the insect has now proved to be a major pest of Lodgepole pine, the first outbreaks occurring in just that area from which it was previously supposed to be absent.

The new host is an introduction to British forestry from Western North America. It is particularly adapted to wet, acid and infertile soils, including peat, and the great bulk of planting has taken place only within the past 15 to 20 years as marginal sites have been accepted for afforestation. In general, the species has proved capable of making adequate growth on such sites with minimum input of fertilizers. It is a matter of debate amongst silviculturists whether alternative species of economic value can be grown satisfactorily on the poorest of these sites. However, while it is generally agreed that cultural solutions must be sought and applied to this pest problem in the long term, there is a clear need for development of effective and safe, insecticidal control measures to protect the existing investment in the more immediate future.

The Pine beauty has a simple life history with one generation per year. In northern Scotland moths emerge in early April from pupae which over-winter beneath needle litter and in the peat soils. Both sexes, in approximately equal numbers, fly to the crowns of trees, where they mate and the females lay their eggs in short rows on older needles over the period mid-April to mid-May. Egg hatch, at the very end of May and in early June, seems to be closely synchronised with the extension of the new shoots of the current year. The young larvae migrate to these shoots and commence feeding on internal tissues at the bases of the developing needle-pairs. The head is within the needles but the rest of the larval body remains exposed. This mode of feeding continues well into the third of the five larval stages, or instars; thereafter the larvae move on to the older needles and start to strip them. The effects of feeding on current shoots are not immediately obvious, but as time goes on the needle-pairs collapse at their bases and if feeding is very intensive the axes of the new shoots are also damaged and eventually collapse. However, there may be total defoliation of current and subsequently older needles, without collapse of the current shoots and in this case live, but puny, terminal buds will be set giving false hope that the trees will survive. Examination of the cambium of totally defoliated trees shows that they die from the tops in winter and early spring. Initially it seemed probable that trees debilitated by partial defoliation would be attacked and killed during the following spring by the bark beetle, *Tomicus piniperda,* thus extending the area of destruction, although this has not occurred in north Scotland. The course of events is in contrast to that in outbreaks of the Pine looper moth, *Bupalus piniaria,* occurring mainly on Scots pine, where defoliation occurs in late summer and autumn, and totally defoliated trees survive the winter but succumb to bark beetle attack in early spring. Pine beauty is clearly a potent pest, always depending of course on numbers present.

Pine beauty larvae were first found feeding in small numbers on Lodgepole pine in Caithness and Sutherland (Highland Region of Scotland) in 1973 and 1974 but had doubtless become established some years previously. The first outbreak occurred in the Rimsdale block of Naver Forest in 1976, when 120 ha of Lodgepole pine, planted between 1958 and 1966, were completely defoliated. Within this block about 60 ha of plantations of similar age and a large area of considerably younger crops remained unaffected, but at the end of the larval feeding period there was a very high pupal population and these areas were clearly at risk. The block totalling 540 ha was therefore treated in June 1977 with Dipel, a preparation of *Bacillus thuringiensis,* applied by helicopter at 1 kg per ha during the early larval stage. This material was chosen following satisfactory laboratory tests, because it is specific to the larvae of Lepidoptera. To be effective it must be ingested and it then acts as a stomach poison. Tests on foliage samples taken after application showed that, theoretically, an adequate dosage had been applied. However, no useful control was achieved. It now seems clear that this failure was due to the larvae feeding on internal tissues for the first half of their life - a fact which was known only as a result of observations in this season. In consequence the remaining older crops (60 ha) were killed and patchy losses occurred in the younger plantings. This experience pointed clearly to the need to use a conventional insecticide with good contact action in future control operations.

Towards the end of the larval feeding period in 1977 a further outbreak was found to have occurred in a part of the Strathy block of Naver Forest, known as the Yellow Bog, which lies about 15 km north of Rimsdale. Here, 60 ha of Lodgepole pine planted in 1966, were completely defoliated while adjacent plantations a few years older were less severely affected. This second outbreak prompted a systematic survey of Pine beauty populations in all significant areas of Lodgepole pine over about 7 years old in Caithness and Sutherland, followed by an appraisal of the risk of damage represented by given population levels. The following sampling procedure was developed:- firstly, locations for sampling areas, each representing approximately 30 ha of Lodgepole pine of susceptible age, were selected from maps; secondly, at each location the pattern of ploughing and planting was used to provide co-ordinates for the random selection of eleven sampling positions within an area of about 0.3 ha; thirdly, at each position the sampling unit consisted of a block of forest litter and peat 30cm x 30cm x 15cm deep, delineated by means of a portable sampling frame. The material was carefully sorted for pupae, and total counts for the eleven sampling units then gave an estimate of the number of pupae per square metre of ground surface in the sampling area. Some 12,000 ha of plantations were covered in this way. Following collation of results it was decided that all blocks in which any sampling area showed a count of 15 pupae per square metre, or more, would be included in the spraying programme. Blocks included in the survey had, by definition, a substantial area of Lodgepole pine of susceptible age; none of the blocks was extremely large and on practical grounds the blocks to which the above criterion applied were included for spraying in their entirety, although including non-susceptible species or areas of younger Lodgepole. The latter may in any case support significant populations of Pine beauty even if not in outbreak numbers. Eighteen blocks, including two in private ownership, were included in the programme, amounting finally to a total of 5,020 ha (320 ha of the Fiag block of Shin Forest were destroyed by fire shortly before spraying was due). Table 1.1 summarises the areas and pupal counts for these blocks.

In mid-May 1978 all blocks in the programme were inspected to check that eggs had been laid in significant numbers and the need to spray was thus confirmed at the last practicable date.

The level of 15 pupae per square metre adopted as the criterion for spraying was necessarily a matter of judgement and not on the basis of precise information. However, subsequent observations have confirmed that this is indeed about the density at which the population must be checked in order to avoid a high probability of serious defoliation.

The blocks to be sprayed are, with one exception, scattered in an area extending 40 km from north to south and 45 km from east to west, all within the eastern half of Sutherland; the small Watten block (30 ha) lies well to the east in Caithness (see Figure 1.1 p. 12). Only four of the blocks have internal forest roads; generally speaking the topography is undulating rather than steep but the terrain is severe, largely on account of very wet ground. Access to perimeters of blocks therefore calls for special cross-country vehicles, and even so is slow and difficult. In these circumstances adequate ground marking to control lane-separation during spraying appeared to present an almost insuperable problem which was finally avoided, very successfully, by the use of an electronic track guidance system as described in Chapter 6.

Although not directly related to the 1978 spraying operation, it should be mentioned here that two further unpredicted Pine beauty outbreaks occurred in 1978, one affecting 30 ha at Torrachilty Forest (Highland Region), the other completely defoliating 50 ha at Bareagle Forest (Dumfries and Galloway Region). In addition, in the autumn of 1978 substantial parts of Shin Forest (Highland Region) and Craigellachie Forest (Grampian Region) were known to have pupal populations representing a definite threat of serious defoliation by the next generation of larvae. There have thus been new outbreaks in each of three successive years and without control measures further outbreaks in 1979 are virtually certain.

Clearly, the outbreaks represent more than an isolated entomological phenomenon. However their cause is largely a matter for speculation at present, and there is a pressing need for a thorough investigation of the ecological system which includes the insect, its host and the environment of both. It has been found that outbreaks in their first year occur on Lodgepole pine growing on deep unflushed peat with *Calluna vulgaris* as the dominant ground vegetation rather than on well-flushed peats characterised by considerable admixture of the Purple moor grass, *Molinia caerulea*. This observation gives a clue to a possible host nutrition factor in the build up of populations: it also offers a probability that Lodgepole pine in general is not greatly at risk. Nevertheless the proven destructiveness of Pine beauty in widely separated parts of Scotland necessitates the widespread pupal surveys which have now been organised and further emphasises the need for properly developed control measures.

REFERENCE

South, R. (1961). *The moths of the British Isles*. London and New York: Frederick Warne.

Stoakley, J.T. (1979). *Pine beauty moth*. Forest Record 120. HMSO, in press.

Table 1.1

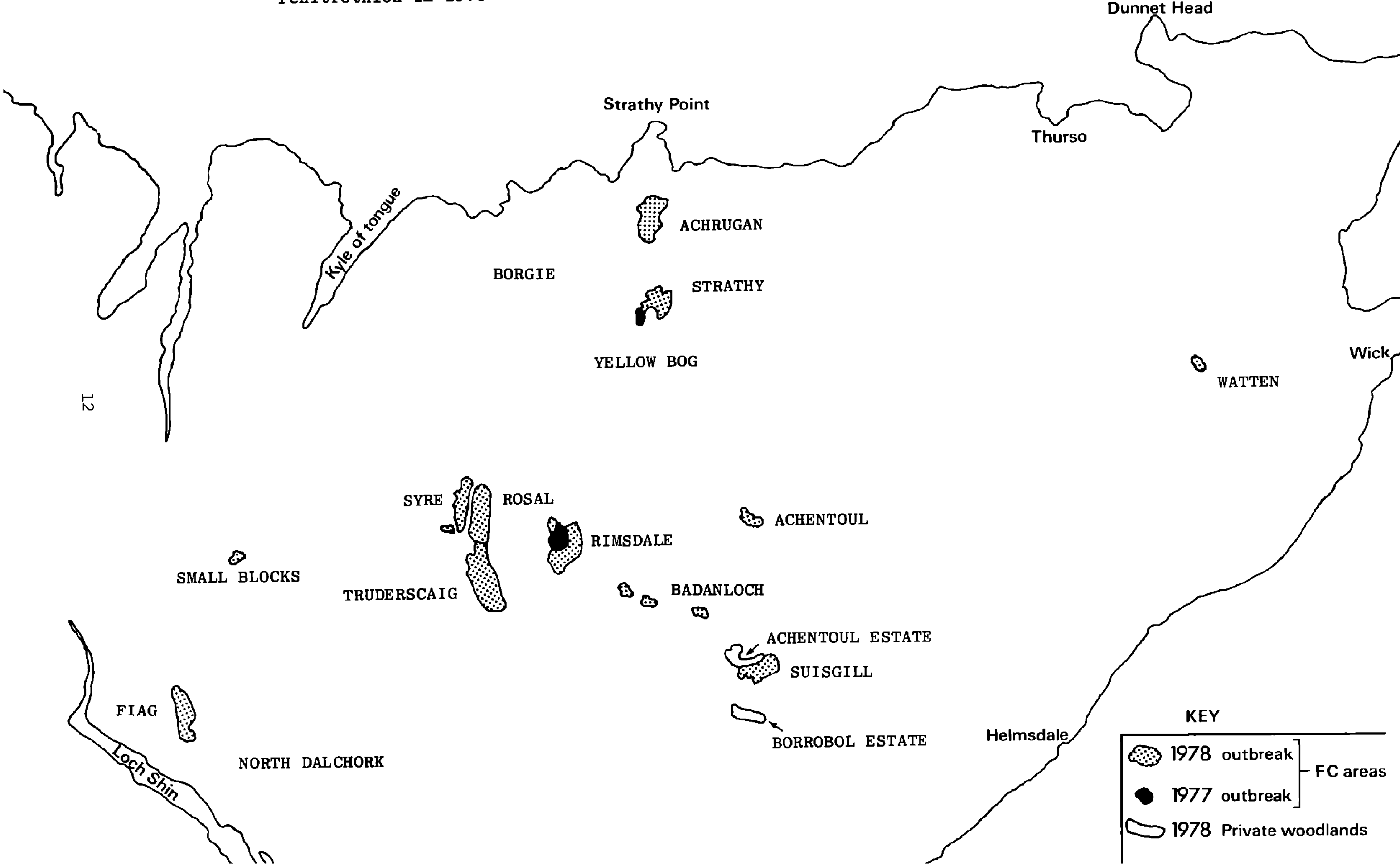
Pine Beauty Pupal Survey, Autumn 1977
Forest Areas Included in Spray Programme

Forest	*Block*	*Mean Count (per m^2)*	*Highest Count (per m^2)*	*Total area (ha)*	*Lodgepole pine (ha)*	*Lodgepole pine Planted 1970 and earlier (ha)*	*Number of Sampling Areas*
Naver	Rimsdale (Excluding 180 ha dead)	45	63	640	400	20	2
	Strathy (Excluding 60 ha dead)	107	359	240	110	110	8
	Achrugan	16	25	590	460	260	5
	Truderscaig	9	22	770	630	190	17
	Rosal	6	15	680	250	250	7
	Syre[1]	5	11	420	140	140	3
	Creag Dhu, Chicken Dhu, Barren Ridge	13	15	140	110	80	2
Helmsdale	Achentoul	77	122	150	130	120	2
	Badanloch (I, II, III)	89	112	100	100	100	3
	Suisgill	22	22	410	320	0	1
Shin	Fiag[2]	9	25	460	140	-	6
Rumster	Watten[3]	13	13	30	30	30	1
Private Estates	Borrobol	13	33	140	140	140	3
	Achentoul[4]	4	6	250	180	-	2
Eighteen Separate Blocks				5020			

1 - Included because of proximity to Rosal
2 - 320 ha lost by fire prior to spraying
3 - Included because of Research planting
4 - Included because of proximity to Suisgill

Figure 1.1

Pine beauty moth outbreak areas sprayed with Fenitrothion in 1978



Chapter 2

DISCUSSION OF AERIAL SPRAYING TECHNIQUES

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INTRODUCTION

The efficient use of an insecticide in crop protection demands:

- a precise definition of the biological target relative to the route of entry of the chosen insecticide;
- specification of the toxic dose relative to the route of entry;
- knowledge of the total population of biological targets which have to be hit and their distribution in space and time;
- an efficient and economic procedure for transmitting the required number of toxic doses to the whole population of biological targets with the minimum wastage en route and on the scale dictated by the spatial and temporal dimensions of the population of biological targets.

The larva of the Noctuid *Panolis flammea* emerges from its egg at a time closely synchronised with the opening of the foliage buds: in Caithness and Sutherland, this is late May and early June. The young larvae align themselves along the axis of the developing needles with their jaws apparently inserted between the axil of the needle pair and the stem. They appear to feed on sap exuded at the cut surface rather than on the plant tissue. The developing needles are thus killed and when this occurs the larvae, now older, move away from the destroyed growth of the current season to the foliage of the previous year. The larval instars occupy some six weeks between June and mid-July, by which time the foliage of the attacked trees is more or less completely eaten, and the tree, deprived of the whole of one season's photosynthesis, usually dies during the subsequent winter (Stoakley 1977).

Maximum crop protection will be achieved if the larvae of *P. flammea* are killed before they destroy the developing foliage of the young vegetative buds. Since at this stage the larvae are evidently feeding in internal tissue, stomach entry of the pesticide can be achieved only if the insecticide is absorbed into the bud tissue and moves into the liquid stream on which the larvae feed. Fenitrothion, the insecticide chosen by the Forestry Commission, is known by the work of Sundaram (1974) to be absorbed beneath the cuticle of needles of Balsam fir and spruce in Canada, where it can be detected months after application, but only minute and biologically insignificant quantities move from this site. The target is therefore described by the route of entry of the chosen insecticide. In this case it will be the larva itself since fenitrothion will be expected to kill by direct contact action, although chemical collected by the foliage can be expected to provide stomach entry for older larvae when they move from the buds to the older foliage.

At the earliest stage, following 100 per cent eclosion, at which larvae can be attacked, the larvae are about 10mm in length and 2mm in breadth offering a surface area of about 0.2 cm^2. The larvae are confined to the buds which are terminal points of the periphery of each branch, the most important and vigorous, and usually the most heavily infested, being located in the top two-thirds of the canopy.

The aim of this study was to develop a target-specific method of aerial application whereby the biggest possible fraction of the insecticide emitted would be collected by the specific target, the first and second instar larvae (L1 and L2), and the minimum by other surfaces, such as the ground.

THE SPECIFICATION FOR A TARGET SPECIFIC METHOD

OPTIMUM DROPLET SIZES

The aim of pesticide application is to transmit a number of toxic doses appropriate to the number of biological targets to be hit, in such a way as to achieve maximum probability of contact. This probability is a function of:

- the number of droplets available (N)
- the time they are in the vicinity of the target (T)
- the collection efficiency of the target (E)

E increases with increased droplet size but N and T decrease by a cube root function. Thus, in practice, the droplets which make the biggest contribution to the dose collected by such targets as larvae, buds and pine needles, are the smallest ones which are collected efficiently (Spillman 1976). This conclusion has been nicely demonstrated in the case of spruce trees by Himel and Moore (1967) and Barry *et al.* (1977). Such experimental evidence, as well as theory and evidence from studies made in different contexts (eg the work of Chamberlain 1966, 1975 etc), led inescapably to the conclusion that the biggest contribution to the dose which the larvae of *P. flammea* would collect in their natural environment would be derived from droplets less than 50 µm, and, probably, more than 30 µm, in diameter. It is interesting to record that Lodgepole pine, faced with a similar problem of capture by the female ovule of male pollen, evolved pollen grains which were measured to be 35 ± 2 µm. No benefit can be derived from using droplets bigger than this size, simply because, dispersing by gravitational sedimentation, their destination is theoretically predictable. These droplets, falling through the needle canopy, would reach the forest floor. Through run-off and leaching, they would constitute a hazard to fish living in streams which drain the forests of the area.

Accordingly, the first requirement was to select a method which would provide, from the volume of liquid likely to be necessary, the maximum number of droplets with a diameter within the range of 30-50 µm, at the target site. This requirement at once dictates the formulation and types of atomisers to be employed. Water, clearly, is unacceptable because water droplets, even of 100 µm diameter, evaporate completely in a 3m fall in air with a relative humidity of 90 per cent or less. The formulation therefore must be one which does not lose a major part of its volume in the time between release and catch, perhaps up to 1000 seconds. During this time the droplet diameter should not decrease by more than about 10 µm, that is a loss in volume from evaporation of not more than 40 per cent can be tolerated.

The performances of atomisers in their production of droplets smaller than 50 µm diameter is very incompletely measured because of the difficulty of collecting a true sample. Field techniques are inadequate because the collection efficiency of the surface selected for sampling, under the prevailing meteorological conditions, is rarely known. This problem of particle sizing had been studied by Parkin and Newman (1976) and led to the development of an ISO Kinetic Cryogenic Probe operating in a 100 knot wind-tunnel. More recently an optical method of particle sizing developed by R. Knollenberg, designated OAP-200X Droplet Spectometer, has become available and this equipment permits rapid determination of the size distribution in spray clouds. The results showed a reasonable accord with those obtained from the Cryogenic Probe.

Aerial spraying in the United Kingdom is usually conducted using boom and nozzle equipment set up to deliver about 20 litres/ha of water borne spray. The Knollenberg spectometer showed that the Micronair AU 3000 (Rotary Cage Atomiser) (at various settings of the propellor blades to produce rotational speeds between 5800-11000 p.m.) together with various pressure nozzles, provided droplet spectra, the volume median diameter of which varied from 120 µm to 250 µm, but, in all cases the number median diameter was roughly constant at 38 ± 3 µm. That is to say, most of the droplets produced by a wide range of equipment and methods were small ones, whatever the volume median diameter selected. The significance of this finding is better illustrated in Table 2.1 page 21, and expressed in a different form in Figure 2.1 page 23.

We are concerned in this case with breaking down the spray liquid to produce the maximum number of droplets of 30-50 µm diameter and the minimum above 100 µm diameter, the latter having little chance, owing to their speed of fall, of being collected by forest canopy. Clearly, rotary atomisers amongst which the Micronair AU 3000 is the one of proven reliability, rotating at the maximum speed, must be chosen.

Thus, the target, dictating droplets of the range of 30-50 µm diameter, also dictated the use of a formulation which had a sufficient proportion of low volatility component to ensure that the droplets produced at the atomiser were about the same sizes as those arriving in the vicinity of the target. The best available way of producing a droplet spectrum of small range of diameters was by employing rotary atomisers.

VOLUME RATE OF APPLICATION

The total number of droplets required to provide a high probability that each 0.2 sq. cm (the approximate surface area of a young larva) of needle receives at least one droplet is a function of the total leaf area of the pine forest. The Forestry Commission estimated the ratio of leaf area to land area lay between 2 and 3. Since we are concerned with both sides of the needles, a total leaf area to be hit was assumed to be 5×10^8 sq. cm per ha. One litre of liquid will provide 1.5×10^{10} droplets of 50 µm diameter. Since the larvae are confined to the peripheral buds and leaves, the volume of liquid required to give a high probability of hit, then, is unlikely to exceed 1 litre/ha. Each 50 µm diameter droplet, weighing about 70 ng, should contain not more than an LD 50 dose, since a 95 per cent probability of a single hit can be achieved only by a mean of about 3.0 droplets per larva, or 15 drops/sq. cm of leaf surface. If the LD 50 is assumed to be of the order of 1 µg per gram larva, each 50 um droplet should contain about 25 ng of active ingredient, ie. a 30 per formulation of active ingredient to carrier is indicated.

These calculations, however, assume:

1. that the estimate of the total leaf area is a measure of the collecting surfaces available in the forest, and,

2. that 100 per cent of the droplets produced by the atomiser are transmitted to the forest canopy.

Both these assumptions clearly had to be evaluated in the field (see the Thetford experiments, Chapter 4) but it is convenient to describe the concept of turbulent dispersal of droplets here.

TURBULENT DISPERSAL OF DROPLETS

The terminal velocity of a 50 µm diameter droplet in still air is about 7 cm/second. Released into non-turbulent air travelling at a velocity of, say, 10m/sec from a height of 10m, such a droplet, assuming no evaporation, would be transported nearly 1500m. Such a droplet containing, say, 1.5 per cent involatile active ingredient in a volatile carrier such as water would, however within 3-4 seconds after release, have a diameter of about 12 µm, and a fall speed of less than 1 cm/second. Released from a height of 10m into non-turbulent air travelling at 10m/second it would be transported at least 10,000m. Such aerial transport of small droplets, commonly termed 'drift' is usually considered undesirable on the grounds of environmental hazard.

The air over a forest, however, is non-turbulent only under zero wind conditions. Turbulence is suppressed when the air is very stable and is particularly so under inversion conditions, that is when air temperature increases with height, (a phenomenon which commonly occurs at night and for a few hours before sunset and after sunrise.)

Friction turbulence is due to the roughness of the forest surface. Somewhere above the canopy the velocity of the air is that of free air flow, the gradient wind determined by the pressure gradient between isobars. Somewhere beneath the canopy air velocity is zero. The air velocity usually increases logarithimically with height above the canopy, and the shear stress caused by this velocity gradient results in the creation of turbulent eddies by which the kinetic energy of the wind above the canopy is transmitted to the air within the canopy. The phenomenon of atmospheric turbulence has been investigated by physicists, and the work of Pasquill (1974) is regarded as the standard reference.

The average speed of the eddies is notated U*, the frictional velocity, which can be determined from the wind profile. The roughness length Z_O is a surface characteristic determining the rate of decrease of wind speed with lowering height. Over tall vegetation such as forests the value of Z_O is about 10 times that over a shorter crop, such as wheat, and the value of U* may be 10 times greater. If U* is bigger than the fall velocity of the droplets then turbulence rather than sedimentation will determine where the droplets go. U* has been measured in a number of crops, including forests. The relationship of U* to the wind profile is expressed by the following equation:

$$U^* = \frac{U(Z)K}{\log_e \frac{Z-d}{Z_o}}$$

Where U* = frictional velocity
U(Z) = wind speed at height Z in m.
Z = spray height above ground
d = zero plane displacement (in forests roughly 0.8 h where h = height of trees)
Z_O = roughness length (0.3 - 1.0 in forests)
K = a contact = Von Karman's constant = 0.4

Thus in a forest with trees, say, 6m in height and a wind speed at 6m above the trees of, say, 3m /second and assuming Z_O = 0.4

$$U^* = \frac{3.0 \times 0.4}{\log_e \frac{7.2}{0.4}}$$

$$= 0.41\text{m per second}$$

Under such conditions droplets smaller than 140 µm diameter will be dispersed largely by turbulence.

The turbulent eddies in which small droplets are entrained carry the droplets into the crop canopy where they may be captured. This process results in small droplets being collected much nearer to their source of release than is predicted by sedimentation. (Figure 2.2 and 2.3),and the position of the peak of deposit from a spray cloud released in a cross wind may be predicted from the following empirical equation developed by Bache (Bache and Sayer 1975).

$$P = \frac{H}{\sqrt{2}\, bi}$$

Where P = position of the peak deposit
b = a constant (0.77)
i = the turbulent intensity
H = spray emission height

and $$\frac{V(RMS)}{\bar{U}} \simeq \frac{U^*}{\bar{U}}$$

Where V(RMS) = root mean square vertical velocity, fluctuations mean
and $\bar{U}$ = wind speed

The relationship of U^* to $\bar{U}$ is shown in Figure 2.4, where it will be seen that the factor increases little with roughness, so that the expression $H/\sqrt{2}\, bi = 0.1$ applies over a wide variety of crop spraying situations, and is relatively insensitive to changes in wind speed.

Thus, a peak deposit of droplets of sizes which are dispersed by turbulence, released from a height, say, of 5m, will occur 50m downwind of the point of release. The results of experimental testing of the model are given by Bache and Sayer (ibid). The model assumes that all droplets transported by turbulent eddies to the canopy are captured, so that the eddies return to the circulation cleansed of suspended particles. This is true only of droplets which the canopy can capture efficiently. The catch efficiency of pine needles has not been measured experimentally, but theory suggests that it should approach 1.0 for droplets of 50 µm diameter but be below 0.4 for droplets of less than 20 µm diameter.

SPATIAL AND TEMPORAL DIMENSIONS

The total area of forest at risk to the Pine beauty moth during 1978 was about 5000 ha in 12 blocks varying from 40 ha, the smallest, to over 1000 ha, the largest, within some 1000 sq. km. of rough undulating country dissected by steep sided valleys. Though oviposition took place over a period of 4-6 weeks between March - May, hatching was expected to occur over the whole area within a few days, being synchronised with the opening of the new tree buds. Noctuid larvae, during their early development, can double their weight each 2-3 days. Accordingly, it is necessary to kill them at the earliest stage to economise on insecticide and to minimise loss of foliage. The spatial and temporal dimensions of the total population of biological targets to be treated made it necessary to establish a target time for completion of spraying, which would expose the forests to minimum risk. A desirable time of 2-3 days would require a work output of 2000 ha per day and economy demanded that this work output be achieved in the cheapest possible way, which, in practice, means with the minimum number of aircraft.

Work output of an aircraft engaged in aerial spraying is a function of some factors determined by the target area, such as length of run, and some such as lane-separation determined by the application technique employed. The time spent spraying is a function of the rate of application of active ingredient, and the discharge rate and of the dilution of the formulation. Maximum work output for a given airspeed can be achieved by the widest acceptable lane-separations which reduce the time spent spraying, and the highest acceptable concentration which reduces the ferry time.

TECHNIQUES AVAILABLE TO MEET SPECIFICATIONS

SUMMARY OF SPECIFICATIONS

The specifications for a target-specific method by which toxic doses of fenitrothion could be transmitted from an airborne source to L1-L2 larvae of *P. flammea* with the minimum wastage en route, and on a scale to provide the maximum protection to 5000 ha of forest, may be summarised as follows:

An airborne system comprising:

1. An insecticide formulation in which volatile concentrations do not exceed 40 per cent of the volume, and in which a 50 µm diameter droplet contains an LD 50 dose of chemical.

2. An atomising system which breaks up the formulation so as to provide the maximum number of droplets between 30-50 µm diameter, and the minimum number outside this range.

3. An operating capability to provide a work output of not less than 2000 ha per day.

LOW VOLUME v. ULTRA LOW VOLUME

Low Volume spraying is the term used to describe conventional spraying in which pesticide formulations are diluted with water to provide a rate of application of 20-30 litres/ha usually through boom and nozzle equipment. Typically the nozzles produce a droplet spectrum with a volume median diameter of not less than 250 µm and rarely more than 400 µm. The bulk of the spray liquid is dispersed by gravity and falls under the aircraft track providing a swath which is about 50 per cent greater than the wing-span of the aircraft. Under stable air conditions (eg early morning and late afternoon, when such spraying normally occurs) over 90 per cent of the liquid so dispersed falls within the swath, although this volume is derived from not more than 15 per cent of the total number of droplets produced. This LV procedure is regarded as a technique for placing pesticides accurately within a defined swath and of minimising the fraction which is lost to the swath and contributes to the drift hazard.

Big droplets (those dispersing by gravity rather than by turbulence ie in forests probably those bigger than 150 µm diameter), though having a high impaction efficiency, are few in number. Thus the number of droplets bigger than 150 µm diameter produced from 20 litres liquid in the droplet spectrum of the D10-45 nozzle (Table 2.1) is of the order of 1400 x 10^6. This number fails to meet the spraying specification, which is that each 0.2 sq. cm of foliage has a 95 per cent chance of collecting at least one droplet. This equates to 15 droplets/sq cm or an estimated 7500 x 10^6 droplets per ha.

Moreover, the time during which such droplets are in the vicinity of the target is small, and those which fail to be intercepted fall to the ground, constituting a contamination hazard, The fraction which is captured and the fraction which falls to the ground is a function of the structure of the forest canopy and can be investigated experimentally.

Small droplets representing nearly 90 per cent of the total droplets produced (Table 2.1), will lose their water in less than 5 seconds after release, the biggest (130 µm) being diminished to about 30 µm diameter and the smallest (in important numbers) to less than 10 µm diameter. If liberated under suitable conditions these will be dispersed by turbulence and a fraction, say up to 50 per cent of the 30 µm diameter droplets, will be captured by the forest foliage, and the remainder escape to the air. Thus small droplets may contribute to larval mortality outside the swath flown, and the probable contribution to the biological goal from this source can be investigated experimentally. If liberated under stable conditions, such small droplets may be transported well beyond the forest boundary with little dilution by dispersal.

Thus conventional LV spraying can be expected to provide the required mortality but at the risk of ground contamination and loss of insecticide from the forest in quantities determined by the conditions under which spraying takes place. On the other hand LV spraying is relatively slow. An aircraft carrying, say, 600 litres discharges its load over 30 ha in about 10 minutes of spraying time, and, if airstrips are available within 5 minutes ferry distance, achieve a work output of up to 90 ha/hr. Thus the target work rate of 2000 ha/day would require 3-4 aircraft and day-long suitable weather.

A system designed to meet fully the specifications set up for the airborne spraying system and, accordingly employing a formulation of low volatility, containing an LD dose of fenitrothion in each droplet of 50 µm diameter, together with a system for producing the maximum number of droplets between 30-50 µm diameter, and the minimum outside this range, is unlikely to require a volume rate of application in excess of 1 litre/ha in order that each 0.2 sq cm of leaf surface has a high degree of chance of collecting at least one droplet. The actual volume rate can be investigated experimentally.

Such a system, employing small droplets, small volumes and a more concentrated formulation, has come to be termed 'ultra low volume' (ULV). The system, operating under turbulent conditions which transport the small droplets from the atomiser to the forest canopy, should permit the maximum fraction to be captured by the foliage, the minimum to fall to the ground, or to be lost to the air. Moreover, using the turbulent air over the forest to effect dispersal, the lane-separation is independent of the aircraft characteristics and can be selected by experiment. A lane-separation of 50m would permit an aircraft carrying a load of 600 litres to treat 500 ha of forest per hour from an airstrip of similar ferry distance, (5 minutes). A single aircraft could therefore meet the target time of 2000 ha/day.

In consequence of this analysis, a trial was organised using simulated formulations to compare LV and ULV spraying techniques over pine trees in Thetford Forest, Norfolk. This trial is described in Chapter 4.

ACKNOWLEDGEMENTS

We are grateful to Mr R.J. Courshee, Director, Agricultural Aviation Research Unit (CIBA-GEIGY), Cranfield, for permission to quote from Dr S. Parkin's and Dr T. Lawson's unpublished work and to unfailing help received from this Unit.

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TABLE 2.1

Droplet Spectra (as percentage of total droplets) Produced by Micronair AU 3000 and Various Nozzles as Measured by Knollenberg OAP 200X Droplet Spectometer (Parkin, C.S. 1978)

Droplet Range	*Micronair Cage Speed rpm*		*Pressure Atomisers Spraying Systems*	
µm	11000	7900	8004	D10-45
40	55	55	34	34
41-50	13	12	20	22
51-60	10	9	12	12
61-70	6	6	7	8
71-80	4	4	6	7
81-90	3	3	5	3
91-100	2.5	2.5	3	3
100	6.5	8.5	13	11
Volume median diameter	120	158.5	240	240
Number median diameter	37.7	38.3	46	37

Figure 2.1

Proportion of droplets in the range of a target class (20-60 um) generated by some atomisers (From Joyce *et al* 1977)

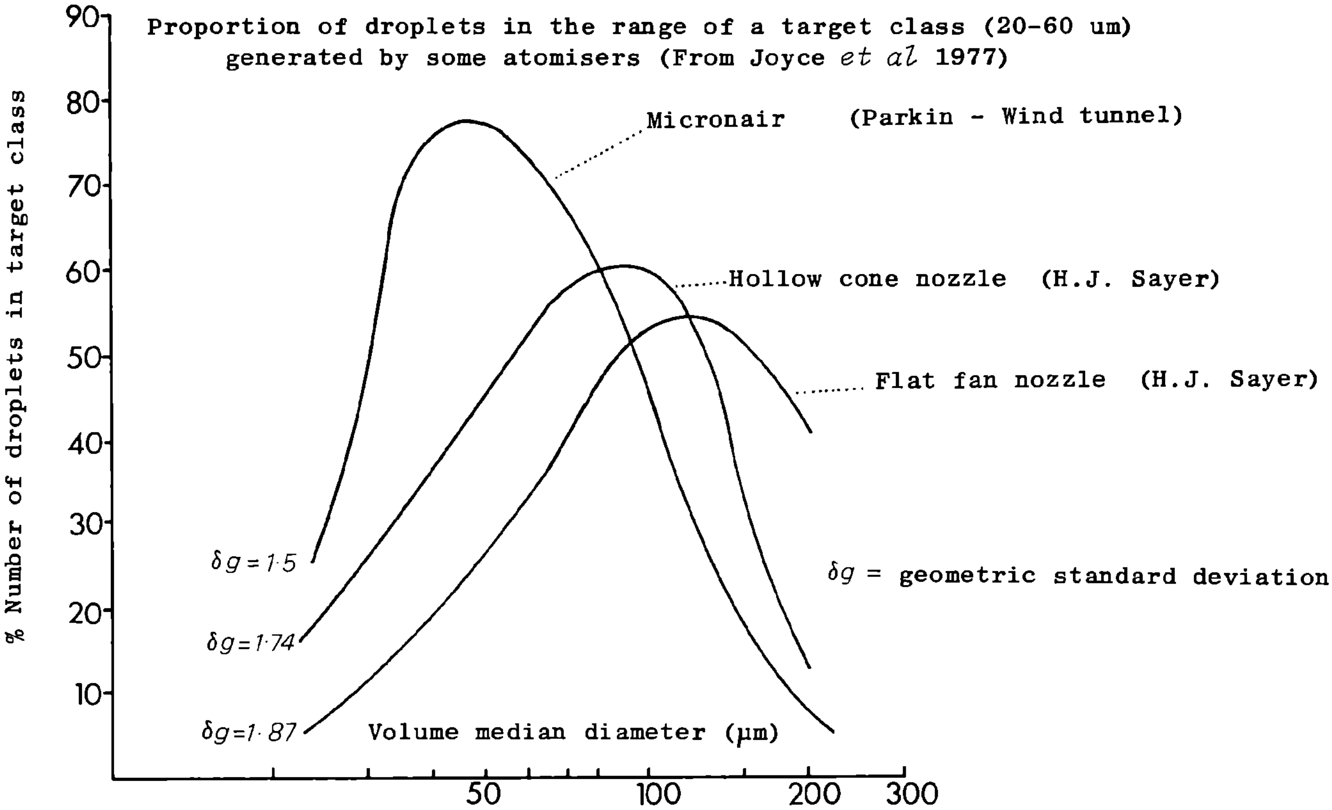
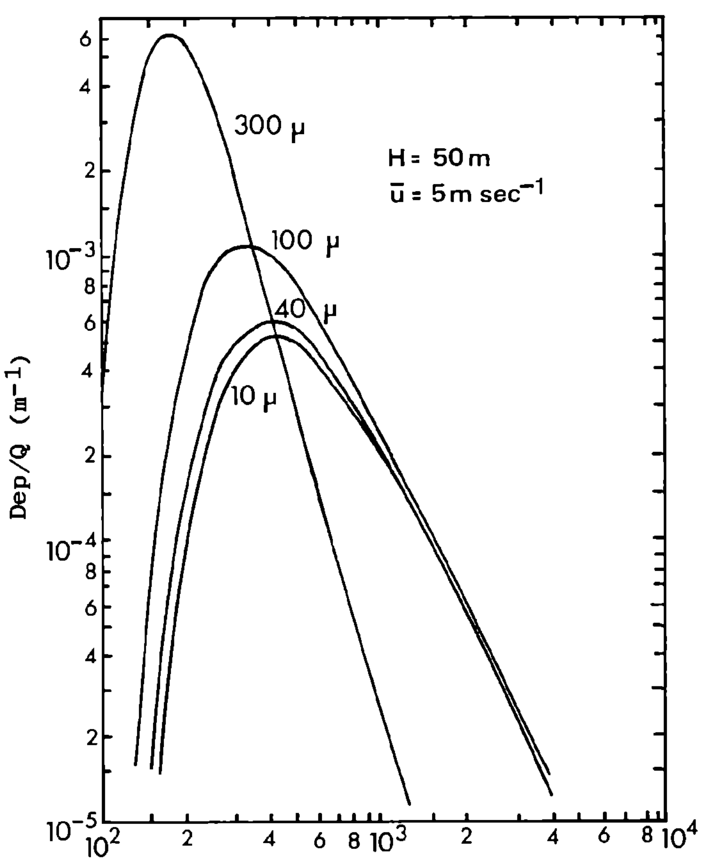


Figure 2.2

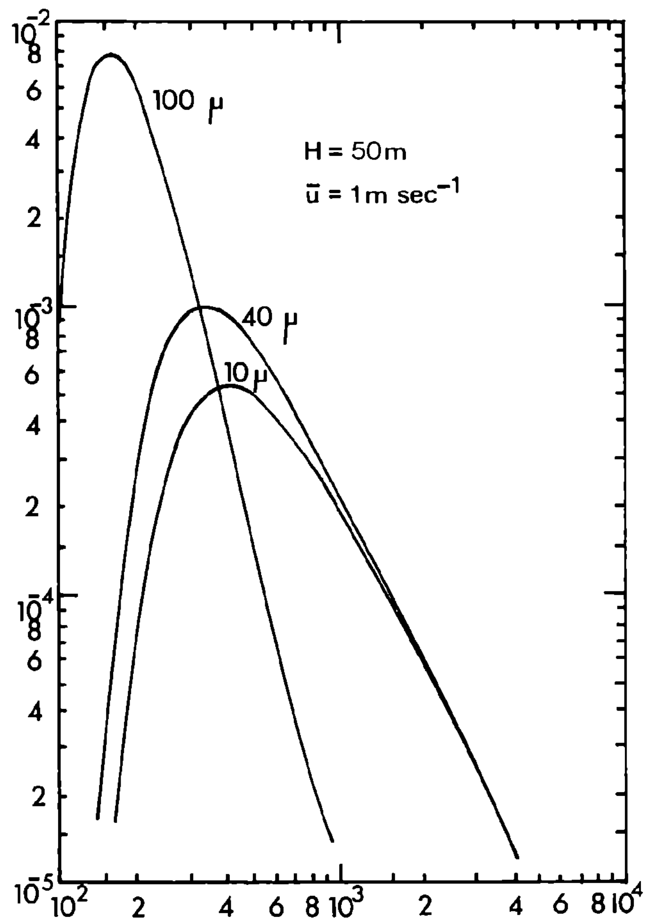
Turbulent dispersal of droplets (From Cramer and Boyle, 1976)



Total surface deposition from elevated crosswind line releases at a height of 50 metres and for a mean wind speed of 5 metres per second for selected drop sizes. (Deposit varies with change in emission rate (Q). Thus Dep/Q = $g/m^2/g/m = m^{-1}$).

Figure 2.3

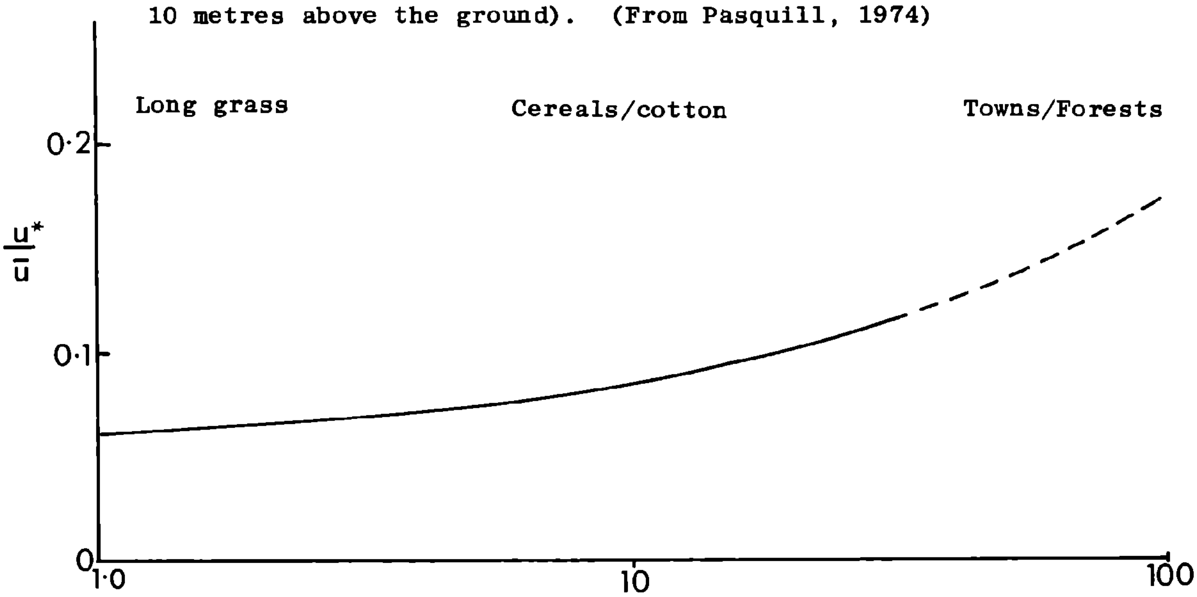
Turbulent dispersal of droplets (Cramer and Boyle, 1976)



Total surface deposition from elevated crosswind line release at a height of 50 metres for a mean wind speed of 1 metre per second for selected drop sizes. (Deposit varies with change in emission rate (Q). Thus Dep/Q = $g/m^2/g/m = m^{-1}$).

Figure 2.4

Variation of frictional velocity (U*) and mean wind (U) with surface roughness under neutral conditions (U measured at 10 metres above the ground). (From Pasquill, 1974)



Chapter 3

SELECTION OF AN INSECTICIDE FOR AERIAL APPLICATION

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INTRODUCTION

The larval stage of the Pine beauty moth occupies about six weeks. For the first half of this period the larvae feed largely on internal tissues at the bases of newly developing needles; thereafter they consume whole needles on earlier years' growth. This behaviour has an important bearing on methods of control using insecticides. In 1977, a preparation of *Bacillus thuringiensis*, a stomach poison with little persistence, was applied to young larvae as a forest operation, but failed because the feeding behaviour precluded ingestion of an effective dosage (See Chapter 1). The use, against young larvae, of alternative materials which depend upon ingestion is also likely to be ineffective for the same reason, and there are several objections to delaying the application of such materials until the larvae have moved onto older needles when ingestion would occur readily. Severe damage to current shoots would not be acceptable (Chapter 1); for effective treatment a larger amount of active ingredient would be needed on account of the increased body weight of the target larvae; and delayed treatment involves the risk that no treatment can in the event be done, eg because of bad weather. There was therefore a clear need to select a contact insecticide for application to first or second instar larvae.

The selection of an insecticide for a particular purpose is, of course, based on a number of considerations, of which the more important are:- effectiveness against the target; safety, both to humans, ie spray operators and people in the vicinity of sprayed areas, and to the environment generally; cost; availability of supplies; suitability for the proposed method of application and convenience of handling. The formulation of the insecticide and its compatibility with the intended diluent also have to be considered.

In general, foliage-feeding larvae of Lepidoptera are well known to be very susceptible to many contact insecticides and in view of the other considerations wide-ranging screening trials were not required. With regard to safety, the basic requirements are always low mammalian toxicity and fairly low persistence. In most forest areas it is also important that the chosen material should have low toxicity to fish and this is certainly necessary in the Scottish Highlands. For large scale application, supplies of the chemical must be available. It was originally intended to treat the whole area by the target-specific ULV application technique (Chapters 2 and 4), this too influenced the choice of material and formulation. The choice of an emulsifiable concentrate formulation enabled the same material to be used both for ULV application, with Butyl dioxitol as the diluent, and for LV application, with water as the diluent, and in the event, the larger part of the area was treated at Low Volume. Finally, subject to confirmatory testing against young Pine beauty larvae, the choice fell on the organo-phosphorus insecticide fenitrothion. This appeared to be a good candidate from all points of view. Furthermore the general information and experience relating to this insecticide is backed up by a great deal of published information, particularly in regard to its effects on the environment, arising from very large scale aerial application, often repeated in successive years, to forests with high populations of the Spruce bud-worm *(Choristoneura fumiferana)* in North America. (Sundaram 1974, Anon 1975, Roberts 1977).

In the earlier planning stages one other insecticide, the organo-phosphorate tetrachlorvinphos (Shell 'Gardona') was considered, in particular because the Forestry Commission had used it very satisfactorily for aerial application against the Pine looper *(Bupalus piniaria)* in 1970 and 1977, replacing DDT used on three occasions in the 1950s and 1960s. Tetrachlorvinphos has extremely low mammalian toxicity (LD50 4000-5000 mg/kg) but was found in tests against Pine looper to be less effective than fenitrothion over periods of 12, 24 and 60 hours (Scott and Brown, 1973). The practical use of a material which was likely to produce relatively low mortality was justified only by a good appreciation of the role of natural controls in the local *Bupalus* populations.* This insecticide was normally formulated as a wettable powder which would not have been suitable for ULV application. Furthermore it became clear in Spring 1978 that supplies were by no means assured. Nevertheless both this material and DDT (which would in no circumstances actually have been used) were included in tests as a basis against which fenitrothion could be compared. Tests were therefore done with the object of obtaining a prompt answer to a pressing question - was fenitrothion effective against Pine beauty larvae by comparison with other insecticides of which there was already some experience in British forestry ? (*Bevan, 1974).

Testing insecticides in the laboratory, especially out of season is, of course, not an entirely straightforward process. It was not practicable to get adult moths emerged from pupae, mated and laying eggs earlier than January. Establishing first instar larvae on suitable food material and raising them to later stages presents considerable difficulties. The use of new pine shoots produced by forcing potted plants depends on obtaining good synchrony with hatching of eggs and initially this was largely a matter of trial and error. The use of an artificial diet proved possible but the survival rate was very low. Young larch foliage which, early in the season, was more easily obtained than pine shoots was also tried with some success. Ideally the method of application of insecticides should simulate field application in so far as this is possible, and for early instars, which appear to move little while feeding, topical application would be most appropriate. However, the small size of young larvae makes this rather impractical, especially for first instar larvae, in view of the relatively large size of the smallest droplets which can be produced from the hollow needle of a conventional micro-applicator. For these reasons the main series of tests was carried out simply by putting young active first instar larvae into containers with treated filter papers, as detailed below.

METHOD

Proprietory formulations of fenitrothion (50% emulsifiable concentrate), tetrachlorvinphos (75% wettable powder) and DDT (25% emulsifiable concentrate) were each diluted to a series of known concentrations with distilled water. Using a pipette, 1 ml quantities of the insecticide solution were dispensed evenly onto labelled filter papers (Whatman's No.1, 90 mm diameter). To prevent loss of insecticide by contact and to facilitate drying, the papers were supported on fine points until used in the tests. Fresh solutions and papers were made up for each test. Untreated filter papers were used for controls.

The tests were made on batches of ten larvae placed in cages, each consisting of a clear plastic container (50 mm diameter by 25 mm deep) with a treated filter paper placed over it and covered by a weighted lid. Only larvae which had hatched from eggs during the previous 24 hours were used for the tests and they were unfed. Room temperature was controlled at 20°C (± 1°C) throughout the period of tests and a light regime of 18 hours light/6 hours dark was maintained.

Following preliminary tests, to obtain an indication of the range of insecticide contrations needed, the three insecticides were tested at five concentrations, 0.08, 0.04, 0.02, 0.01 and 0.005% of active ingredient, with four replications, ie four test cages, for each treatment. The test cages were arranged according to a 4 x 4 partially balanced lattice design intended to minimise effects which might be due to position on the bench or to the fact that the cages were to be set up over several days, as larvae became available.

Mortality was assessed at 12, 18 and 24 hours from the setting up of each test cage.

RESULTS

Table 3.1 shows mean percentage mortalities against insecticides and treatment rates with cumulative results after 12, 18 and 24 hours.

Analyses of variance of the percentage mortalities in test cages, transformed by angles, produced the following information:-

AFTER 12 HOURS

Overall the three insecticide treatments gave highly significant mortality compared with untreated controls (P = 0.01); differences between the insecticide treatments were very highly significant (P = 0.001) and mortality due to fenitrothion was highly significant (P = 0.01) compared with the other two insecticides overall.

Differences between treatment rates were very highly significant (P = 0.001), the two highest rates (0.08 and 0.04%) giving greater mortality, which was highly significant compared with that due to the three lower rates overall.

AFTER 18 HOURS

Differences in mortality due to the insecticides were no more than significant (P = 0.05); mortality due to fenitrothion was significantly greater (P = 0.05) than for the other two insecticides overall.

Differences due to treatment rates were also no more than significant (P = 0.05) overall but with different patterns for each insecticide. For DDT, the two highest rates (0.08 and 0.04%) gave significantly higher mortality than the lower rates; for tetrachlorvinphos, the highest rate (0.08%) gave significantly higher mortality than 0.04 and 0.02% which themselves gave significantly higher mortality than the two lowest rates (0.01 and 0.005%); for fenitrothion, only the lowest rate (0.005%) gave mortality significantly lower than the highest (0.08%) and there were no significant differences between the four higher rates (0.08, 0.04, 0.02 and 0.01%).

AFTER 24 HOURS

Mortality due to fenitrothion was still significantly greater than for DDT or tetrachlorvinphos overall.

Differences due to rate of treatment were not significant overall; however, for DDT, the lowest rate (0.005%) gave significantly less mortality than the two highest rates (0.08 and 0.04%); for tetrachlorvinphos the two lowest rates gave significantly lower mortality than the rest; while for fenitrothion there were no significant differences due to rate.

The tests described above indicated that fenitrothion is considerably more toxic to Pine beauty larvae than tetrachlorvinphos or DDT and served to confirm the choice of fenitrothion for field use. The efficacy of this insecticide applied from the air is described in Chapter 8.

Supplementary to the tests described above, a small laboratory trial was carried out to estimate an LD 90 of fenitrothion for second instar larvae. The larvae, which were raised on an artificial diet, had a mean weight of 5 mg and were treated with water solutions of fenitrothion of 0.0125, 0.0375 and 0.075% active ingredient, plus additional wetter, by topical application of single droplets of 0.25 µl to each individual. Controls treated with water plus wetter suffered no mortality; the 0.0125% solution also produced no mortality after 72 hours; the 0.0375% solution gave 90% mortality after 6 hours and 100% mortality after 12 hours, and the 0.075% solution gave 100% mortality after 6 hours. A single droplet of 0.0375% solution is equivalent to 24 ppm of mean larval weight and the results therefore suggest an approximate LD 90 of 24 µg/g after 6 hours. This, of course, is an essential piece of information for the development of models of droplet application against larvae on tree crops (Chapter 2).

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Table 3.1

Results of Insecticide Tests Against First Instar Larvae in the Laboratory

Insecticide	*Treatment Rates* *% Concentration of Active Ingredient in 1 ml Water Applied to Test Surfaces*	*Mean % Mortality* *Cumulative Values After:-* *12 hours*		*18 hours*		*24 hours*	
			Overall		*Overall*		*Overall*
	0.08	37.5		70.0		77.5	
	0.04	65.0		82.5		97.5	
DDT	0.02	12.5	27.0	40.0	50.5	62.5	65.0
	0.01	12.5		30.0		55.0	
	0.005	7.5		30.0		45.0	
	0.08	55.0		92.5		97.5	
	0.04	62.5		70.0		80.0	
Tetrachlorvinphos	0.02	15.0	26.5	40.0	43.0	60.0	53.0
	0.01	0		7.5		15.0	
	0.005	0		5.0		12.5	
	0.08	87.5		95.0		100.0	
	0.04	70.0		87.5		100.0	
Fenitrothion	0.02	70.0	63.5	80.0	82.0	87.5	94.0
	0.01	65.0		90.0		100.0	
	0.005	25.0		57.5		82.5	
Control		2.5		2.5		2.5	

Chapter 4

LOW-VOLUME AND ULTRA-LOW-VOLUME SPRAY TRIALS FROM AIRCRAFT OVER THETFORD FOREST

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INTRODUCTION

Following discussions an agreement was made between the Forestry Commission and the Cranfield Institute of Technology to collaborate in determining the most target-specific method of applying the insecticide fenitrothion, in order to maximise efficiency of use, and, at the same time, minimise both dosage, contamination of non-target surfaces, particularly the ground and hence, through leaching, the salmon streams.

Since the biological target was the larva feeding on the opening foliage buds, a target-specific method was likely to involve droplets less than 50 µm in diameter. Such droplets have a low sedimentation velocity and therefore an innate tendency to drift. It was necessary therefore to provide data on the relative efficiency of the method chosen to control drift and thus to reduce hazard to a minimum in order to obtain the approval of the Ministry of Agriculture for the proposed technique. In this connection and for the purposes of obtaining as efficient control as possible, data were required on the optimum spray droplet size for collection by pine buds and larvae and the best method of application over a forest canopy. We also wanted to know the number of droplets and therefore the volume of spray needed to provide a high chance of achieving a deposit of at least 1 droplet/20mm^2 (taken at the time of the experiment as the superficial area of a first instar larva). To determine these data, an experiment using simulated formulations was conducted in late April 1978 to compare the effectiveness of three types of spray emission.

DETAILS OF THE TRIALS

THE TEST TARGET

A plantation of mixed Scots pine *Pinus sylvestris* and Corsican pine *Pinus nigra* var. *maritima*, planted in 1968 in Thetford Forest, Norfolk, was chosen as the target area, as the tree spacing and height variation was considered to approximate closely enough to the Sutherland plantations for the purposes of the trial (although of course, the growing buds of these trees in April were in a different condition from those of Lodgepole pine in early June).

The trees varied in height from 1.5 to 5 metres averaging 4m with a ground spacing of 2m to 3m except in the gaps. The crop was open enough to allow passage in most places.

The test area, illustrated in Figure 4.1 p. 48, was about 300m long crosswind and at least 300m long downwind of the chosen aircraft flight path. It was bounded on the upwind side, that is to the east, by a plantation of 2m high pines extending for at least 400m. The plot downwind of the target plot was planted with trees of a similar size to those of the test area. On both the north and south edges of these plots trees 8m to 10m in height provided edging strips roughly parallel to the wind direction. Fire break rides provided access to the test plot.

The pilots were asked to fly parallel to the upwind edge of the test area with their flight path about 10m downwind of that edge. Prior to the test four sampling lines, parallel to the wind and about 25m apart were chosen in the centre part of the test plot. For each line ten trees, 10m apart, were selected, the first being directly under the centre-line of the aircraft flight path. The lines deviated laterally in places where a tree was missing in order to maintain the correct downwind spacing. Lengths of string were used to ensure consistent spacing.

By each selected tree four 50mm by 50mm pieces of white Bristol board were placed horizontally on the ground, just outside the edge of the tree canopy, at each of the four points of the compass.

METEOROLOGICAL MEASUREMENTS

A Land Rover belonging to the Building Research Establishment, Watford, fitted with a telescopic mast able to carry a wide variety of meteorological instruments, was positioned just off centre of the ride downwind of the test area. Wind speeds and directions were measured at 2m, 4.9m, 8m and 16m above the ground, the 4.9m being just clear of the top of the local canopy.

The trials took place between 11.25 and 11.35 hours under seven-eighths cloud conditions with a ground temperature of 14.2°C. Table 4.1 p. 41 , gives the measured mean and fluctuating wind components at the various heights and Figure 4.2 p. 48 , shows the mean wind profile indicating that the aircraft spray was released into a mean wind of 3m/sec. to 3.5m/sec. depending on aircraft height. The high standard deviation values relative to the mean speeds show that very turbulent conditions existed above and within the canopy as would be expected. It follows that turbulent dispersion would be a major factor in determining the flight trajectory of small and moderate sized droplets.

AIRCRAFT EQUIPMENT

Two aircraft were used for the trials, both being loaded at Cranfield and flying to the Thetford test area and back non-stop. The Cessna Agwagon of Bowker Air Services was fitted with a standard boom and nozzle system using sixty-six nozzles with D6 orifices and 45° swirl plates. All the nozzles were set 45° downwards and forwards relative to the flight direction. The spray pressure was 2.4 bar (35 p.s.i.). The Auster Aiglet of the Agricultural Aviation Research Unit of Ciba-Geigy Ltd was fitted with two Micronair 3000 units independently supplied from separate tanks in the rear seat compartment. One Micronair had a blade setting angle of 25° whilst the other was 45°.

The Cessna made one cross wind spray run at a height above the tree canopy estimated at four to five metres at a speed of 160 kph (100 mph) spraying at a rate of 0.063 litres per metre travelled.

The Auster made four spray runs at a height above the canopy of six to eight metres at 185 kph (115 mph) spraying from each Micronair unit at a rate of 0.0015 litres per metre flown, corresponding to a total emission rate of 0.006 litres per metre.

The Cessna spray was water with a 0.25 per cent red fluorescent particle tracer added after dissolving it in a small amount of hexylene glycol, whilst the Auster spray was entirely hexylene glycol with 0.25 per cent fluorescent particle tracer added. A green tracer was sprayed by the Micronair with blades set at 25° whilst a blue tracer was used by the other Micronair unit with 45° blade setting.

The Cessna spraying water with a red tracer at a rate of 10.5 times that from each Micronair was representative of LV spraying and the estimated volume median diameter (v.m.d.) and volume average diameter (v.a.d.) were 250 μm and 158 μm respectively. The Micronair emissions were representative of ULV spraying and the estimated v.m.d. and v.a.d. for the unit with 45° blade settings were 132 μm and 103 μm respectively whilst for the 25° blade settings v.m.d. and v.a.d. values were estimated at 88 μm and 69 μm.

RESULTS AND DISCUSSION

METHOD OF ANALYSIS

The results were obtained solely by counting the number of droplets on the samples. For ground deposit assessment the Bristol board cards were used, whilst for the tree counts, samples of the growing shoots were cut from the top whorl and from the half height of the chosen trees, at each of the four points of the compass. Thus eight twig samples and four card samples were collected from each of the forty chosen trees. From each of the twigs five needles near the growing end were selected at random and examined under a microscope using ultra-violet illumination. The numbers of fluorescent spots of each colour on both sides of the five needles were noted.

Preliminary spray trials on pine needles had indicated that all three colours could be seen easily under ultra-violet light. However, when the actual trial samples were studied several days after the trial it was found that whilst the red fluorescent dye showed extremely well, the blue and green particles had been absorbed into the cell structure of the needles probably because their glycol carrier had dissolved the wax covering the needle. As a consequence only some of the blue fluorescent particles could be seen, primarily the bigger droplets which stained several cells, and far fewer still of the green fluorescent particles.

An estimate of the numbers of droplets emitted per metre of aircraft flight run was made from the known flow rate and the estimated volume average diameters given previously. This was compared with a very approximate calculation of the total numbers caught on the tree foliage, using an estimated leaf area to ground area ratio of five and extrapolating the sample readings to obtain a mean deposit rate per needle over the full downwind catchment. It was estimated that about 34 per cent of the red-dyed LV spray drops were seen, 45 per cent of the blue-dyed ULV 45° blade-setting drops and only 3 per cent of the green fluorescent particles emitted by the fine pitch Micronair unit. There must be some doubt about these values since estimating from top and middle tree height samples is a calculation of low accuracy.

The figures, however, seem to be of the right order. A lot of the smaller droplets of the water-based LV spray would have evaporated to such a small size that they were unlikely to be caught, or if caught, seen. Only the larger droplets of the blue dye could be seen and only a few of the green were not absorbed and were therefore invisible. It was disappointing that in spite of preliminary tests the blue and green dyes proved difficult or impossible to see. With the failure of the dyes to show up, certain assumptions became necessary in order that the choice of spray technique could rest on a sound scientific base.

It is thought likely that only about 34 per cent of the LV spray did, in fact, reach the needles in drops of any significant size, the rest dropping to the ground or evaporating away. Experience would also lead us to expect that at least 80 per cent of the ULV droplets will have been deposited on the trees. This suggests that all the red, only 56 per cent blue and 3.8 per cent of the green dyed droplets caught on the samples were visible.

GROUND DEPOSITS

Only the red-stained droplets of the LV spray were found on the ground cards, there being no trace of the finer sprays. The deposit on the cards was assessed at five grades: zero, light, moderate, heavy and very heavy. Averaged over the total number of card samples there was an even distribution of droplets over all points of the compass, the variation being less than ± 10 per cent. Even on individual trees the variation was only over two grades or more on 17 per cent of the trees, probably those which had a close neighbour on one side. It much be concluded that the high level of turbulence within the gaps between the trees completely eliminated any of the bias due to gradient wind alone.

Figure 4.3 p. 49, shows the variation in the quantity of the LV spray reaching the ground with distance downwind of the flight path. It can be seen that the peak deposit rate occurs about 25m downwind of the spray line and that there is still a significant deposit rate at the sampling points most downwind. The low rate of decrease of deposit level with distance downwind at this point suggests that a considerable number of droplets, presumably the small ones, were still airborne. The cards showed that the further downwind the station the smaller the apparent size of droplet falling on the cards.

It is interesting to note that none of the ULV spray was found at ground level.

DEPOSITS ON THE TREES

The overall distribution of droplets around the various aspects of the trees is shown in Figure 4.4 p. 49. For all sprays there is a distinct reduction in spray deposit on the lee side of the tree both at tree-top and mid-tree height. On average the leeside deposits are only half those of the windward and side aspects. This result is somewhat surprising in view of the evenness of the ground deposits. There is some slight evidence that the variation at mid-tree height is less than at the top of the tree but it is clear that even averaged out over all the tree samples, tree aspect is a contributing factor to the variation in deposit levels.

The overall distribution of deposit with downwind direction is shown in Figure 4.5 p. 50, for both the near tree-top and middle-tree heights. The individual sample results vary dramatically as can be seen from Figure 4.6 p. 50, but the accumulated totals show quite distinct trends which are different for the LV and ULV sprays. The differences between the two ULV sprays are too small to distinguish. The LV spray has two distinct peaks, one about 10m downwind and the second about 30m downwind, whilst the ULV has just one peak at 30m downwind of the aircraft flight path. The large deposit at 10m downwind is difficult to explain since it infers that with the aircraft at 4m to 5m above the canopy and a wind speed of 3m/sec. the mean downwind velocity was 1.35m/sec. which suggests a droplet diameter on average of 320 µm. Now it is improbable that the mode size for the LV spray was anything like as big as that, even at emission from the nozzles, and certainly not after evaporating for three or more seconds. A more plausible explanation is that the peak is primarily associated with the smaller droplets of the spray from the upwind end of the boom. These lost weight rapidly and were not blown so rapidly downwind because of the wing tip vortex effect as described by Dee and Nicholas (1968), an effect which must have been significant as the aircraft height above the canopy was only one third of the span of the aircraft and its height above the ground only two thirds of the span.

If this is the explanation then the spray from the other part of the boom would tend to be moved downwind and slightly upwards by the downwind tip effect so reducing the intensity of the deposit peak from that side. If the dominant number of droplets was small then turbulent diffusion dictated their descent pattern, and from the work of Uk and Lawson (1978) for the turbulence levels measured, the peak deposit at canopy top level should be 25m to 30m downwind depending upon the position of their originating nozzle and the rate of evaporation. This agrees well with the position of the second peak. The increase in turbulence to be expected from the aircraft-induced effects would increase the impaction efficiency of the smaller droplets. Further downwind the rate of collection falls off rapidly suggesting that the droplets had become so small that their impaction efficiency was falling significantly. A similar double peak was described by Courshee (1978).

The ULV sprays were emitted from the Micronairs mounted well inboard of the wing tips of the Auster. The aircraft flew almost 0.8 to 1.0 spans above the canopy at a higher speed and lower wing-loading so the wing tip vortex effect should have been smaller, but perhaps more important was the non-volatile nature of the glycol keeping the droplets much the same size as they were generated and preventing losses as in the case of the LV spray. Estimates for the position of the peak deposit using the Uk and Lawson's method gives about 35m downwind which agrees quite well with the experimental results.

It is unfortunate that the sampling positions were not extended further downwind as all the results show a near constant rate of deposit with distance downwind beyond about 60m downwind.

It is apparent that the ULV spray gives a less peaky distribution with downwind distance and is therefore most suitable for an overlapping swath method of application.

COMPARISON OF LV AND ULV RESULTS

In the previous section the overall trends in deposit were considered. However, in practice it is the actual probability of getting the insecticide on the target surface which is of paramount importance. Thus to compare two techniques one should not look at average deposit rates but the probability of missing a target in each case. The numbers of droplets per five needles for all the tree samples are given in Table 4.2 p. 42 . It can be seen that the variations from tree to tree are tremendous. This is due to a large number of factors most of which cannot be controlled, such as the variation in size, shape and spacing of the trees, the effects of terrain on wind profile and the random nature of the turbulence of the wind itself.

If one considers the samples of one particular spray, say the LV one with the red fluorescent particles, and looks at the samples from near the top of the trees at a particular distance downwind of the spray-line, one still finds a tremendous variation as illustrated by Figure 4.6 p. 50. This shows the number of droplets per needle for the samples taken 30m downwind of the spray-line, in terms of the average number of droplets per needle taken over all the tree samples at that height and with that spray technique. The minimum coverage is 0.33 of the average whilst the maximum is 4.35 times the average. In this set of sixteen samples, there is a probability of 15 out of 16 of having at least half the average droplet density, but only a probability of 12 out of 16 of having a density equal to the average.

If two successive lines, say those 30m and 40m downwind, are considered together, then in a similar way the probability of getting more than 50 per cent or 100 per cent of the average number of droplets on every sample needle can be calculated. The accuracy of the prediction will increase because twice the number of samples will be considered. Since the samples are taken from lines of 10m spacing downwind, each line can be assumed to represent a 10m wide strip parallel to the aircraft flight path. Thus the probability of obtaining a certain number of droplets on every needle of every tree over strips of various widths from one spray run can be calculated.

The effect of multiple spray runs at various lane-separations can also be calculated. For example, if we consider an aircraft spraying as the Cessna, but with a 30m lane separation then the effective deposit on the top north part of a tree directly under a flight path should be the sum of the top north deposits of the samples taken from the trees 0m, 30m, 60m, 90m, etc. downwind. Similarly the effective deposit on a tree 10m downwind of any of the flight paths would be the sum of the sample results from the same position on trees 10m, 40m, 70m, 100m etc. Thus the effect of overlapping swaths on probability can be obtained and, by considering a variety of flight path separation distances, the reduction in probability with increase in separation calculated.

The average number of drops per needle examined was 11.97, 4.77 and 1.74 for the samples from near the top of the tree for the LV (red), ULV 45° blades (blue) and ULV 25° blades (green) respectively. For the samples taken from the middle of the tree the average number of drops per needle was 4.09, 1.46 and 0.33 respectively. Measurement of the needle sizes gave an average surface area, top and bottom, of 150 mm^2 and hence the average area per drop on the samples from near the top of the trees was 12.5 mm^2, 31.4 mm^2 and 86.2 mm^2/drop respectively and for the samples from the middle of the trees 36.7 mm^2, 103 mm^2 and 455 mm^2/drop.

If the number of droplets on the needles relative to those seen are in the ratios of 1:1, 1:0.56 and 1:0.038 as suggested above, then the average areas per droplet caught by the tree top needles are 12.5 mm^2, 17.6 mm^2 and 3.3 mm^2 for the LV, ULV 45° blades and ULV 25° blades respectively and for the middle tree samples 36.7 mm^2, 56.6 mm^2 and 17.3 mm^2 respectively. These average coverages were obtained with the aircraft emission rates of 0.063 litres/metre for LV and 0.006 litres/metre ULV.

By combining these average coverages with the probabilities associated with various aircraft lane-separations, it is possible to calculate the dosage rate per hectare required to give a specified probability of having a minimum required coverage. Figure 4.7 p. 51, shows the result obtained for the LV application on the near tree-top needles and Figure 4.8 p. 51, that for the ULV spray generated by the 45° bladed Micronair. Since the number distribution for the 25° bladed Micronair would be similar, except for the drops at the larger end of the size range, the general form of the result was expected to be similar to that of Figure 4.8 p. 51, but with the higher probabilities associated with the larger number of drops per litre emitted. In view of the low fraction of drops seen, probability calculations were not made for the 25° case.

Figure 4.7 p. 57, shows clearly that the required dosage for a given coverage hardly increases with lane-separation up to one of beyond 50 metres. Thus considerable flying time and hence cost would be saved if the aircraft flew a 50m lane-separation technique. However, to do this and obtain probabilities of satisfactory coverage above 95 per cent on the tree-tops (less than 70 per cent at mid-tree height) would require an emission rate of over 260 litre/min and thus, with aircraft pumps of adequate capacity, a huge v.m.d. It was decided that 150 litre/min was a maximum acceptable emission rate from six Micronair units and, with a 25m lane-separation, this suggested a probability of 97 per cent of having a drop every 20 mm^2 on needles at the top of the tree and, on those near the middle of the tree, of about 80 per cent.

The results for the ULV spray as analysed from the sample obtained using the Micronair with 45° blade settings, Figure 4.8 p. 51, show a less obvious upper limit to desirable lane-separation. However, beyond a lane-separation of 50m the dosage required for high probabilities starts to rise quite rapidly, and for this reason a 50m lane-separation was recommended for the ULV application. Figure 4.8 p. 51, suggests that for a 15 litre/min emission rate there would be an 81 per cent probability of getting one drop per 20 mm^2 on the top needles and only about 50 per cent probability for the needles near the middle height of the tree using Micronairs with 45° blade settings.

However, with the blade settings at 25°, although most of the emitted droplets would be the same size as for the 45° blade setting, there would be over three times as many if the volume average diameter was 69 µm instead of 103 µm as predicted. Thus with 25° blade settings, an emission rate of 15 litre/min and a lane-separation of 50 metres, the probabilities of getting one drop per 20 mm^2 of needle area on the top of the tree of about 99 per cent would be expected and 81 per cent at the middle of the tree height. In view of this it was decided to recommend for ULV spraying a flow rate of 15 litre/min from two Micronairs with blades set at 25° and the aircraft flying at 50m/second on lanes 50 metres apart.

For a similar probability of getting at least one drop per 20 mm^2 of needle area from the LV spray as the ULV 25° blade conditions, the dosage per hectare has to be twenty times greater. This, in part, because some of the very large drops fall rapidly and penetrate to the ground before the water evaporates completely, but mainly because the small droplets generated evaporate to such small values they are not collected efficiently by the needles. It must be the medium sizes of the droplet size spectrum which evaporate to the 30 µm - 80 µm size range whichare caught by the foliage together with some of the largest droplets. Since the large and medium size droplets contain the bulk of the mass emitted, one would not expect to need a significantly higher dosage of active ingredient per hectare for the LV spray relative to the ULV, although some increase is indicated to allow for the amount falling to the ground.

The major economic advantage of the ULV spray technique is that the aircraft whilst spraying covers twice the area per unit time because twice the lane-separation is possible. Again, since the emission rate is only one tenth of that for the LV spraying it can spray for ten times the time, and consequently the time and cost of flying from base to spray site is dramatically reduced. It is estimated that the affected area in Sutherland can be sprayed in less than two days using the ULV technique whilst almost two weeks would be required for the LV. The saving in fuel and hire costs is obvious.

CONCLUSIONS

1. The amount of spray falling to the ground was far greater for the LV spray than for the ULV spray.

2. The distribution of ULV spray downwind of the sprayline was less peaky than that for the LV emission, suggesting that a more even coverage could be obtained by overlapping swaths.

3. The coverage on the lee side of the trees was about half that of the other aspects. There was some slight evidence to suggest that this uneveness decreased towards the bottom of the trees.

4. Considerable variation in the coverage was inevitable because of tree, site and wind turbulence variations. As a result it was essential to examine the probabilities of obtaining a specified coverage using a defined dosage.

5. The lane-separation for LV spraying is limited by the maximum rate of emission which can be obtained whilst keeping the droplet sizes within the range which will be caught by the target.

6. Using the needles near the extremities of the tree as target areas, it was concluded that an aircraft flying at 50m/second at 4m to 5m above the canopy should spray 150 litres/min using a 25m lane-separation in order to achieve at least an 80 per cent probability of getting one drop per 20 mm^2 of needle surface area if a LV spray technique was specified.

7. A much better technique would be to spray from an aircraft flying at six to eight metres above the tree canopy at 50m per second spraying at a rate of 15 litres/min using a lane-separation of 50m. Such a technique should require a slightly smaller dosage per hectare of active ingredient but would take only about 15 per cent of the time required for the LV spray programme and consequently would be a significantly cheaper operation.

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IN RETROSPECT

Preliminary results from the Sutherland operations indicate that overall about 97 per cent of the Pine beauty moth larvae were killed. This is somewhat greater than would be expected from the Thetford trial results. The reason is probably linked to the size and target area of the larvae.

Firstly, the larvae were bigger than anticipated largely due to the delay in mounting the operation. Again the larvae were attacked whilst feeding mainly on the exposed growing buds of the Lodgepole pine, and in that position exposed a greater surface area of body than the assumed 20 mm^2. As a protrusion on the growing bud they were subjected to an increase in local wind speed because of the interference effect of the growing shoot and therefore the droplet collection efficiency was improved.

There seems little doubt that the high kill rate was achieved because plenty of droplets of a size which would impact on the target larvae were available. The greater level of active ingredient found in the dead larvae from the ULV spray area shows that the bigger droplets of the LV spray were less effective in reaching the specific target.

Table 4.1

Wind Conditions Averaged Over Test Line

	HEIGHT ABOVE THE GROUND											
	2.0 m			*4.9 m*			*8.0 m*			*16.0 m*		
	East Wind Speed	*South Wind Speed*	*Upward Speed*	*East Wind Speed*	*South Wind Speed*	*Upward Speed*	*East Wind Speed*	*South Wind Speed*	*Upward Speed*	*East Wind Speed*	*South Wind Speed*	*Upward Speed*
Mean Value m/sec	1.10	0.15	0.02	2.61	0.25	0.24	3.46	0.24	0.03	4.26	0.33	0.46
Standard Deviation m/sec	0.71	0.75	0.33	1.21	1.32	0.45	1.36	1.46	0.47	1.45	1.65	0.60
Maximum Value m/sec	4.99	4.34	1.73	8.03	5.98	2.72	9.57	5.36	2.48	9.57	5.77	3.82
Minimum Value m/sec	0.83	6.02	2.13	1.54	6.51	2.18	0.58	6.21	3.46	1.12	8.77	3.83

Table 4.2(a)

Low-Volume and Ultra-Low-Volume
Spray Trials From Aircraft Over Thetford Forest

Droplets per five needles on four aspects at two levels and score for ground deposit 1 = zero, to 5 = very heavy

Line Tree	*Spray*	*Tree Top*					*Middle of Tree*					*Ground*			
		North	*East*	*South*	*West*		*North*	*East*	*South*	*West*		*North*	*East*	*South*	*West*
	LV	1	0	11	12	24	0	0	0	0	0	0	0	1	2
C 1	ULV 45°	0	0	0	0	0	0	0	0	0	0				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
	LV	175	345	416	443	1379	89	238	279	145	751	1	2	4	2
C 2	ULV 45°	0	0	1	0	1	0	0	0	0	0				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
	LV	194	293	266	25	778	131	98	17	37	283	4	4	2	3
C 3	ULV 45°	29	18	11	2	60	5	10	0	2	17				
	ULV 25°	0	0	0	0	0	0	0	1	0	1				
	LV	110	261	224	94	689	53	75	56	22	206	3	3	2	3
C 4	ULV 45°	50	66	60	17	193	50	33	30	6	119				
	ULV 25°	3	4	5	1	13	9	1	1	1	12				
	LV	108	83	88	65	344	16	43	88	48	195	2	2	3	3
C 5	ULV 45°	30	35	35	27	127	3	8	56	16	83				
	ULV 25°	27	26	13	15	81	6	1	5	0	12				
	LV	38	46	15	46	145	32	12		2	46	2	2	2	2
C 6	ULV 45°	15	28	13	12	68	14	5		2	21				
	ULV 25°	5	5	1	2	13	5	1		0	6				
	LV	10	18	21	11	60	8	7	3	9	27	2	1	2	2
C 7	ULV 45°	28	25	24	9	86	19	8	4	7	38				
	ULV 25°	1	1	5	4	11	3	0	0	2	5				

Note: Tree No.1 is under aircraft flight line. Trees number away from flight line.

Table 4.2(b)

C Totals		North	East	South	West		North	East	South	West	
	LV	711	1119	1113	744	3687	401	495	462	275	1633
	ULV 45°	284	314	231	121	950	132	101	109	47	389
	ULV 25°	63	73	51	33	220	37	10	12	6	62

Line Tree	*Spray*	*Tree Top*					*Middle of Tree*					*Ground*			
		North	*East*	*South*	*West*		*North*	*East*	*South*	*West*		*North*	*East*	*South*	*West*
	LV	41	47	51	28	167	63	14	2	4	83	1	1	1	1
C 8	ULV 45°	94	98	68	45	305	32	26	6	3	67				
	ULV 25°	16	18	20	5	59	14	5	4	1	24				
	LV	10	2	8	14	34	2	2	5	1	10	1	1	1	2
C 9	ULV 45°	8	10	10	8	36	1	6	5	3	15				
	ULV 25°	1	2	0	5	8	0	0	0	0	0				
C 10	LV	24	24	13	6	67	7	6	12	7	32	1	1	1	1
	ULV 45°	30	34	9	1	74	8	5	8	8	29				
	ULV 25°	10	17	7	1	35	0	2	1	2	5				
	LV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
D 1	ULV 45°	0	0	0	0	0	0	0	0	0	0				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
	LV	17	6	11	17	51	15	0	11	5	31	2	2	4	3
D 2	ULV 45°	0	0	0	0	0	0	0	0	0	0				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
	LV	85	99	63	32	279	30	37	8	6	81	2	3	2	2
D 3	ULV 45°	39	36	31	11	117	7	3	2	4	16				
	ULV 25°	60	39	10	26	135	1	8	0	2	11				
	LV	161	125	181	90	557	67	39	50	68	224	2	3	3	3
D 4	ULV 45°	98	68	90	28	284	60	26	9	38	133				
	ULV 25°	73	34	45	11	163	33	15	3	6	57				

Table 4.2(c)

Line Tree	Spray	Tree Top					Middle of Tree					Ground			
		North	East	South	West		North	East	South	West		North	East	South	West
D 5	LV	88	153	147	68	456	12	40	19	9	80	3	3	3	2
	ULV 45°	28	43	21	8	100	5	29	6	8	48				
	ULV 25°	40	26	21	11	98	2	3	4	2	11				
D 6	LV	64	135	127	84	410	45	28	55	13	141	2	3	2	2
	ULV 45°	25	47	40	25	137	15	9	18	0	42				
	ULV 25°	15	13	12	10	50	1	2	3	2	8				
D 7	LV	82	66	68	20	236	9	23	27	5	64	2	3	3	2
	ULV 45°	52	54	32	15	153	3	6	17	9	35				
	ULV 25°	14	24	10	5	53	2	3	0	1	6				
D 8	LV	8	17	16	11	52	0	3	2	3	8	1	1	1	1
	ULV 45°	4	14	15	18	51	1	2	3	1	7				
	ULV 25°	2	9	9	5	25	0	0	0	0	0				
D 9	LV	10	16	24	18	68	2	8	7	5	22	2	2	1	2
	ULV 45°	11	8	16	7	42	0	2	3	1	6				
	ULV 25°	2	2	6	4	14	0	1	3	1	5				
D 10	LV	12	19	15	15	61	15	10	22	2	49	2	2	2	2
	ULV 45°	9	21	12	12	54	13	8	7	7	35				
	ULV 25°	3	2	3	3	11	5	3	4	1	13				
D Totals	LV	527	636	652	355	2170	195	188	201	116	700				
	ULV 45°	266	291	257	124	938	104	85	65	68	322				
	ULV 25°	209	149	116	75	549	44	35	17	15	111				

Table 4.2(d)

Line Tree	Spray	Tree Top North	Tree Top East	Tree Top South	Tree Top West		Middle of Tree North	Middle of Tree East	Middle of Tree South	Middle of Tree West		Ground North	Ground East	Ground South	Ground West
E 1	LV	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	ULV 45°	0	0	0	0	0	0	0	0	0					
	ULV 25°	0	0	0	0	0	0	0	0	0					
E 2	LV	90	322	280	119	811	0	2	0	2	4	0	2	1	0
	ULV 45°	0	0	0	0	0	0	0	0	0	0				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
E 3	LV	26	26	41	30	123	19	15	6	3	43	3	2	2	1
	ULV 45°	0	0	0	0	0	0	0	0	0	0				
	ULV 25°	0	0	1	0	1	0	0	0	0	0				
E 4	LV	55	65	56	32	208	24	18	50	9	101	2	3	3	2
	ULV 45°	3	10	17	8	38	3	0	6	1	10				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
E 5	LV	54	52	50	11	167	9	12	2	2	25	2	1	1	2
	ULV 45°	32	27	28	10	97	8	1	1	3	13				
	ULV 25°	4	3	9	0	16	2	1	0	7	10				
E 6	LV	18		77	18	113	4	0	0	1	5	1	1	0	1
	ULV 45°	30		120	18	168	0	0	1	1	2				
	ULV 25°	6		27	0	33	0	0	0	0	0				
E 7	LV	28	32	34	8	102	2	3	0	2	7	1	1	1	0
	ULV 45°	36	24	32	18	110	2	6	1	1	10				
	ULV 25°	8	4	14	8	34	0	0	0	0	0				

Table 4.2(e)

		North	East	South	West		North	East	South	West	
E Totals	LV	373	577	615	238	1803	62	62	68	21	213
	ULV 45°	212	130	325	93	760	16	18	20	9	63
	ULV 25°	77	63	104	26	270	2	7	9	8	26

Line Tree	Spray	Tree Top North	Tree Top East	Tree Top South	Tree Top West		Middle of Tree North	Middle of Tree East	Middle of Tree South	Middle of Tree West		Ground North	Ground East	Ground South	Ground West
E 8	LV	19	16	16		51	1	1	3	0	5	1	2	1	1
	ULV 45°	21	26	25		72	1	1	2	2	6				
	ULV 25°	9	13	14		36	0	5	3	1	9				
E 9	LV	35	16	23	13	87	2	2	4	1	9	1	1	1	0
	ULV 45°	58	18	58	24	158	2	4	8	0	14				
	ULV 25°	25	11	11	10	57	0	0	4	0	4				
E 10	LV	48	48	38	7	141	1	9	3	1	14	1	1	1	1
	ULV 45°	32	25	45	15	117	0	6	1	1	8				
	ULV 25°	25	32	28	8	93	0	1	2	0	3				
F 1	LV	0	0	0	0	0	0	0	0	0	0	1	0	0	0
	ULV 45°	0	0	0	0	0	0	0	0	0	0				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
F 2	LV	70	138	70	60	338	10	71	59	18	158	2	3	2	2
	ULV 45°	2	4	6	3	15	3	6	6	0	15				
	ULV 25°	0	0	0	0	0	0	0	0	0	0				
F 3	LV	167	217	161	96	641	26	58	75	15	174	3	3	2	2
	ULV 45°	73	146	89	60	368	12	44	49	18	123				
	ULV 25°	0	3	5	2	10	1	1	2	1	5				
F 4	LV	102	125	68	20	315	97	62	33	12	204	3	3	2	1
	ULV 45°	59	64	24	11	158	14	23	20	4	61				
	ULV 25°	7	11	4	2	24	1	1	1	1	4				

Table 4.2(f)

Line Tree	*Spray*	*Tree Top*					*Middle of tree*					*Ground*			
		North	*East*	*South*	*West*		*North*	*East*	*South*	*West*		*North*	*East*	*South*	*West*
	LV	81	60	95	28	264	15	35	26	25	101	1	2	2	1
F 5	ULV 45°	53	37	72	19	181	40	34	14	4	92		-		
	ULV 25°	15	9	16	3	43	4	2	3	2	11				
	LV	31	35	37	21	124	7	13	7	3	30	1	2	1	1
F 6	ULV 45°	42	31	61	16	150	7	12	13	2	34				
	ULV 25°	15	28	32	11	86	2	6	3	0	11				
	LV	8	14	9	4	35	1	1	6	0	8	1	1	0	0
F 7	ULV 45°	12	26	36	8	82	3	0	4	2	9				
	ULV 25°	10	32	19	5	66	2	1	8	0	11				
	LV	11	8	8	2	29	2	4	1	5	12	1	0	0	0
F 8	ULV 45°	10	12	17	1	40	3	2	3	5	13				
	ULV 25°	4	6	9	4	23	0	0	0	1	1				
	LV	19	13	2	8	42	5	3	3	4	15	1	0	1	1
F 9	ULV 45°	18	27	8	10	63	5	9	4	3	21				
	ULV 25°	9	15	4	3	31	2	3	5	1	11				
	LV	5	2	4	2	13	0	0	1	0	1	0	1	1	1
F 10	ULV 45°	28	7	15	10	60	2	2	7	4	15				
	ULV 25°	15	11	18	11	55	1	3	1	1	6				
F	LV	494	612	454	241	1801	163	247	211	82	703				
Totals	ULV 45°	297	354	328	138	1117	89	132	120	42	383				
	ULV 25°	75	115	107	41	338	13	17	23	7	60				

Figure 4.1

Layout of test area in Thetford Forest

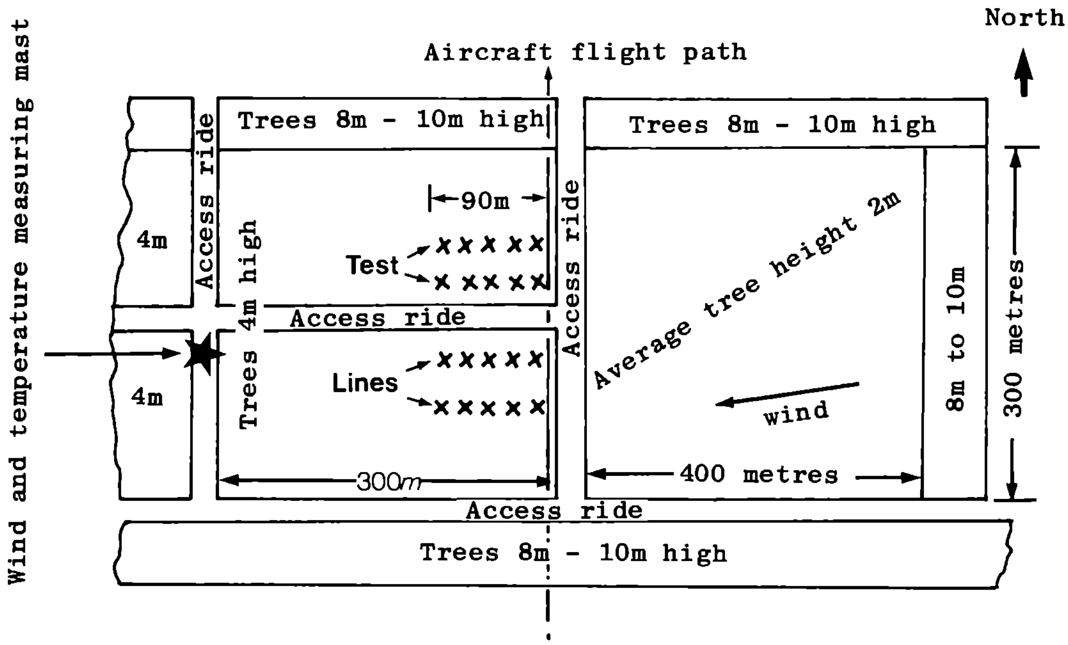
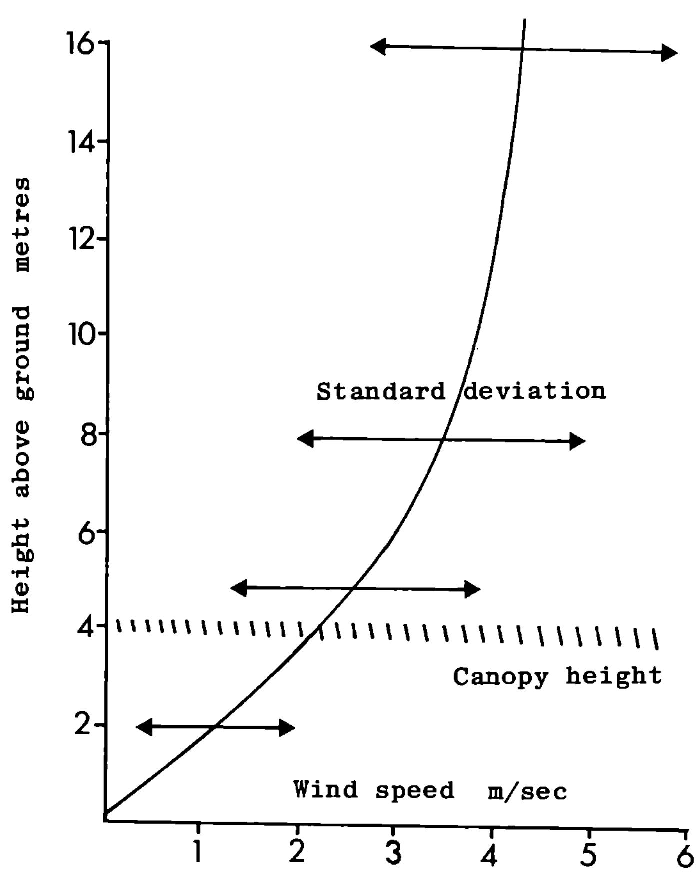


Figure 4.2



Wind profile

Figure 4.3

Downwind distribution of low volume spray on the ground

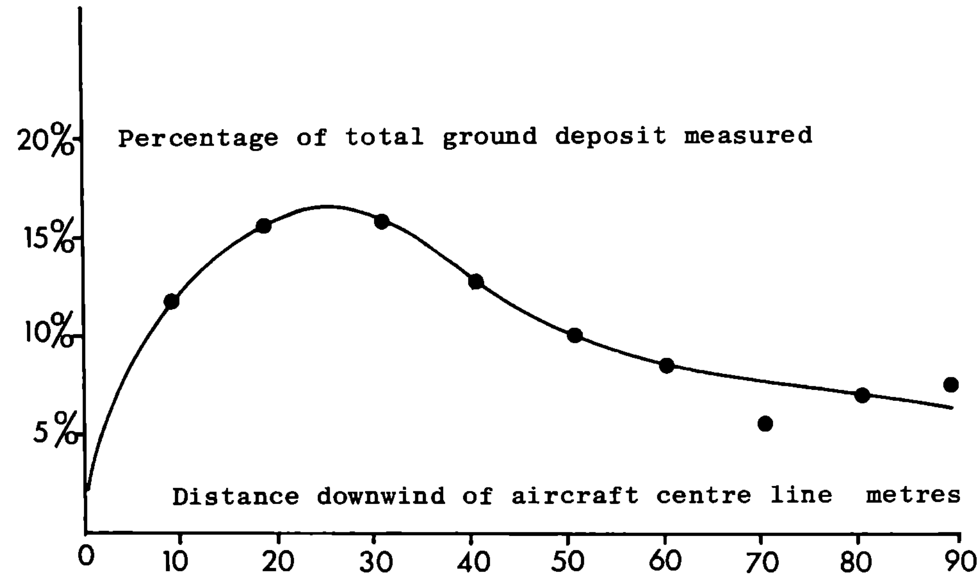


Figure 4.4

Variation of tree deposit with aspect

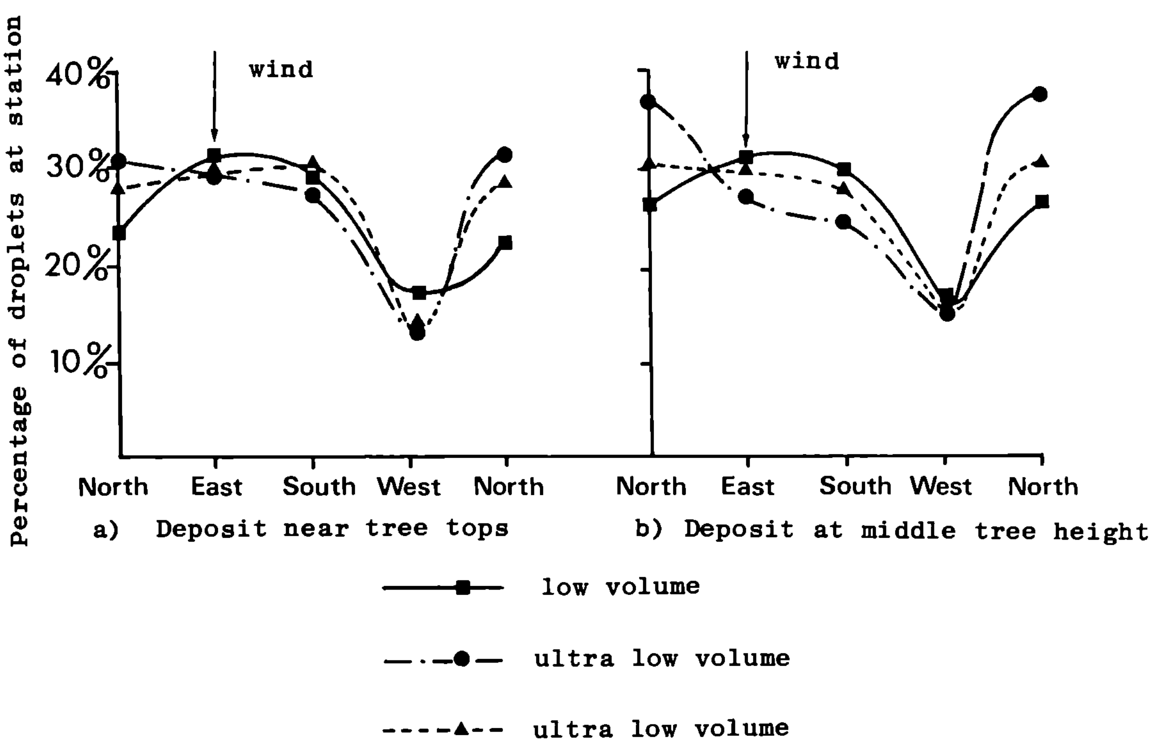


Figure 4.5

Downwind distribution of spray on trees

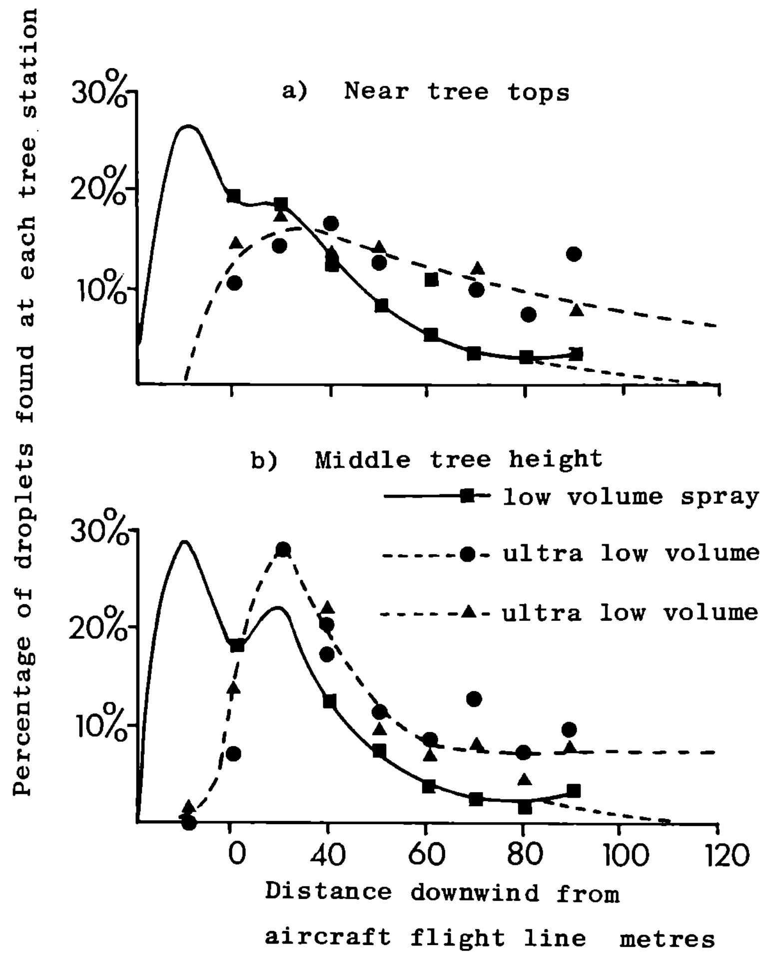


Figure 4.6

Typical variation of deposit over samples at same tree height and distance downwind of spray line

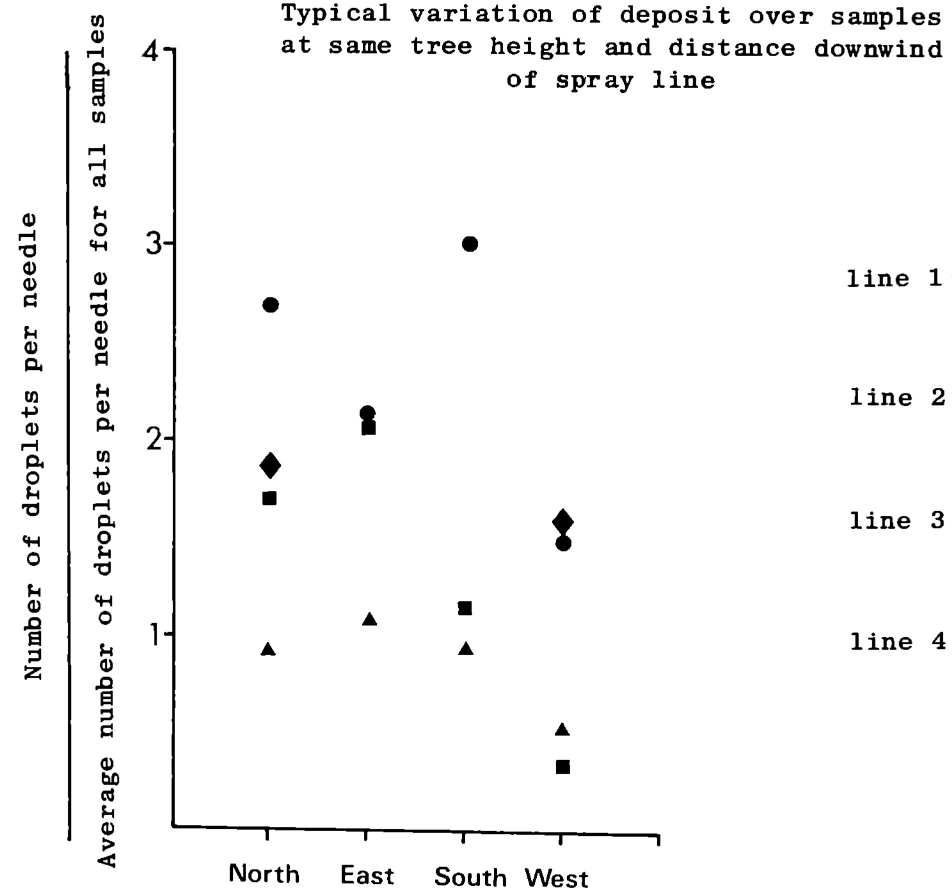
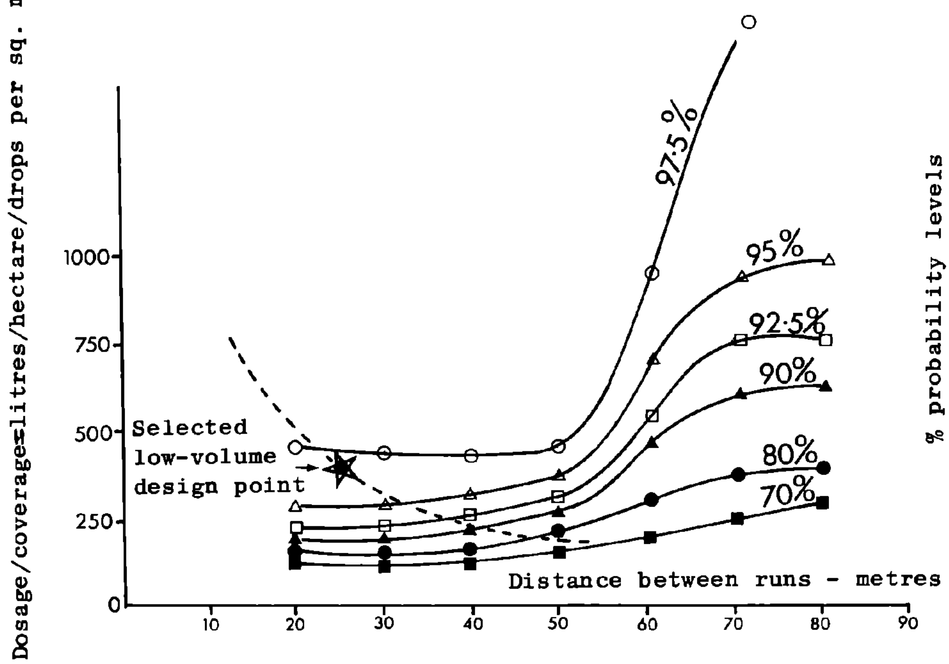


Figure 4.7

Characteristics with low volume spray onto tree tops



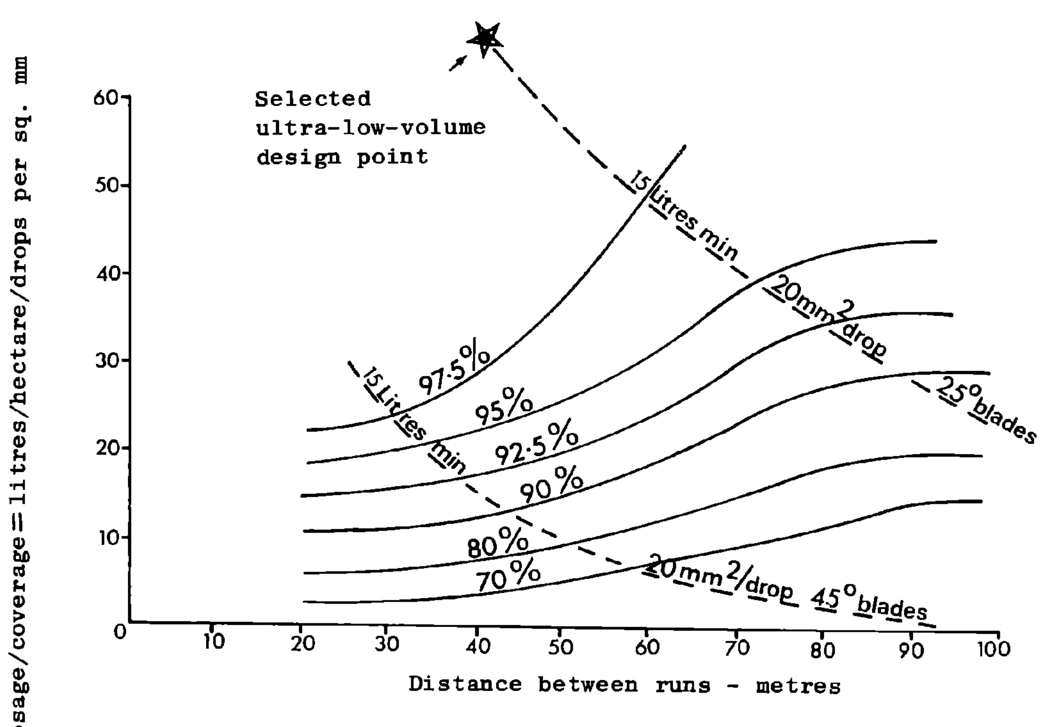


Figure 4.8

Characteristics with ultra-low-volume spray onto tree tops

(45^{o} Blades)

Chapter 5

SELECTION OF SPRAY TECHNIQUE AND CLEARANCE PROCEDURE

D. Bevan
Forestry Commission

INTRODUCTION

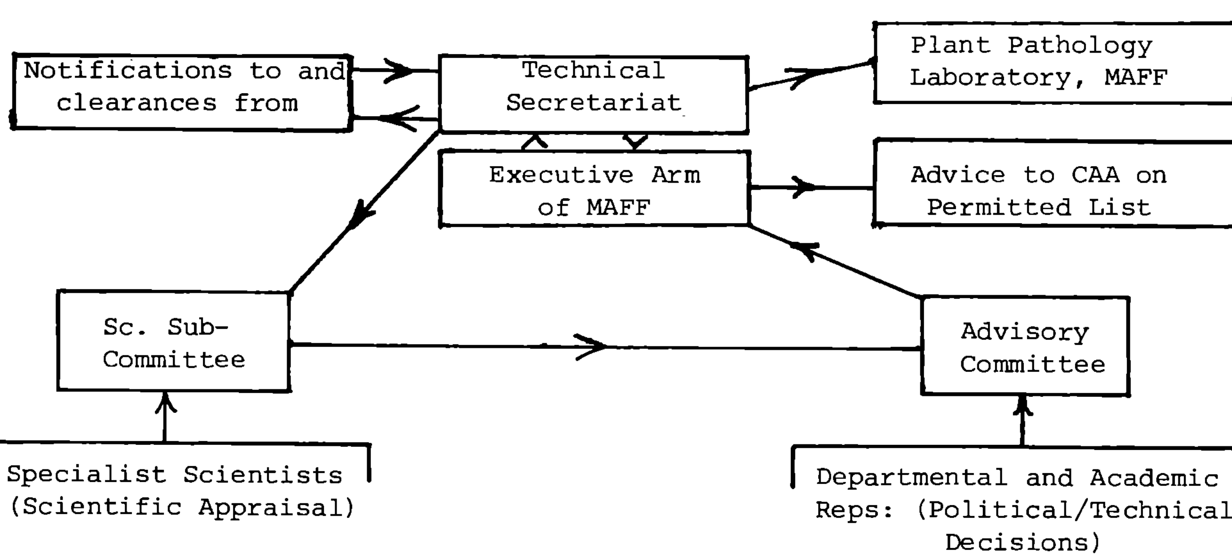
Detailed information on the area of Lodgepole pine threatened by *Panolis flammea* in 1978 was available at the beginning of December 1977. It was clear that a total of about 5,000 ha would require treatment with insecticides if wide scale defoliation and death of trees were to be avoided (see Chapter 1). Laboratory screening tests of alternative insecticides, short-listed for low toxicity and persistence as well as suitability for use in a United Kingdom forest context, were planned immediately and were put in train as soon as adults had been forced into emergence, had laid eggs, and larvae had reached an appropriate size for test. The results were ready by March 1st 1978 (Chapter 4). Fenitrothion appeared superior in its ability to kill at low levels of application and was therefore selected for use. Meanwhile contact had been made with Professor Vernon Joyce, Professor of Bio-aeronautics at Cranfield College of Aeronautics, who was later appointed as Consultant to the Forestry Commission for the control operation. He strongly advised the Commission to consider a target specific ultra low volume (ULV) technique, (Chapter 2), basing his advice on both economic and environmental considerations.

No chemical, however, has been given clearance under the Pesticides Safety Precautions Scheme (PSPS) for aerial application by any ULV technique, and there is therefore effectively an embargo on aerial ULV spraying in the UK, although it is widely used in other parts of the world. There may have been a lack of interest in the United Kingdom in that traditional low volume (LV) methods have provided generally good control in a country in which the pattern of spraying-demand tends to be for treatment of small fields and isolated forest blocks. It is, of course, the larger type of operation in which the economies of ULV become most attractive. At the same time there has always been a degree of suspicion about ULV application, both as to its efficiency and to the possible hazards to man and to domestic animals and wildlife. ULV as a term on its own merely refers to any technique which aims at application of the minimum volume per unit area compatible with economic control (WHO 1971). ULV inevitably involves devices designed specifically to produce very fine division of relatively concentrated material. It seems then that the method, superficially at least, must be more hazardous than conventional LV, since the latter allows a larger amount of more dilute chemical to achieve a similar coverage with larger droplets. That this is not the case in a properly controlled operation is explained by Joyce and Spillman (Chapter 2). At the same time it must be admitted that application at ULV rates is more demanding technically than conventional spraying and bad applications in the past have sometimes led to complete failure. In recent years, progress in the development of spray atomisers and ancillary gear have allowed the control of droplet spectra to within close limits. Our knowledge of droplet and spray cloud behaviour has also advanced to a point where spray techniques can be tailored to suit the conditions specified, so that a very high proportion of the chemical applied reaches the target and pollution is reduced to a minimum. It was for the purpose of calibrating the spraying equipment and matching droplet size and dosage rate to the target pine crop under United Kingdom conditions that a preliminary trial-spraying was carried out in Thetford Forest, Norfolk on April 27th 1978 (Chapter 4).

It should be appreciated that there is no obligation for any user to seek clearance under the PSPS for the aerial application of fenitrothion applied at normal LV rates. The use of this insecticide upon non-edible crops has been declared acceptable since 1971, and this declaration is published in a Recommendation Sheet issued by the Ministry of Agriculture, Fisheries and Food (Pesticides Branch) in the normal way. The insecticide, incidentally, is also approved against a wide range of agricultural and horticultural pests under the Agricultural Chemical Approval Scheme. It also appears in the Civil Aviation Authorities (CAA)'permitted list' of chemicals cleared under PSPS for application from the air at LV rate.

It may be appropriate to explain the term 'clearance' and the working of the Pesticides Safety Precaution Scheme. Briefly, clearances of various kinds are given to manufacturers for specific products, under the PSPS. The PSPS is a formally agreed scheme between Government and Industry whereby Industry undertakes to notify any product containing a new chemical, or comprising a new formulation or for a new use of an existing chemical formulation. The full procedure involves the notification being first processed through the Scientific Sub-Committee for scrutiny by specialist scientists. It is then passed to the Advisory Committee on Pesticides and other Toxic Chemicals which is responsible for final decisions. The latter committee consists of representatives from other Government departments as well as independent non-Government members from the academic world. This committee thus not only taps a wide range of experience and opinion, but is also sensitive to public wish. Its function might be described therefore as both political and technical.

Diagramatically then:



So, with the technical decision by the Forestry Commission and their Consultants that a target-specific ULV application would provide the best means of controlling *P. flammea*, came the requirement to seek clearance for this'new use' as well as for the slight modification to a standard formulation resulting from the addition of a glycol, Butyl dioxitol (introduced here as a diluent). An application was therefore lodged with the Ministry of Agriculture, Fisheries and Food (Pesticide Division) for clearance for a ULV application of Ciba Geigy's Fenitrothion 50 EC in Butyl dioxitol on March 3rd 1978. Only three months was available for members of the two committees and the executive arm of the PSPS to carry out their scientific appraisals, to seek departmental reaction to the proposal, and to formulate the details of any clearance and plan for environmental monitoring. It gave even less time for monitoring agencies to plan their programme, make field assessments and to assemble equipment and to design appropriate sampling techniques, and the brevity of the notice given was impressed upon the Forestry Commission. At the same time the suddenness of the emergency was recognised, as also were the technical opportunities offered for obtaining basic information of wider application than to forestry alone.

It soon became clear that a major concern was the possibility of an unacceptable level of air pollution arising in the immediate vicinity of the ULV spray cloud. In particular, information upon 'inhalation toxicity' hazards to man were called for by members of the committees with responsibilities in the health and safety fields. Indeed, for a time, it appeared that doubts on this issue, combined with the insubstantial and rather inconclusive evidence in the literature upon the ability of fine droplets (say of 30 µm and under) to penetrate air passages, was likely to prejudice any chance of clearance being given for ULV at all. However, expert opinion seemed fairly unanimous that particles below 5-10 µm constitute the greater bulk of those actually inhaled and that some 50 per cent of them will be in the 1-2 µm diameter region (Watson 1954 and Matthews 1978), particles greater than this being filtered out in the nose or deposited in the mouth. Technically then a method which led to fewer, or even a similar number, of droplets within a range taken as hazardous would seem to have the weight of advantage, if a higher proportion of those droplets were to be intercepted by the tree crop target rather than by any other non-target component of the environment, including man.

The view might be taken that it was not useful to erect the specture of putative hazard without any toxicological data on threshold levels, or, indeed, evidence upon the probability of any hazard existing at all with the very small amounts of low toxicity chemicals present. On the other hand, a general philosophy of minimising risk cannot be faulted. It is clear from the terms of the clearance finally awarded through the PSPS, and quoted in full and final form below, that there was still much concern over such hazards. The ULV application was therefore restricted 'to selected sites which are at least 2 miles away from major roads and areas of habitation' - a condition, it should be noted, possible to satisfy in only very few areas in Britain even in a region of low population density such as Caithness and Sutherland.

The following was the final clearance given:-

12 May 1978

PESTICIDES SAFETY PRECAUTIONS SCHEME : ULV AERIAL APPLICATION OF FENITROTHION

1. Fenitrothion is the BSI common name for dimethyl 3-methyl-4-nitrophenyl phosphorothionate, a non-systemic organophosphorus insecticide of low acute oral and dermal mammalian toxicity. Commercial clearance has been given for its use on any edible crop subject to a minimum interval of 2 weeks between last application and harvest and also for similar use in the home garden. Departments have also agreed to commercial clearance for its use in food storage practice as a dust, solid or liquid concentrate, ready-to-use spray and

as a lacquer. A number of 50% emulsifiable concentrate formulations of fenitrothion are included in the Aerial Application Permission.

2. You have requested clearance for the aerial application of fenitrothion by a novel procedure, developed by Professor Joyce of the Cranfield College of Aeronautics, to approximately 5000 ha of Lodgepole pine plantations to control Pine beauty *(Panolis flammea)* in the far north of Scotland. The spraying method is a type of Ultra Low Volume technique which results in a drop spectrum in which 95 per cent of the spray volume consists of drops in the 40-60 micron range, the remaining 5 per cent consisting of drops of a smaller size. The technique has been widely used in other countries being applied to the canopy with very little reaching the ground.

3. Your Department would like to apply 600 grams of Fenitrothion 50 EC admixed with 400 grams of the glycol, Butyl dioxitol and applied at 300 g ai/ha. We understand simulation trials were conducted in Thetford forest during April to ascertain the efficacy of the system.

4. Departments have taken advice and considered your request under the terms of the Scheme together with the data you have submitted. They felt that insufficient information was available for an unqualified agreement to be given for the proposed use. In particular, data were not available on the extent of drift from the proposed use and it was noted that some of the areas to be sprayed were in close proximity to major roads and some habitation. They therefore agreed to LIMITED CLEARANCE for the use of fenitrothion only provided the following conditions are observed.

4.1 Aerial ULV application should not exceed 1,500 ha and must be restricted to selected sites which are at least 2 miles away from major roads and areas of human habitation. The remaining area should be sprayed using conventional aerial spraying techniques, at conventional low volume rates. This will effectively limit the use of the novel spraying technique to Fiag plantation and the more southerly plantation of Strathy Forest, and we understand that it may be possible to make arrangements so that the most southerly part of the Naver Forest (Truderscaig) could comply with the general requirements of the recommendations.

4.2 Precise details of the formulation to be used must be submitted to the PSPS Secretariat along with details of the acute toxicity of this formulation.

4.3 Operators handling the concentrated formulation must be fully aware of the potential hazard associated with the handling of this formulation and must comply with the precautions on the product label.

4.4 The method of spraying makes it difficult to predict if contamination of the air in the cockpit will occur. For this reason, pilot hazard cannot be readily assessed and the following should therefore be undertaken:-

4.4.1 frequent medical examination, including visual function;

4.4.2 daily measurement of whole blood cholinesterase levels (before and after flying);

4.4.3 pilots should wear personal contamination monitors of the aspiration type for subsequent analysis for fenitrothion.

4.5 The spraying operations should be adequately monitored for environmental effects and if meaningful data are to be obtained, individuals performing the work will need to be consulted on the number and type of sample they could handle and the method by which they should be despatched. The Forestry Commission should be responsible for this co-ordination with Mr A.V. Holden (Officer in Charge of the DAFS Freshwater Fisheries Laboratory). They should consult the Nature Conservancy Council, the River Purification Boards, DAFS (Dr Graham), Pest Infestation Control Laboratory, Slough (Mr Papworth), PPL Harpenden (Dr Thomas) and any other relevant authorities.

4.6 The Forestry Commission should be aware of its responsibility to ensure the safety of third parties eg inhabitants, workers, forest workers, casual visitors in the sites to be treated, and should submit to Dr Thomas, PPL Harpenden, the proposals for putting such safety measures into effect. These should be copied to Dr Moir of SHHD, Edinburgh.

5. I should be glad to receive your acceptance of these conditions and would point out that a detailed report on all these conditions will be required in support of any future application for clearance.

6. This clearance in no way commits Departments to agree to any other use of this chemical. A new notification should be submitted at least three months before further clearance is required.

REFERENCES

Matthews, G.A. (1978). Priv: Comm:

Watson, H.H. (1954). *British Journal of Physical Medicine* 17, 275.

WHO, (1971). Application and dispersal of insecticides. *World Health Organisation Technical Report Series*, No. 465, Geneva.

Chapter 6

GETTING OFF THE GROUND

E.J.S. Michie
Forestry Commission

N.R. Kinvig
Pilot, CIBA-Pilatus Aerial Spraying Company

A.W. Neal
Heliscot Ltd, Inverness

While approval was being sought for the application of fenitrothion, a notice of intent was sent out to the following for information:

The Press
BBC Highland
Highland Region Water and Sewerage Department
Nature Conservancy Council
Royal Society for Protection of Birds
North Scotland College of Agriculture
Scottish Woodland Owners Association
Scottish Beekeepers Association
National Farmers Union
Department of Agriculture and Fisheries for Scotland
Scottish Wildlife Trust

This was followed by a meeting at Rimsdale with the Highland River Purification Board, the Department of Agriculture for Scotland (Freshwater Fisheries Laboratory) and the Nature Conservancy. From this time, continuing liaison took place with the organisations concerned, the neighbouring riparian owners, the Scottish Home and Health Department and the Press, up to and during the spraying operation. Permission was given to use Dounreay Airfield (United Kingdom Atomic Energy Authority) and a field strip at Achentoul.

Possible road closures were arranged with the Police and an extensive radio network set up.

Arrangements were made to commence spraying on 8 June but adverse weather conditions postponed this until 12 June. The operation was completed on 21 June.

OPERATIONAL DETAILS

THE CONTRACT

The spraying contract was drawn up with Heliscot Ltd., an agricultural spraying company operating helicopters from Inverness. Choice of aircraft was based on the following considerations:-

1. Track Guidance System capabilities.

2. ULV and LV spraying facilities

3. CIBA-Pilatus-developed spray equipment with special metering device and instant electric shut-off valves.

4. STOL performance, well-proven in an agricultural role.

THE AIRCRAFT

The aircraft having these capabilities was owned and operated by CIBA-Pilatus Aerial Spraying Co., Glarus, Switzerland. The machine, a Pilatus PC6 Turbo-Porter, registered HB-FFC, is a single-engined high-wing utility aircraft with STOL characteristics and is able to operate safely off sub-standard airstrips. The turbo prop engine (PT6A-20 or PT6A-27) over the years has proven to be extremely reliable, most engines reaching a TBO of 3500 hours in the agricultural role.

The maximum take-off weight of 6100 lbs enables the aircraft to carry a maximum payload of 2590 lbs (309 U.S. gal). The Pilatus is an extremely manoeuvrable and rugged aircraft, making it a suitable piece of farm machinery.

THE TRACK GUIDANCE SYSTEM (T.G.S.)

AGRI-FIX, the track guidance system used, is manufactured by Decca Survey Systems, Inc., Houston, USA. It is an aircraft track guidance system designed for use in aerial application. The system comprises two portable ground transmitting stations (Master and Slave). The power supply input to each station allows for the use of batteries or mains supply.

The aircraft is fitted with a small antenna and receiver which is coupled to a flying instrument display in front of the pilot. The display provides indications to assist in flying at predetermined parallel flight track intervals, thereby obviating the need for ground marking.

The Master and Slave stations transmit a phase-locked hyperbolic signal pattern at a fixed frequency. The hyperbolic pattern consists of a series of half-phase position lines and - depending on the actual frequency used - these lines occur at intervals of 80 to 90 metres. The aircraft receiver is basically a phase-measuring device which drives an instrument display indicating where the aircraft is in relation to the pattern lines. With the use of display, the system can be used by the pilot to maintain the aircraft on predetermined flight tracks down to 1/50 lane intervals and can, therefore, be used to fly at any track width desired. The aircraft can track only by following the direction of the hyperbolic lines. Thus, the position of the ground stations (or base line) needs to be adjusted in azimuth to provide a signal lattice with the desired direction over the spray area.

On this operation, the stations were deployed at a distance of 45 km. The Master station was sited near Chicken Dubh (04° 37'W 58° 19'N) and the Slave Station in the Achentoul block, Helmsdale Forest at 03° 56'W 58° 14'N, giving a spray direction of 020° and 200°. This direction was chosen because of the situation of the large areas sprayable with Agri-Fix. The system, of course, does have its limitations in hilly country where contour flying takes precedence because of lane bending, flight safety or aircraft performance. However, the advantages outweighed the disadvantages on this operation.

The LV spraying was carried out at tracking intervals of 25 metres and the ULV spraying at 50 metre tracking intervals. On a small trial plot of 40 ha (100 acres) tracking intervals of 100 metres were used with extremely good results.

THE SPRAY SYSTEM

The aircraft was equipped with six Micronair AU3000 rotary atomisers with a 25° blade angle. The ground support equipment, supplied by Heliscot, was able to load the aircraft at a rate of 100 gal/minute.

The system, manufactured in stainless steel and Teflon, is most resistant to all chemicals and provided:-

- Wind-driven pump with synchronised variable pitch fan head.
- External pump source connection (for ground wash-out).
- Easy cleanable filter.
- Re-circulation bypass.
- Electrically actuated emission rate control valve.
- Pressure indicator.
- Accurate flow meter system with cockpit indicator.
- From one up to six electrically operated, individually or collectively wind-driven micronairs. These micronairs are equipped with an exclusive shut-off device, ensuring an instant and accurate ON-OFF function.
- Quick change capability from Micronair to Boom and Nozzle system.
- Electrically operated, pneumatically actuated high-speed ON-OFF valve.

Emission rate control as well as ON-OFF operation are finger-tip controls, operated by column-grip fitted buttons for safety and comfort. A hydraulic brake system stops pump and Micronairs from rotating for take-off and landing and ferry flights.

This system enables the pilot to apply any aerial spray requirement with the very best efficiency from High Volume right down to Ultra Low Volume. The pump, bypass, and Micronairs can be adjusted to any required setting needed for the various application requirements.

Emission range is from 3 litres/min to 300 litres/min, while the controllable droplet size range is from 50 to 450 microns.

THE LV AND ULV OPERATIONS

Calibration flights were flown on the 6 June, with satisfactory results. A final check flight was made before spraying commenced on 12 June, again proving satisfactory.

Due to the extensive area involved and the difficulty experienced in locating suitable airstrips, Dounreay airfield was utilised on 12-16 June to fly all ULV areas and immediately accessible LV blocks. A grass field near Achentoul was used thereafter.

Weather conditions prevented spraying on 9, 10, 11 and 20 June and restricted operations on 15 (wind), 17 and 18 (morning fog) and 19 (wind).

The ULV rate, 1 litre/ha, enabled an area of 800 ha (2000 acres) to be treated per sortie of 800 litres, while a similar load treated only 40 ha (100 acres) at the LV rate.

The ULV areas were, on average, about 29 miles from Dounreay, giving a total flight time of 2 hr 10 min. Output was about 309 ha per flight hour.

The LV areas were nearer the Achentoul airstrip - about 10 miles on average and were covered in 42 hours. Output was 88 ha per flight hour.

Table 6.1 gives operational details.

Table 6.1

Spraying Operational Details

Forest	Dates & Times June 1978		Mean Wind Direction/ Speed (Knots)	Ambient Air Temp. ^{o}C	ULV/LV	Remarks
Fiag	12	1420-1555	350°/20	10	ULV	Moderate turbulence
Watten	12	1630-1715	350°/20	10	LV	
Truderscaig	13	0925-1135	360°/11	8	ULV	
Strathy	13	1235-1335	360°/10	8	ULV	
Strathy Trial Plots	13	1425-1455	360°/10	8	ULV	Dye mixed with chemical
Achrugan	13	1550-1915	360°/10	8	LV	
	14	0710-1145	120°/10-140/15	6-8	LV	
Strathy Trial Plots	14	1200-1230	120°/10	8	LV	Dye
Rosal	14	1825-1945	130°/16	9	LV	
	15	0730-0830	130°/20	8	LV	Weather stopped spraying
	16	0855-1930	060°/10-010/15	8-13	LV	
	17	1555-1625	010°/10	12	LV	
Badanloch/Achentoul	16	0600-1130	060°/10	8	LV	
Achentoul	17	0950-1005	010°/10	8	LV	
Syre	17	1010-1550	010°/10-15	10-13	LV	
Creag Dubh	17	1645-1800	360°/20	14	LV	
Achentoul	18	1155-1245	010°/5	8-9	LV	
Borrobol	18	1455-1920	330°/10	14-15	LV	
Rimsdale	18	1005-2040	330°/10	9-15	LV	
Suisgill	19	0920-1025	240°/15-25	9	LV	Wind stopped spraying
	21	0300-0700	calm/lt & var	4-7	LV	
Achentoul Estate	21	0705-1100	330°/5	7-8	LV	
Shelter Belts	21	0955-1345	330°/5	8-11	LV	
Chicken Dhu and Barren Ridge	21	1140-1330	030°/5	10	LV	

Chapter 7

COLLECTION OF SPRAY DROPLETS AND CHEMICAL BY LARVAE, FOLIAGE AND GROUND DEPOSITION

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INTRODUCTION

The Thetford trials (Chapter 2) confirmed that the performance specification (a 95 per cent probability that each 20mm^2 of foliage surface would collect at least one droplet of about 50 µm diameter) could be met by an application rate of one litre/ha, provided that the liquid employed was such that the droplet diameter at the target did not differ substantially from its diameter at the atomiser. Accordingly, the following spraying parameters were recommended.

RECOMMENDED SPRAYING PARAMETERS (ULV)

Spray mixture	:	6 parts Fenitrothion 50 EC in 4 parts of Butyl dioxytol (ie 30 per concentrate of active ingredient).
Atomiser	:	2, Micronair AU 3000, standard 5" cage, fitted with 13.5" flat blades set at 25°.
Application rate	:	1 litre per hectare.
Release height of spray	:	6m above canopy top.
Lane separation	:	50m
Emission rate	:	15 litre/min (viz. 7.5 litre/min per atomiser, assuming spraying speed of 180 km/h).

This recommendation for an application at ULV rates by incremental spraying and turbulent dispersal, constituted a first usage of such a technique in Britain and the possibility was immediately raised by the clearing authorities that the use of small droplets under turbulent conditions might place at risk people and animals outside the target area. Consequently the Ministry of Agriculture gave limited clearance, under the Pesticide Safety Precautions Scheme (PSPS), for the method, the use of which had to be confined to where the following conditions could be observed:

> "The aerial ULV application should not exceed 1500 ha and must be restricted to selected sites which are at least 2 miles away from roads and human habitation. The remaining areas should be sprayed using conventional aerial spraying techniques .... at conventional low volume rates".

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The permission provided no guidance regarding the parameters to be observed in conventional, low volume application. Since the most important hazard to be minimised was that to fish, and streams were likely to be contaminated by big droplets which were not intercepted by the foliage, it was decided that LV applications should also be made by Micronair atomiser. This decision would also have economic advantages in that both LV and ULV treatments could be applied by the same equipment. Accordingly, the following parameters were suggested for the LV spraying.

APPROVED SPRAYING PARAMETERS (LV)

Spray mixture	:	3 parts Fenitrothion 50 EC in 97 parts of water.
Atomiser	:	6 Micronair AU 3000, standard 5" cage, fitted with 13.5" flat blades set at 25°.
Application rate	:	20 litre/ha.
Release height of spray	:	3m above canopy top.
Lane separation	:	25m
Emission rate	:	150 litre/min (25 litre/min per atomiser)

(assuming spraying speed of 180 km/h)

Although the Thetford trials showed that adequate deposit densities on foliage could be achieved up to 50m from the droplet source, use of such a lane-separation at the flight speed of the Porter Pilatus would have required an emission rate of 300 litres/min and this was beyond the capacity of the pumps.

THE FORESTS

The forests are described in Chapter 1 . They covered 5020 ha in 18 blocks, within a total area of some 1000 sq. km. The blocks varied in size from 40 ha to over 1000 ha, in undulating country dissected by steep-sided burns. Long dimensions sometimes exceeded 5 km, and blocks were separated on occasions by hills of up to 500m in height.

The dimensions of the forest blocks made accurate track guidance essential for accurate spraying. The distribution of the blocks and the poor road communications made a largely airborne electronic system an economic dictate. The terrain was not suitable for the construction of temporary loading strips and the only airfield was located some 30 km distance from the furthest block.

THE AIRCRAFT

The spraying techniques authorised by the PSPS clearance, and the terrain made it essential that the aircraft employed possessed the following capabilities:

- at least 500 litre pay load with 2 hours endurance
- 6 Micronair atomisers
- accurate metering of the spray liquid to provide flow rates from 7.5 ± 0.5 to 25.0 ± 0.5 litres/min per atomiser

- electronic track guidance system to provide an overall accuracy of ± 20m of the chosen track.

The spray contractors, Heliscot of Dalcross Airport, Inverness, provided a Pilatus Turbo Porter for this purpose chartered from CIBA-Pilatus, Stans, Switzerland, the aircraft being fitted with Decca Agri-Fix Track Guidance equipment (Walker 1973).

COMPARISON OF LV AND ULV APPLICATIONS

OBJECTIVES

Since monitoring of the whole project area was not possible, it was decided to make a detailed comparison of the results in two blocks, one sprayed at LV and the other at ULV rates, based on the following assessments:

- mortality amongst larvae of *Panolis flammea*,
- the distribution of spray droplets on needles, on branches within trees, and between trees through the length of the block,
- the quantity of fenitrothion collected by buds, needles and larvae,
- the ground deposit.

These assessments were achieved in a single trial on 40 ha selected for each treatment, the spray liquid being marked with insoluble fluorescent tracers.

SAMPLING FOR LARVAE

Before spraying, 200 larvae were collected from each treatment and placed on clean foliage in plastic containers. Immediately after spraying a further 200 larvae were collected. They were then distributed as follows:

Table 7.1

Foliage	*Larvae* *Unsprayed*	*Sprayed*	*Total*
Unsprayed	100	100	200
Sprayed	100	100	200
TOTAL	200	200	400

In addition immediately after the spray, 5 batches, each of 25 larvae, were collected from the ULV and 2 from the LV plot and placed in vials containing 10 ml ethanol, for chemical analysis of spray collection.

SAMPLING STATIONS

Before spraying, sampling stations were established in each block as follows:

Strathy (ULV)

The block, a very narrow one (about 2 km x 250m), was located on the side of a burn which had a slope varying from 1:1 to 1:2, the bottom of the slope being planted to Sitka spruce and thus permitting sampling lines of not more than 50m of Lodgepole pine. Eight such sampling lines, each separated by about 100m, were selected and along each sampling line were established 5 stations each about 10m apart.

Badanloch (LV)

The whole block occupied 100 ha and lay on an east facing slope. In the centre of this block 4 sampling lines were established, each separated by about 100m. Along each sampling line 10 stations were established each separated by about 10m.

Sampling of Foliage

After spraying, a tree at each station was felled and its overall height measured. Foliage samples, each consisting of the terminal 20-30 cm of branch containing the foliage bud of the current season and needles of the previous season's growth, were taken as follows:

Topmost nodes	:	branch terminals from north, south, east and west aspects,
One third from top terminal bud	:	branch terminals from north, south, east and west aspects.

Thus from the ULV plot an upper and lower sample from each aspect was taken from each of 5 stations in each of 8 lines and from the LV plot, similar samples from 10 stations in 4 lines, giving a total of 320 foliage samples from each plot. Each sample was placed in a labelled paper bag. In the field laboratory, 20 pairs of needles were removed from each sample of twin lines A and C (ULV plot) and from line G (LV plot) and placed in vials for subsequent chemical analysis, thus giving a total of 40 samples from each plot.

Sampling for Ground Deposit

At each station pieces of Bristol board, each measuring 5 cm x 5 cm, were placed on the ground before spraying at aspects north, south, east and west, thus giving a total of 160 ground samples from each of the LV and ULV plots.

Spray Liquid

The following spray mixtures were applied:

ULV: 40 litres of spray mixture containing:

24 litres Fenitrothion 50 EC
16 litres Butyl dioxytol
1 kg (2.5%) Rocket Red 20 fluorescent pigment
(particle size 0.1 µm)

LV: 800 litres of spray mixture containing:

24 litres Fenitrothion 50 EC
1 kg (0.125%) Lumogen LT fluorescent pigment
(particle size 2 µm 1 ± 2)

water to 800 litres

APPLICATION

For the ULV and LV trial, it was decided to employ for the ULV 'sequential application' (Joyce 1976). In incremental spraying, the dose collected by the target is incremented due to overlapping swaths by contributions from 2-3 successive spray runs separated in time by the speed of traverse of successive spray runs. Sequential spraying connotes the deliberate separation of these increments in time. In practice, in Strathy, this meant that half the spray liquid was applied on day 1 using a lane-separation of 100m and the second half on day 2, again using a 100m lane-separation, both spray runs being made at a height (6m above the canopy) selected for a 50m lane-separation. This separation in time of the application of two half doses provides opportunities on two dissimilar occasions instead of one for spray droplets to hit their targets, and the longer the separation in time the more chances are available for different meteorological conditions and less for overdosing of the target.

In the case of the ULV plot the larvae collected after spraying in accordance with Table 7.1 were collected on day 1, after application of the first half dose.

EXAMINATION FOR DROPLET COLLECTION

The foliage samples and Bristol board cards were brought to Cranfield and examined under a 100 watt (Black Light) UV lamp (Magnaflux Limited). Both dyes collected on the Bristol boards fluoresced brilliantly, but droplets were too numerous to count, though clearly the number were much higher on the cards exposed to LV than those exposed to ULV spray. The following scores were therefore adopted:

Table 7.2

ULV		*LV*	
Grade	*Score*	*Grade*	*Score*
a (1-10)	5	V-L 1-10	5
b (11-20)	15	L 100	50
c (21-30)	25	M 100	400-250
d (31-40)	35	H 400	500
e (41-50)	45		
f (51-60)	55		

On the foliage, however, the Rocket Red used in the ULV sprays failed to produce fluorescent markings of the droplets. It must be assumed that the small particles of the pigment were absorbed into the tissue which was sprayed whilst it was still alive on the tree. This contrasted with the stains which remained easily visible for weeks after spraying on branches which had been severed from the trees before spraying. On the contrary, the droplets of the LV spray, marked with Lumogen, were brilliantly visible but usually in too large numbers to be countable. Accordingly samples of 5 pairs of needles were taken at random (in white light) from the sample branch. It was found that on some, droplets could be counted, but on others, they were too numerous. Accordingly the following procedure was adopted.

Low coverage 25% droplets counted
M = Medium coverage 25-50% score 150
H = High coverage 50% score 250

WEATHER

During the period covered by the operation, the weather conditions over northern Scotland were characterised from 10-13th July by NW winds of 20 knots at Dounreay, gusting to 38 knots, with occasional showers. On 13th June, the day that ULV spraying began at Strathy, the wind slackened, and the approach of an anti-cyclone brought sunny, dry weather with northerly winds of 7-8 knots. The dry bulb temperature at spraying was 11.5°C, on 13th June, but reached 14.0°C on 14th June, whilst the wind on 14th June veered to the SE and increased to 13 knots.

On the day of the LV spraying, 16th June, winds were easterly, 1-6 knots, with dry bulb temperatures of 10°C and wet bulb 8°C.

No detailed meteorological measurements were taken in the forests during spraying because of the great variability of wind velocities due to the undulating nature of the terrain, dissected by burns, and the variable forest canopy.

The weather again deteriorated after 17th June with the approach of a cold front bringing periods of rain and drizzle and northerly winds of 9-14 knots at Dounreay.

RESULTS

DROPLET COLLECTION BY THE CANOPY

The samples taken permitted an analysis of the variance of deposits in relation to wind aspect (north, south, east and west), height (topmost branches and branches at 2/3 height of tree), and trees within lines and between lines.

Examination of the frequency with which different numbers of droplets were recorded on needles showed clearly two groups, one with a mode of about 30 per pair of needles and the other with a mode of about 150 per pair of needles (Figure 7.1). These two groups were recorded equally in each aspect, 25.0 per cent, 25.4 per cent, 23.9 per cent and 25.7 per cent being recorded on the north-, west-, south- and east-located branches respectively (Table 7.4). Further consideration of the distribution of droplets on the branches showed that whilst the branches from each aspect were equally exposed to the spray cloud, individual branches had an upwind, exposed aspect with the bigger droplet collection, and a downwind, protected aspect with a smaller droplet collection.

An analysis of variance of droplet collection was then made of the mean number of droplets per needle pair irrespective of aspect (Table 7.5).

Significant differences in spray deposits were evident between individual trees, between the upper and lower levels, between stations within lines and between lines, but these differences are of less interest than the probability of any needle receiving less than a certain level of deposit. This was calculated by plotting the frequency with which different levels of deposit were achieved onto arithmetic probability paper and the results are tabulated (Table 7.6). From this table it can be seen that if a 95 per cent kill were required, this could be achieved if the lethal dose were less than about 40 droplets per needle pair (or, on the scale employed, about 25 per cent coverage).

CHEMICAL ANALYSIS OF DEPOSITS

The deposits of fenitrothion on needles and buds is tabulated as μg/g on fresh vegetation (Table 7.7). As in the case of the droplet collection, chemical determination of the quantity of fenitrothion collected by the foliage and buds failed to reveal significant differences in relation to aspect in either the LV or ULV treatments. The needles exposed to the ULV spray, however, collected over 50 per cent more fenitrothion than those exposed to the LV spray and this difference was significant at the 1 per cent level of probability. On the other hand, the buds exposed to the ULV spray collected 34 per cent less fenitrothion than those exposed to the LV spray and this difference was significant at P = 0.05.

The trees of Strathy, where the ULV treatment was applied, were of a different provenance from those of Badanloch where the LV treatment was applied. The mean length of samples of needles from Strathy and Badanloch was 45mm and 28mm respectively. The similar vegetative growth in the Strathy and Badanloch samples was shown by the average numbers of needles of the 1977 foliage which were 92 and 96 per branch respectively. Thus the area of needles available for intercepting the spray cloud may have been greater on Strathy than on Badanloch although the numbers of branches per ha was not estimated. On the other hand, the buds, representing the 1978 foliage, had a mean length of 140mm and 170mm in Strathy and Badanloch respectively, though the Strathy buds weighed a little more. Being essentially cylindrical in structure their intercepting surface, represented by their plan area, is a function of their diameter and therefore was little different in the two Blocks. Accordingly, the efficiency with which the spray cloud was attenuated in the two areas can be compared by an analysis of the total weight of fenitrothion collected by needles and buds irrespective of their weight (Table 7.8).

Table 7.7 suggests that the ULV spray was more available for collection by the major collecting surfaces, the needles, whilst Table 7.8 suggests that the foliage in Strathy was more efficient, through its greater surface area, in extracting droplets from the spray cloud.

RELATIONSHIP OF DROPLET TO FENITROTHION COLLECTION

This relationship, which could be sought only in the LV treatments at Badenloch, was investigated by an analysis of co-variance between the mean number of droplets per 5 pairs of needles and the mean quantity of fenitrothion recorded on 5 pairs of needles. The analysis is recorded in Table 7.9, and the regression plotted in Figure 7.2

The mean quantity of fenitrothion recorded in 5 pairs of needles in the LV treatment was 5.9 μg or 590 ng per needle. The mean number of drops was 50 per needle. Hence each droplet contained about 12 ng of fenitrothion, but was obtained from a spray formulation containing only 1.5 per cent active ingredient. It can be inferred from this calculation that the droplets collected by the pine needles were emitted as droplets of an average diameter of about 120 μm. Assuming that by the time they had reached the target they had lost all their water (viz 98.5 per cent of their volume), their volume on collection would have been about 30 μm diameter. The deposit on the Badenloch foliage thus was derived from not more than about 8 per cent of the total emitted number of droplets, although they contained over 80 per cent of the total chemical applied.

On the other hand, the needles from Strathy collected an average of 1.0 µg or 1030 ng per needle, in droplets whose size at the target was very little different from that at the atomiser. Because of the absence of evaporation, all the drops produced were available to make their contribution to spray collection, that is 20 per cent more chemical than was available in Badenloch.

SPRAY COLLECTION BY LARVAE

The results of the chemical analysis of the larvae are summarised in Table 7.10. The total amount of chemical collected per larvae was not significantly different in the ULV and LV treatments, but the larvae in the LV plot with a mean weight of 108 ng were nearly 4 times bigger than those in the ULV plot with a mean weight of 28 ng. Thus the larvae in Strathy (ULV) collected over 3 times the amount of chemical (expressed as fenitrothion per gram of larvae), compared with those from Badanloch (LV), but, due to the small number of samples from the LV sprayed plot, this difference could have been due to chance.

LARVAL MORTALITY IN SAMPLES

Unsprayed larvae placed on foliage sprayed at both LV and ULV rates all died within 24 hours. Larvae, collected within 15 minutes of completion of the application of the first half dose to the ULV plot and placed on unsprayed foliage, were examined 24 hours later and 94 per cent were dead. The remainder died within 36 hours. Larvae collected and treated similarly after the LV application all died within 24 hours. Amongst unsprayed larvae placed on unsprayed foliage, the mortality recorded after 14 days was 1 per cent.

It appeared therefore that in both the LV and ULV treatments a contribution to mortality was made by both direct and indirect action (contact or stomach entry or both).

GROUND DEPOSITS

The fraction of the chemical applied to the trial plots which was not intercepted by the tree canopy and thereby contributed to ground contamination, was estimated by analysis of the droplets recorded on the Bristol cards placed on the ground beneath the trees. The results of the counts of droplets is summarised in Table 7.11.

In both plots the ground deposits were remarkably even. Although significant differences could be established between the deposits recorded at different aspects, and between lines, and stations within lines, these were small and unimportant.

In the ULV sprayed plot, where the overall mean deposit was 0.54 ± 0.002 drops/sq.cm, the drop sizes varied from less than 11 to 210 µm diameter with a mode between 80 - 150 µm diameter and average diameter of 117 µm. Because the formulation was non-volatile each droplet contained 30 per cent active ingredient. The overall ground deposit could thus be estimated at 13.5g/ha. Over 90 per cent of this deposit was derived from droplets in excess of 150 µm diameter which represented 38 per cent of the total numbers of droplets recorded on the cards, but less than 3 per cent of the droplets emitted.

In the LV sprayed plot, where the overall mean deposit was 14.7 drops/sq. cm, the drop sizes recorded varied from 11 to 520 µm diameter with a mode between 100 & 200 µm and an average drop diameter of 163 µm. These droplets at formation contained 1.5 per cent active ingredient. They experienced a fall of about 15m during which evaporation of water took place. Droplets which began life below about 150 µm would lose their water more or less completely, so that their concentration of active ingredient was 100 per cent. Those which began life larger than 350 µm would show little change of size, so that their concentration of active ingredient remained at 1.5 per cent. The overall ground deposit from the LV spray, after taking into account evaporation, could be estimated at 115 g/ha, that is over eight times that in the ULV sprayed plot.

DISCUSSION

The Forestry Commission entomologists conducted an independent survey to estimate larval mortality in the two treatments. They concluded that in both treatments the mortality was 97.5 per cent. Both treatments were equally successful in protecting the trees in both plots.

The Ministry of Agriculture's Plant Pathology Laboratory recorded the spray collection by volunteers outside the sprayed plots and detected no significant differences between the two treatments, though in both cases the quantity of chemical collected on clothing and in respirators worn by the volunteers was regarded as trivial. It was not possible, however, from the data to determine the total quantity of chemical which failed to be collected in the target area. Experiments conducted elsewhere (eg Lawson 1977) suggest that this was unlikely to exceed 1 per cent of the total applied in the case of the ULV spray. In the case of the LV spray, the amount of fenitrothion and the number of droplets collected by the pine needles suggest that all droplets less than 120 µm in diameter lost all their water by evaporation and probably failed to impact on the needles. These droplets represented about 20 per cent of the total volume applied.

A rough balance sheet can therefore be constructed of the fate of the chemicals in the treatments.

Table 7.3

Aerial Spraying against *P.flammea*
The Fate of the Fenitrothion Applied (9 g/ha)

	ULV	*LV*
Applied	300	300
Lost outside target area	3	60
Lost to ground	13.5	115
Collected by target surface	283.5	125
Percentage collected by targets	94.5	41.7

That is to say the target surfaces in the ULV treated plot collected over twice as much chemical as those in the LV sprayed plot, an approximation which accords reasonably well with the chemical analysis of chemical on needles in which the ULV treated needles collected nearly 75 per cent more chemical than the LV treated needles; when account is taken of the different amount of foliage in the two plots.

It is clear, however, that both treatments were overdosed with fenitrothion, the first half of the ULV treatment at 150 g/ha over a 100m swath providing 100 per cent mortality of *P. flammea* larvae in 36 hours. Table 7.3 provides the estimate that there was a 98 per cent chance that each needle would collect a dose exceeding 20 drops per pair of needles. This equates on our measurements to 120 ng per needle, or about 2 ng/sq. mm of needle surface. Larvae at spraying exposed a surface area of about 100 sq. mm and therefore should have collected 200 ng of fenitrothion. The larvae on the ULV plot weighing 28 mg therefore collected about 8 ppm and on the LV plot the larvae, weighing 108 mg collected about 2 ppm. Evidently the LD 50 of larvae to fenitrothion is of the order of 1 ppm.

The trial showed clearly that there is no advantage in LV spraying whereby the volume rate of application is increased 20 times by adding water. The evaporation of water from small droplets results in loss of chemical outside the target area, and the presence of big droplets due to a coarsening of the v.m.d. resulted in greater ground deposit. These disadvantages of LV spraying were minimised in our trials because Micronair atomisers were employed enabling the LV treatments to provide a v.m.d. of about 200 µm. Nozzle equipment normally employed for this type of operation would give a v.m.d. of 300-350 µm, thus exacerbating losses to the ground.

On the contrary, LV rates of application hindered the operation. Thus the Pilatus Porter, carrying a load of 800 litres, discharged this load in just over 5 minutes of spraying over 40 ha when spraying at LV rates. The same load was applied at ULV rates to 800 ha in 53 minutes of spray time. In both LV and ULV treatments the biological effect was achieved by small droplets ($<$ 50 µm diameter) which were dispersed downwind by natural turbulence. Both rates of application could have been flown at lane intervals of 100m, though, in the case of LV rates, this would have required an emission rate of 600 litres/min which is in excess of the capability of the pumps and atomisers.

Thus, though the mean ferry distance for the ULV treatments was 100 km, so that each sortie occupied 2 hour 10 minutes, a work output of 310 ha/h. was achieved. The whole operation could have been completed in the first two good days, viz 12-13th June, and thus saved the trees from one further week of damage and reduced the cost of charter of the aircraft.

It should be noted that the ULV applications in this trial can be regarded as synonymous with CDA (controlled droplet application).

SUMMARY

In an aerial spraying operation in Sutherland, northern Scotland, some 5000 ha of Lodgepole pine at risk to damage from larvae of *P. flammea* were treated with Fenitrothion 50% EC at a rate of 300 g active ingredient/ha,1150 ha being treated at ULV rates (1 litre/ha of 30 per cent active ingredient diluted with Butyl dioxitol) and 3550 ha at LV rates (20 litres/ha, 1.5 per cent active ingredient diluted with water). The two treatments were compared in trials over plots of about 40 ha.

Analysis of chemical collection by pine needles showed that those exposed to ULV rates collected nearly 75 per cent more active ingredient than those exposed to LV rates (590 ng compared with 1030 ng per needle). The larvae in the ULV plots collected three times as much active ingredients as those in the LV plots (1285 ng compared with 409 ng/g larvae). The amount of chemical lost to the ground was over 8 times greater in the LV compared with the ULV sprayed plot (13.5 compared with 115 g/ha).

97.5 per cent mortality amongst *P. flammea* larvae was recorded 36 hours after spraying and there were clear indications that half the dose applied at ULV rates would have provided adequate control.

Despite a total ferry of 100 km, compared with 30 km from the LV spraying, the ULV spraying, at a work rate of over 309 ha/h, could have completed the operation in 14 hours. The LV spraying achieved a work rate of 88 ha/h and required over 50 hours of flying which occupied 13 days.

Airborne drift was not measured, but measurements of the contamination of observers outside the sprayed areas revealed no differences between the treatments, in both cases the amount of chemical collected on clothing and filtered through respirators being trivial.

Spraying at ULV rates was better than at LV rates in all respects. ULV in this trial is synonymous with CDA (controlled droplet application).

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Table 7.4

Aerial Spraying Against *P. flammea*
Frequency of Droplet Collection by Needles
(Total Number of Droplets Counted on Pairs of Needles from 320 Samples)

Class and Mean	*Frequency* *N*	*W*	*S*	*E*	*Total*	*Total Droplets* *N*	*W*	*S*	*E*	*Total*
0-20(10)	84	83	97	95	359	840	830	970	950	3590
21-40(30)	84	93	78	93	348	2520	2790	2340	2790	10440
41-60(50)	51	43	49	29	172	2550	2150	2450	1450	8600
61-80(70)	19	16	15	11	61	1330	1120	1050	770	4270
81-100(90)	7	7	6	8	28	630	630	540	720	2520
M = 150	135	134	140	137	546	20250	20100	21000	20550	81900
H = 250	20	24	13	27	84	5000	6000	3250	6750	21000
Total	400	400	398	400	1598	33120	33621	31600	33980	132320

Table 7.5

Aerial Spraying Against *P. flammea*
Mean Number of Droplets Per Pair of Needles

Station	*Canopy Top Lines* *E*	*F*	*G*	*H*	*Mean*	*Mid Canopy Lines* *E*	*F*	*G*	*H*	*Mean*	*Station Mean*
1	113	27	115	109	91.0	93	51	74	54	68.0	79.5
2	104	42	138	32	79.0	60	108	65	12	61.2	70.1
3	111	143	103	25	95.5	119	75	57	89	85.0	90.2
4	180	180	109	102	142.7	110	60	41	45	64.0	103.3
5	90	92	69	133	96.0	62	64	29	41	49.0	72.5
6	94	162	136	103	123.7	103	105	66	22	74.0	99.0
7	182	166	113	31	123.0	91	129	96	13	82.3	102.6
8	183	107	134	68	123.0	47	92	52	28	54.7	88.9
9	118	136	62	74	97.5	40	96	21	16	43.3	70.4
10	127	66	23	28	61.0	51	24	13	12	25.0	43.0
Mean	130	112	100	70	103.0	78	80	51	33	60.5	82.0

Standard Deviation $\pm$ 26.6

Standard Error Grand Mean $\pm$ 3

Co-Efficient of Variation 26%

Standard Error Level Means $\pm$ 4

Standard Error Line Means $\pm$ 13

Standard Error Station Means $\pm$ 8

Table 7.6

Aerial Spraying Against *P. flammea*
The Probability that Needles have Collected Minimum Dosages

Level (Droplets/Needle Pair)	*Probability that Stated Level is Exceeded*
More than 20	98
40	94
60	85
80	73
100	57
120	38
140	22
160	10
180	4

Table 7.7

Aerial Spraying Against *P. flammea*
Deposits of Fenitrothion in µg/g Fresh Vegetation

Method	*Needles and Aspect*					*Buds and Aspect*				
	N	*W*	*S*	*E*	*Mean*	*N*	*W*	*S*	*E*	*Mean*
LV	10.3	12.7	15.4	10.8	12.6	11.6	12.3	10.2	12.7	11.7
ULV	17.1	19.4	18.1	24.2	19.7	6.0	7.4	9.9	7.5	7.7
Differences	6.8	6.7	2.7	13.4	7.1	-5.6	-4.9	-0.3	-5.2	-4.0

	Needles	Buds
Standard Deviations	±15.5	± 6.6
Standard Error Overall Means	± 1.7	± 0.75
Standard Error Aspect Means	± 2.5	± 1.1
Standard Error Difference	± 1.3	± 0.2

Table 7.8

Aerial Spraying Against *P. flammea*
Analysis of Fenitrothion
Collected by 20 Pairs of Needles and Single Buds (µg)

	LV	*ULV*
Mean Deposit on 20 Needles	23.6	41.2
Mean Deposit on Single Buds	17.5	18.8

Needles		Buds	
S D	± 2.6	S D	± 1.8
S E	± 0.41	S E	± 0.38

Table 7.9

Aerial Spraying Against *P. flammea*
Analysis of Co-Variance Between Droplets (X)
and Fenitrothion (Y) on 5 Pairs of Needles

Source of Variance	*Degrees of Freedom*	*X*	*Y*	*Mean Squared XY*
Stations	9	1429.45	25.88	135.24
Aspect	3	260.63	1.95	5.28
Residual	27	243.75	6.85	20.10
Total	39			

$\bar{X}$ = 50 $\bar{Y}$ = 5.9 r = 0.4917**

b = 2.93 X = 33 + 3Y

Analyses of Regression

Source of Variance	*Degrees of Freedom*	*Sums of Squares*	*Mean Square*	*F Ratio*
Regression	1	1591.34	1591.34	7.97**
Deviations	25	4990.06	199.60	
Total	26	6581.40		

Standard Deviation of Estimate of Y = 14.13

Standard Error of Estimate of Y = 2.23

** significant at P = 0.01

Table 7.10

Aerial Spraying Against *P. flammea*
Chemical Analysis of Larvae After Spraying

Batch	Total Chemical on Batches of 25 larvae (μg)		Batch	ng per g of larvae	
	ULV	*LV*		*ULV*	*LV*
1	5.7	2.3	1	950	396
2	6.9	2.1	2	1725	418
3	2.2		3	468	
4	2.1		4	600	
5	5.0		5	2683	
	22.4	4.4		6426	814
Mean	4.5	2.2		1285.2	407
Standard Error of Means	± 1.96	± 0.10		± 824	± 11
Pooled SD	± 1.96			± 824	
	1.39 (not significant)			1.27(not significant)	

Table 7.11

Aerial Spraying Against *P. flammea*
Ground Deposits (Droplets per Card of 25 cm^2)

Aspect Mean	*North*	*West*	*South*	*East*	
ULV	13	12	14	13	
LV	364	384	376	344	
Line Mean	*A*	*B*	*C*	*D*	
ULV	11.5	11.0	13.5	12.0	
	18.5	13.0	14.5	13.5	
	E	*F*	*G*	*H*	
LV	356.5	439	390	282.5	
Station Mean	*1*	*2*	*3*	*4*	*5*
ULV	14	10	8	16	6
Station Mean	*1*	*2*	*3*	*4*	*5*
LV	422	318	362	359	390
	6	*7*	*8*	*9*	*10*
	347	406	362	259	381

	ULV	*LV*
Overall Mean	13.5	367
Standard Error Overall mean	± 0.06	± 6
" Aspect Mean	± 0.12	± 12
" Line Mean	± 0.17	± 12
" Station Mean	± 0.19	± 19

Figure 7.1

Deposition of droplets on needles at Badanloch (LV Spray)

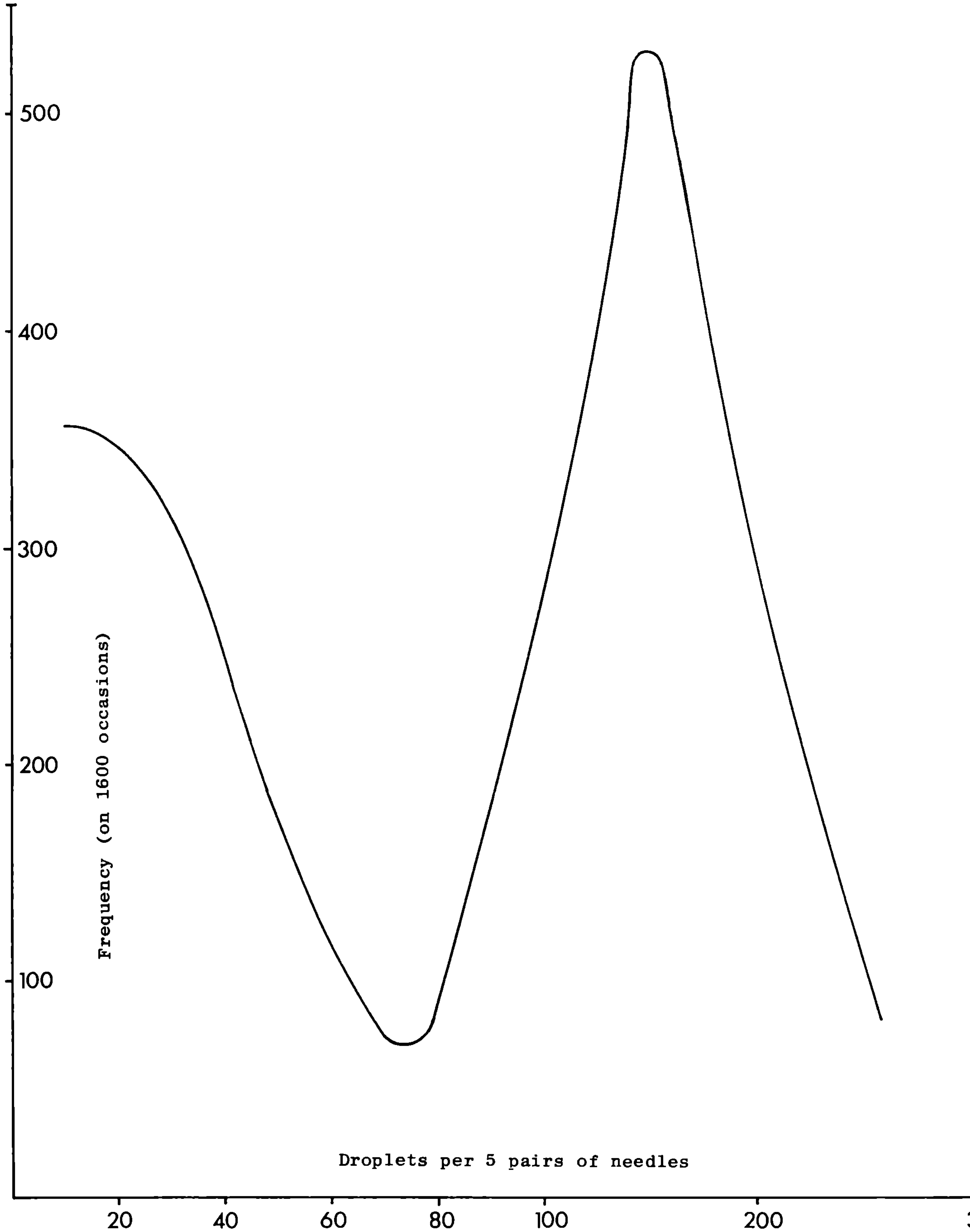
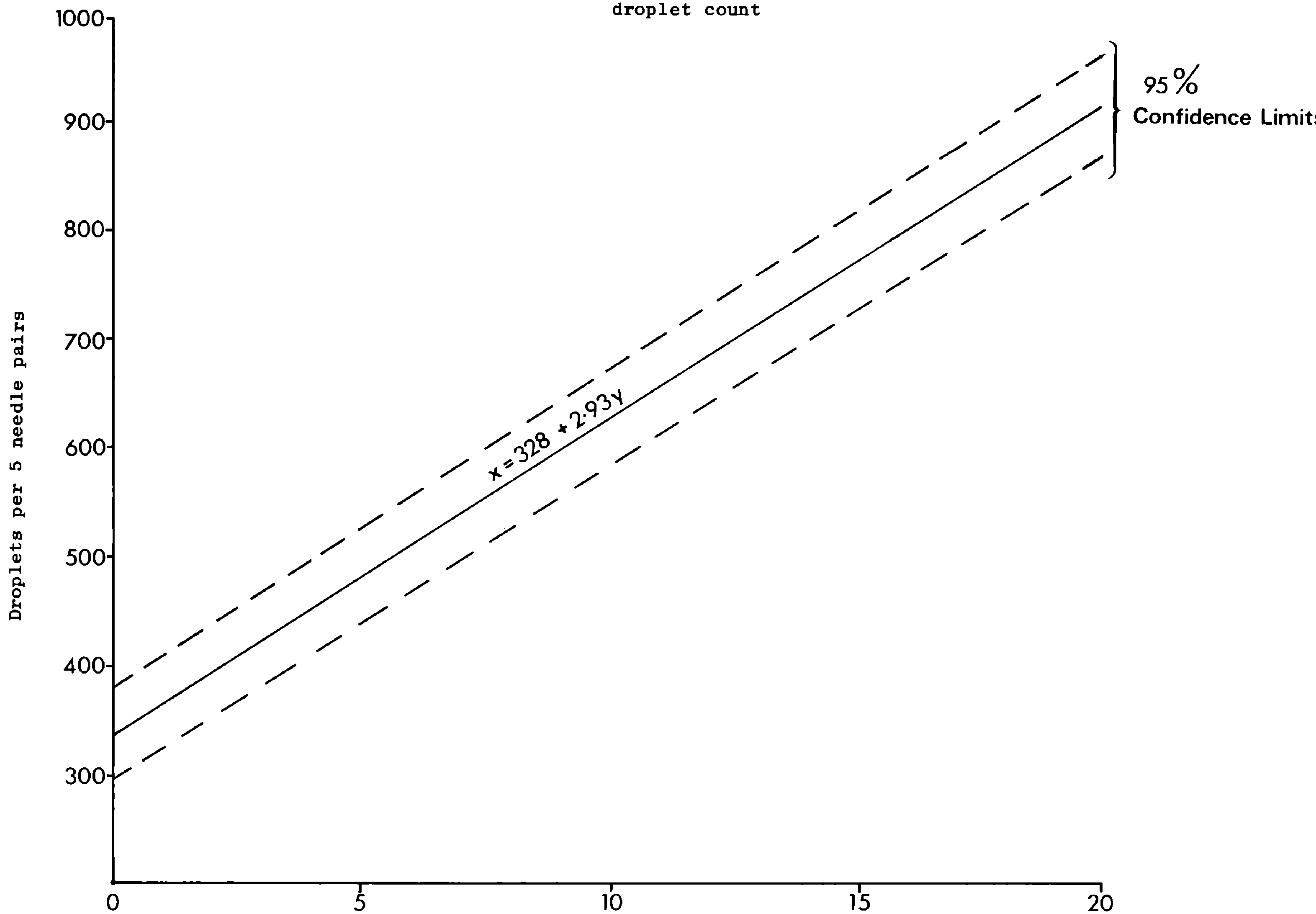


Figure 7.2 Relationship of chemical analysis and droplet count



Chapter 8

LARVAL MORTALITY

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Forestry Commission

The effectiveness of the spraying was assessed by counting numbers of dead *Panolis* larvae falling from the trees and estimating the numbers still surviving on the foliage. This was done for two selected plots, one representing the ULV treatment and the other the LV. Dead larvae which dropped from the trees were collected in round polythene basins (35 cm diameter) placed on the ground below. They were counted and removed at intervals following the fenitrothion spraying. After 2-3 days it was judged that deaths from the effect of fenitrothion had almost entirely ceased. Trees in the vicinity of the collecting basins were then thoroughly sprayed, by mistblower, with a 0.2% solution of gamma HCH in water in order to kill all remaining larvae and count the additional number dropping. This additional number (corrected for the "tail-end" of fenitrothion mortality also estimated) was used to calculate the proportion of larvae which had survived the original spraying operation.

ULV ASSESSMENT PLOT, STRATHY

The assessment plot was located in Lodgepole pine (P67) in Compartments 10 and 11. Eight rows of five basins, with about 10 metre spacing between basins, were placed along the ploughing rows under the trees. Rows ran approximately east to west, ie at right angles to the flight of the spraying aircraft. Four of these rows were selected for treatment with HCH while the other four rows (well separated to avoid drift of HCH spray) provided a check on "tail-end" mortality due to fenitrothion.

The assessment plot at Strathy was sprayed on 13th and 14th June and the first count of dropped larvae was done on the 17th. It appeared that by far the greatest number of larvae had dropped by that time. A second count on 18th June showed a much reduced rate of drop. Immediately following this the HCH spray was applied to the trees above 20 of the 40 basins. Two days later (20th June) a final count was done on all basins.

The counts are summarised below for the 'series A' basins (sprayed with HCH) and the 'series B' basins (check series, not sprayed with HCH).

Date	*Series A*	*Series B*
17 June	1139	1112
18 June	23	13
20 June	29	11

The numbers of larvae dropping in the two series were closely similar before the HCH was applied. Thus the two series are believed to be comparable and the figure for additional drop in series A (29) is reduced by the number in series B (11) to correct for the small number of residual deaths attributed to fenitrothion. This gives an estimated 18 larvae surviving over the basins where 1139 + 23 + 11 = 1173 fenitrothion-killed larvae were collected.

The proportional mortality is thus estimated as $\frac{1173}{1191}$ = 98.5%. The eighteen surviving larvae, expressed in terms of unit area, represent a density of 9.4 per square metre.

Of the 2,251 larvae collected on 17th June the instar breakdown was as follows:-

Instar	*Number*	%
I	39	1.7
II	737	32.8
III	1418	63.0
IV	57	2.5

The greater proportion of larvae killed by the spray were in the third instar, and a significant number of second instar were also present.

LV ASSESSMENT PLOT, BADANLOCH

The LV assessment was carried out on the Badanloch 2 block of Helmsdale forest, consisting of Lodgepole pine, P66. Four rows of 10 basins, with about 10 metre spacing between basins, were placed along the ploughing rows under the trees. Rows ran approximately north-east to south-west, ie at right angles to the flight of the spraying aircraft, and were spaced equidistantly along the length of the block. Two of the rows were selected for treatment with HCH and the other two provided a check on "tail-end" mortality due to fenitrothion.

Badanloch 2 was sprayed on 16th June and the first count of dropped larvae was done on the 17th. Examination of the foliage at that time showed that virtually all larvae had dropped. The second count, on 18th June, revealed a very small additional drop that day. HCH was then applied over the basins of two of the rows. On 20th June the final examination of the basins was made.

The counts are summarised below for the 'series C' basins (sprayed with HCH) and the 'series D' basins (check series, not sprayed with HCH).

Date	*Series C*	*Series D*
17 June	1445	1287*
18 June	20	49*
20 June	61	23

* Corrected for 1 missing count in each case.

The numbers of larvae dropping in the two series were similar before the HCH was applied. Thus the two series are believed to be comparable and the figure for additional drop in series C (61) is reduced by the number in series D (23) to correct for the small number of residual deaths attributed to fenitrothion. This gives an estimated 38 larvae surviving over the basins where 1445 + 20 + 23 = 1488 fenitrothion-killed larvae were collected.

The proportional mortality is thus estimated as $\frac{1488}{1526}$ = 97.5%. The 38 surviving larvae, expressed in terms of unit area, represent a density of 19.8 per square metre.

2,657 larvae collected on 17th June were differentiated to instars as follows:-

Instar	*Number*	%
I	4	0.2
II	272	10.2
III	1746	65.7
IV	635	23.9

As in the Strathy plot, the greater proportion of larvae killed were in the third instar, but in this case fourth instars were also well represented.

Chapter 9

MONITORING THE PILOT AND AIRCRAFT

THE PILOT

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Departure from the spraying programme described in a communication of 19 May 1978* rather obscured the issues arising from the study but did not in the event materially influence the conclusions which could be drawn as a result of medical monitoring.

METHODOLOGY OF MEDICAL MONITORING

Medical supervision involved careful clinical examination before and at the end of each day of spraying operation. Additionally, blood samples for evidence of cholinesterase activity were obtained at each examination (Table 9.1).

During successive medical examinations, the only alteration noted was that of delayed pupillary response to light which was first observed following the afternoon session on Day 1. This reduced light response was sustained during Day 2 and had recovered by 1300 hours on Day 3.

COCKPIT MONITORING OF FENITROTHION

The report provided by the Institute of Occupational Medicine indicated that maximum levels of fenitrothion (2.0 mg/cu.m during entire flight and 9.0 mg/cu.m during actual spraying time) were found during LV spraying at Watten on Day 1. The next highest levels (0.2 mg/cu.m and 0.6 mg/cu.m respectively) were reported during the preceding ULV spraying over Fiag.

CONCLUSIONS OF MEDICAL AND COCKPIT MONITORING

It is reasonable to assume that there is a direct relationship between high cockpit levels of fenitrothion and the altered pupillary responses found.

The explanation for the high cockpit levels during the operation over Watten appears to relate to the small size of Watten which involved the aircraft turning into its own spray path. It is understood that weather conditions, namely wind direction and speed, intensified concentrations of fenitrothion found during spraying of Watten.

COMMENTS

The original spraying programme suggested that ULV spraying would take place on Day 2 and that Days 1 and 3 would be devoted to LV spraying. In fact both LV and ULV spraying took place, without prior or subsequent notice to EMAS**, on all 3 days. As medical surveillance took place only at the beginning and end of each day's operations, it is not possible to state conclusively what effects were due to LV or ULV spraying other than on the basis of cockpit monitoring of fenitrothion.

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* Editor's Note: The original plan to spray by LV and ULV on separate days, suggested in the letter of 19 May referred to by Dr Bell, had to be changed at short notice on 11 June prior to spraying, in consequence of the weather conditions prevailing during the period.

** Employment Medical Advisory Service.

As a multi-disciplinary scientific study, this operation failed to fulfil the basic essential of such a study by departing from the announced and agreed protocol without notice. Despite this, there is sufficient medical evidence to suggest that ULV spraying of organo-phosphorous chemicals is certainly no more hazardous than LV spraying and is, in fact, probably less hazardous for the aviator.

THE AIRCRAFT

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Institute of Occupational Medicine

In the United Kingdom, threshold limit values (TLV) (HSE, 1978), which are based on values published by the American Conference of Governmental and Industrial Hygienists, are used as a guide to acceptable levels of occupational exposure to a wide range of chemicals. Two types of TLV are now defined (ACGIH, 1978). TLV - TWA is the time-weighted average concentration for a normal 8 hour work-day or 40 hour work-week to which nearly all workers may be repeatedly exposed, day after day, without adverse effect. TLV - STEL (short-term exposure limit) is the maximum concentration to which workers can be exposed for a period up to 15 minutes continuously without suffering from 1) irritation, 2) chronic or irreversible tissue change, 3) narcosis of sufficient degree to increase accident proneness, impair self-rescue or materially reduce work efficiency, provided that no more than four excursions are permitted with at least 40 minutes between excursion periods and that TLV - TWA is not exceeded. In setting a TLV the animal and human toxicity, irritating effects and narcotic effects of the material are taken into account. Unfortunately TLV's are not defined for fenitrothion or Butyl dioxitol. Some guide to acceptable levels of exposure can be obtained by investigating foreign limits and by comparing the toxicity of these chemicals with similar chemicals for which TLV's have been defined.

Fenitrothion is chemically similar to methyl parathion and parathion which have TLV - TWA's of 0.2 and 0.1 mg/cu.m respectively, and TLV - STEL's of 0.6 and 0.3 mg/cu.m respectively. It is, however, much less toxic to rats than either methyl parathion and parathion (Christensen, 1973), and Krehm (1973) in a review described work which indicated that fenitrothion is less toxic to rats than methyl parathion and parathion, and that its short-term effects on humans are less severe. However, there is little evidence on possible long-term effects on humans. In the USSR fenitrothion is treated as being as hazardous as methyl parathion and slightly less hazardous than parathion; their respective shift-average exposure limits are 0.1, 0.1 and 0.05 mg/cu.m respectively. From the available evidence it seems reasonable to take the TLV's of methyl parathion, TLV - TWA 0.2 mg/cu.m and TLV - STEL 0.6 mg/cu.m, as safe exposure limits for fenitrothion.

Butyl dioxitol is very much less toxic than fenitrothion. It has similar toxicity to three chemically similar compounds, 2-butoxyethanol, 2-ethoxyethanol and 2-methoxyethanol, which have TLV - TWA's of 240, 370 and 80 mg/cu.m respectively (Christensen, 1973). If the Butyl dioxitol concentration were to approach these levels in the spray plane cabin during ULV spraying, it is likely that the fenitrothion concentration would be in the same order of magnitude. It is very likely that exposure to such a high fenitrothion concentration would have serious and possibly immediate consequences.

SAMPLING AND ANALYSIS

Measurements of both fenitrothion and Butyl dioxitol were made between 12 and 14 June 1978 during ULV spraying of Fiag, Truderscaig and Strathy forests, and during LV spraying of Watten and Achrugan forests (Table 9.2). The sampling point was in the plane cabin immediately above the door, around 30 cm from the pilot's head. As it was impracticable for the investigator to accompany the pilot during spraying, the pilot switched the equipment on before take-off and off on landing.

For sampling, air was drawn at 500 ml/min through a glass sampling tube (1.7 cm diam. x 10 cm long) containing 6 to 12 mesh activated charcoal.

In the laboratory the charcoal was treated with carbon disulphide and the resulting solution was analysed by gas chromatography. A 6ft x ¼ inch glass column packed with 3% OV101 on Gas Chrom Q was used at 150° for butyl dioxitol analyses and at 210° for fenitrothion analyses. The carrier gas was helium and a flame ionisation detector was used.

RESULTS AND DISCUSSION

Concentrations averaged out over the entire sampling time and over only the spraying time are given for each sample (Table 9.2). The latter figure may give a better picture of exposures if it is assumed that all exposure during flying occurred while spraying was in progress.

In only one sample, taken during LV spraying at Watten, was the fenitrothion concentration high enough to cause concern. There, the concentration of fenitrothion averaged over the entire flight was 2 mg/cu.m, equivalent to 9 mg/cu.m over spraying time only. This compares with the short-term guide discussed earlier of 0.6 mg/cu.m. The high exposure of the pilot to fenitrothion during the spraying of Watten may have arisen from the size and shape of the forest and the wind direction. Watten is small and narrow, running from the northwest to the southeast. The wind during spraying was from the north. The combination of these conditions probably caused the pilot to spray downwind of, and fly through, previously sprayed areas. The smallness of the forest also meant that there was insufficient time for the pesticide to settle.

The second highest measured concentration of fenitrothion was 0.2 mg/cu.m averaged over the whole flight or 0.6 mg/cu.m averaged over the spraying time only. This sample was taken during ULV spraying of Fiag when the flying time was only just over an hour and the spraying lasted 25 minutes. The fenitrothion concentrations for all other samples were very low. Butyl dioxitol concentrations were less than 0.15 mg/cu.m in all samples. The low levels of Butyl dioxitol observed during LV spraying may have arisen from earlier contamination of the cabin during ULV spraying or spray loading. They are, however, almost insignificantly low when compared with the TLV's of 2-butoxyethanol, 2-ethoxyethanol and 2-methoxyethanol (240, 370 and 80 mg/cu.m respectively) and are of little consequence.

The generally low levels of exposure to fenitrothion and Butyl dioxitol are much as expected when the normal spraying pattern is considered. The spray pilot normally ensures that he is always flying upwind of any area he has sprayed which means that the spray is always being blown away from the plane.

There is no evidence that during ULV spraying the pilot is liable to be exposed to more pesticide than during LV spraying.

The short period of high exposure to fenitrothion during the 12 June is consistent with abnormal pupil dilation of the pilot observed on the 12 and 13 June (Table O.1). If it is assumed that the abnormal pupil dilation was a result of atmospheric fenitrothion in the cabin, these results add weight to the argument for short-term exposure limits for substances such as fenitrothion. The pilot's 8 hour time-weighted average fenitrothion exposure for 12 June was 0.2 ppm which would appear to be acceptable from the limited information available.

ACKNOWLEDGEMENTS

Many thanks are due to the pilot, Noel Kinvig, and his engineer, Werner Krummenacher, for their help and co-operation which made the air sampling possible. The provision of facilities in the hanger at Dounreay Airport by Brian Wellford, the air traffic controller, was also greatly appreciated.

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Table 9.1

Medical Examination of the Pilot

Date	*Time*	*Visual Acuity*	*Pupils*	*Visual Field*	*Day's Exposure before Test (hours)**	*Serum ChE iu/litre*
7.6.78	17.05	6/4 R & L N5 R & L	Equal react to L & A.	Full	Nil	-
9.6.78	a.m.					6662
12.6.78	13.15	"	"	"	"	6510
	17.30	"	Resting pupil contracted even in dark room.	"	2½	6813
13.6.78	08.30	"	Pupils remain constricted at rest.	"	Nil	6888
	15.15	"	"	"	3½	7040
14.6.78	13.05	"	Pupils reacting. Do dilate in darkened room.	"	5	6283

Normal ChE values for method used:- 3000 - 9000 iu/litre.

* The times given are total flying hours, but the spraying periods were significantly shorter. (See Table 9.2).

Table 9.2

Fenitrothion and Butyl Dioxitol Concentrations Measured in the Spray Plane Cabin

					Mean Concentrations (mg/cu.m)			
					Fenitrothion		Butyl dioxitol	
			Time (minutes)					
Sample	*Date*	*Description*	*Flying*	*Spraying*	*During Total Flying Time*	*During* Spraying*	*During Total Flying Time*	*During* Spraying*
1	12.6.78	ULV Fiag	65	24	0.2	0.6	n.d.	n.d.
2	12.6.78	LV Watten	45	10	2	9	n.d.	n.d.
3	13.6.78	ULV Truderscaig and Strathy	170	120	n.d.	n.d.	0.03	0.05
4	13.6.78	LV Achruggan	144	50	n.d.	n.d.	0.04	0.11
5	14.6.78	LV Achruggan	200	80	0.08	0.2	0.06	0.15
6	14.6.78	ULV Strathy	35	10	n.d.	n.d.	**	**

n.d. = not detected.

Fenitrothion detection limits: Sample 3 0.05)
4 0.05)
6 0.2) Flight averages in mg/cu.m

Butyl dioxitol detection limits: Sample 1 0.05)
2 0.08)

* Spray average concentration is the exposure concentration assuming that all exposure arose during spraying.

** Sample contaminated - no result.

Chapter 10

EVALUATION OF RISKS TO HUMANS AT GROUND LEVEL

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INTRODUCTION

Measurements of human exposure to spray drift were undertaken as part of a study concerned with many aspects of the aerial application of fenitrothion against the Pine beauty moth on pine forests in Sutherland and Caithness. The chemical was to be applied at ULV and LV rates in accordance with conditions laid down under the Pesticides Safety Precaution Scheme.

METHOD OF EVALUATION

PRELIMINARY STUDIES

A preliminary study was made in a pine forest at Thetford, Norfolk, to compare spray deposition levels and drift hazards from almost simultaneous applications from the air of a suitable simulant (ie hexylene glycol) for fenitrothion liquid concentrate in undiluted form and on dilution with water. The applications were only of short duration (few seconds) and quantitative assessments of inhalation and contact hazards by chemical methods were therefore not attempted. However, studies of the deposition of droplets on small horizontal and vertical targets in clearings within the trees and along the spray swath, and similar positions 50 metres downwind, indicated that under extreme conditions a peak level of about 0.6 ml of the undiluted spray liquid could be deposited on a human target (2 sq m) within the spray swath in ULV operations, and about 1.3 ml of the same liquid plus the appropriate amount of water (ratio 40:1) in LV operations, under the same conditions. Similar calculations for depositions of spray 50 metres downwind of the sprayed area suggested that corresponding peak levels of contamination could be of the order of 0.2 ml (ULV spray drift), and not less than 0.11 ml (plus water) LV spray drift, ignoring probable effects of evaporation.

The volume median diameters (vmd) of the spray droplets collected on horizontal and vertical targets up to two metres from the ground were 70 microns (ULV concentrate spray) and 180 microns (LV aqueous spray). At corresponding positions 50 metres downwind of the sprayed area, the volume median diameters of the spray deposits were respectively 55 microns (ULV) and 68 microns (LV). Some evaporation of the water-based spray appeared to have taken place therefore, and the estimated exposure to the pesticide simulant in the LV spray was probably greater than the suggested level (0.11 ml), 50 metres downwind.

MEASUREMENT OF INHALATION AND CONTACT HAZARDS

Operational delays meant that full-scale sets of measurements for evaluation of the 'chemical' risks to humans at ground level could not be undertaken whilst forests in north Scotland were being sprayed with fenitrothion. Human observers were used, however, to obtain some information on drift hazards. Following on experience gained in the preliminary trial, volunteers were fitted with spray-resistant boiler suits complete with sampling pads for the measurement of surface contamination. In addition, each volunteer wore a respirator modified to simulate nasal breathing characteristics and thereby provide a measurement of exposure by inhalation. One observer remained on the downwind side of the first spray swath at the edge of the forest. A second observer was positioned 50 metres downwind in the open country from this point and a third 150 metres downwind from the edge of the forest.

One set of measurements was made at Strathy forest (ULV spray, 13 June 1978) and another at Badanloch (LV spray, 16 June 1978). Analyses were made by extraction with hexane and final determination by gas chromatography. Minimum recovery figures proved to be 80 per cent for the procedure including 'losses' on prolonged storage of 'spiked' sampling pads.

RESULTS

EXPOSURE LEVELS BY CONTACT WITH SPRAY DRIFT

Although the periods of exposure of the volunteers to spray drift were only 20-25 minutes, exposure levels were calculated for comparative purposes on an hourly basis (Table 10.1).

EXPOSURE LEVELS BY INHALATION OF SPRAY PARTICLES

A breathing rate of 15 litres air per minute was assumed in calculations of exposure levels by inhalation (Table 10.2).

DISCUSSION AND CONCLUSIONS

The results from the preliminary trial and subsequent applications of fenitrothion (ULV and LV) cannot readily be compared with one another since the wind conditions and other meteorological factors were significantly different. The tree canopy was certainly far more open in the preliminary trial than that observed in forests in Scotland which could have accounted for the marked difference between the estimated exposure levels. Operational factors to do with the aircraft and spraying system and the presence of steep slopes within and outside the forest could also have had significant effects on exposure levels.

Nevertheless the recorded exposure levels to fenitrothion by inhalation and contact even at the highest values (Tables 10.1 and 10.2) could hardly be regarded as immediately dangerous to an unprotected person over an eight hour exposure period. Present work suggests that nothing is gained from the safety viewpoint by the application of water-based sprays (LV) but further studies appear to be indicated nevertheless, perhaps on the lines of the Thetford trial, in order to provide more data on the safety, or otherwise, and the efficiency of ULV versus LV aerial applications in all possible conditions.

ACKNOWLEDGEMENT

Development of the analytical method and subsequent analyses of the samples for fenitrothion content by J.W. Edmunds (Pesticides Residue Analysis Department) is greatly appreciated.

Table 10.1

Exposure Levels by Contact with Fenitrothion Spray Particles

Observers Sampling Position	*Contamination Found on Designated Areas of Human Target mg Fenitrothion Deposited per Hour*				
	Head + Neck (1200 sq cm)	*Trunk (7600 sq cm)*	*Upper Extremities (3600 sq cm)*	*Lower Extremities (7600 sq cm)*	*Total (on 2 sq m)*
ULV					
0 m (in spray swath)	0.05	0.08	0.16	0.05	0.34
50 m downwind	0.05	0.87	0.38	1.33	2.63
150 m downwind	0.13	0.56	0.20	0.80	1.69
LV					
0 n (in spray swath)	0.60	3.04	0.86	3.52	8.02
50 m downwind	0.48	2.28	0.59	6.27	9.62
150 m downwind	0.21	1.10	0.45	0.67	2.43

Note: Surface wind speeds ULV spray = 11 kph; LV spray = 11-18 kph

Table 10.2

Exposure Levels by Inhalation of Fenitrothion Spray Particles

Observers Position	*Concentration of Fenitrothion in Observers Breathing Zone: mg/cu m (assumed breathing rate 15 l/min)*	
	ULV spray	*LV spray*
0 m (in spray swath)	0.0039	0.0047
50 m downwind	0.0012	0.0037
150 m downwind	0.0068	0.0011

Chapter 11

DEPOSITION OF FENITROTHION AT GROUND LEVEL

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SAMPLING PROGRAMME

The forests chosen for measurement of the amount of fenitrothion deposited at ground level were Truderscaig (770 ha), Strathy (240 ha), Achruggan (590 ha) and Rosal (680 ha). Truderscaig and Strathy forests were to be sprayed by the ULV technique and Achruggan and Rosal were to be sprayed by the conventional LV technique. Approximately 50 sampling positions were chosen in each forest area. These were mainly located in transects across the forests or parts of them, and extended to a distance of 200m outside the forest in a direction expected to be downwind. The sampling positions within the forests were generally located in pairs, one position being under the tree canopy and the other in the open nearby but at least 2m from any overhead tree cover. The density of the cover provided by the tree canopy at each position was assessed on a 4-point scale, 1 indicated very light cover, 4 indicated very dense cover.

APPLICATION OF FENITROTHION

Both the ULV and the LV methods of application were designed to apply 300 g of active ingredient per hectare. The ULV formulation comprised 6 parts of fenitrothion 50% emulsifiable concentrate and 4 parts of a glycol, Butyl dioxitol, and was applied at a rate of 1 litre per hectare from a height of 6m above the tree canopy. The LV formulation comprised 3 parts of fenitrothion 50% emulsifiable concentrate and 97 parts of water applied at a rate of 20 litres per hectare from a height of 3m above the tree canopy.

The applications to the areas where deposition was being measured were made at the following times -

Truderscaig	-	13.6.78	-	09.35 to 11.10 h
Strathy	-	13.6.78	-	13.00 to 14.40 h
Achruggan	-	13.6.78	-	16.00 to 19.10 h
	-	14.6.78	-	06.10 to 10.46 h
Rosal	-	14.6.78	-	18.40 to 19.57 h
	-	15.6.78	-	07.47 to 08.02 h

SAMPLING AND ANALYSIS

Preliminary laboratory tests using plain glass plates as a means of collecting and retaining fenitrothion droplets showed that the stability of fenitrothion deposits on glass was poor and exposure to weather gave variable and low recoveries of fenitrothion. Further tests were done using glass plates coated with a thin layer of silica gel with 13 per cent calcium sulphate as a binding agent. Plates, each 100 sq cm in area, were coated with the silica gel using a thin layer chromatography spreader and amounts of fenitrothion varying between 5 and 50 µg were applied to the plates using a microlitre syringe.

After exposure outside for periods up to 24 hours the silica gell was carefully removed from the glass and transferred to flasks containing acetone. Following thorough shaking and filtration, the acetone extracts were concentrated and the fenitrothion levels determined by gas-liquid chromatography. The results showed that the silica gel had retained a mean of 90 per cent of the fenitrothion during the exposure period and that the method of analysis gave consistently high recoveries of fenitrothion from the silica gel layer. The silica gel layers were robust and resistant enough to handling damage to be practicable for field use. It was decided to adopt this technique for collection of spray droplets depositing on the ground.

Two hundred and forty plates measuring 5 x 20 cm were prepared by thorough cleaning and coating with a thin layer of the silica gel absorbent. The plates were distributed in the four forests at positions shown on the maps (Figures 14.1 to 14.3 pp.170-172) about 3 hours before the start of the spraying operation in each forest. The plates were placed flat on the ground with the silica gel layer uppermost, and care was taken to ensure that ground foliage did not obscure the surface of the plate in any way. At this time an assessment was made of the degree of tree foliage cover above each plate and this was noted using the four-point scale. Immediately after the distribution of the plates in each forest, three other plates were dosed with 10, 25 and 50 µg of fenitrothion and left exposed in an open situation at least 1000m from the edge of the area to be sprayed. As soon as possible after completion of the spraying the plates were collected from each forest as were the dosed plates. They were all taken to a local laboratory where the silica gel layers were carefully scraped from the plates and transferred to glass bottles by washing in with 50 ml of acetone. The concentration of fenitrothion would be stable in acetone solution and these were then stored until analysis.

The acetone solutions were filtered and concentrated to a standard volume. The amount of fenitrothion in each solution was determined by gas chromatography using 2 per cent silicone XE60 as the stationary phase and a phosphorus-specific flame photometric detector. The limit of detection of the analysis was 0.1 µg per sample extract which is equivalent to a spray deposit of 0.1 g per hectare. The chromatograms were also examined for the presence of any derivatives of fenitrothion but no other phosphorus-containing compound was noted. The identity of fenitrothion was confirmed in a random selection of the samples by examination by electron impact gas chromatography/ mass spectrometry. A further selection of samples covering a wide range of fenitrothion concentrations were critically analysed by gas chromatography/ mass spectrometry using single ion monitoring at m/e values of 244 and 260 and this failed to indicate the presence of residues of fenitro-oxon or S-methyl fenitrothion in any of the samples.

RESULTS

The fenitrothion depositions at all the sampling positions within the forests are given in Table 11.1 p. 99. Table 11.3 p.101, shows a summary of all these results and gives the means of the results obtained from positions in the open and under tree cover. Table 11.3 gives a breakdown of the results under tree cover with respect to the degree of cover at the sampling positions. The results of the depositions outside the forests are given in Table 11.4 p.102.

Lower recoveries were obtained from the sampling plates which were dosed at the time of spraying than those obtained from the earlier laboratory trials but the recoveries were consistent and gave an overall mean of 40% ± 9%. This lower recovery figure probably reflects the longer time interval between dosing and transfer into acetone solution, and also the higher temperatures during this period than during the laboratory trials. All the results have been adjusted for a recovery of 40 per cent.

DISCUSSION

The means of all the results from within the forests show that less fenitrothion reached ground level when ULV spraying was used. A similar finding is shown by the results from only the sample positions in the open, but the picture was less clear from the samples taken under the trees. In the case of Truderscaig the cover was very light and the results are more comparable with those obtained from sample positions in the open within the forests. There seems to be little difference between the effects of the two spray methods for sample positions located under trees providing a low degree of cover. However with tree cover rated 3, that is where the foliage provides a reasonably dense cover, the results strongly indicate that the ULV spray was more readily trapped by the foliage than the LV spray. Unfortunately only at Strathy were there any number of sample positions under trees with a degree of cover rated as 4, so that no useful comparison can be made of these results.

Some of the results also indicate that some areas of the forests were missed by the spraying application; in particular, the south-east corner of Achruggan received little or no fenitrothion. The very limited area covered by the sampling makes it likely that several other areas may have been inadequately sprayed. The results from Rosal show clearly that only the west side of the forest had been sprayed before the sampling programme was completed and further delays caused by adverse weather made it impossible to finish the sampling in this forest.

During the collection of the sample plates from Rosal a heavy mortality of Pine sawfly larvae was noted extending across the forest from west to east. No fenitrothion was found in samples taken across this area, confirming that the LV spraying of Rosal had only covered the west edge of the forest by that time. It seems likely that the ULV spraying at Truderscaig on the previous day had been carried out north of the agreed area and up to the forest road dividing the Truderscaig/Rosal forests. No sampling plates were exposed in Rosal at the time of the Truderscaig spraying operation, so this could not be confirmed by analysis.

The sampling positions which were selected to measure deposition outside the forest areas were expected to be in a downwind direction, but during the period of the spraying operation the wind direction changed from west to a more northerly direction. The sampling positions at Achrugan were probably the nearest to an accurate downwind direction. The results show that very little fenitrothion was deposited outside the target areas, even at a distance of 20m from the forest except at Strathy. It seems likely that the sampling positions outside Strathy forest received a direct application of fenitrothion since the results are comparable with those measured at open positions within the forest. The sample positions outside Strathy forest were in an area where the forest boundary formed an inverted 'V' shape and it might have been difficult to avoid spraying this area. There was evidence of Pine sawfly mortality on very young trees planted outside the forest boundary on the north-east side of Truderscaig but the samples taken nearby show little or no fenitrothion deposition.

CONCLUSION

The results show that the amount of fenitrothion reaching ground level as a result of ULV spraying was much less than that resulting from the LV spraying. This difference was greater where the cover provided by the tree foliage was denser. There was no evidence of spray drift causing much contamination of ground outside the target areas.

There was evidence of at least one area of Achruggan forest being missed by the spray and one area outside the forest at Strathy receiving a direct application.

The sampling programme was a useful opportunity to assess methods of monitoring a large scale application of a pesticide and, although the methods used here were largely successful, several difficulties were encountered and improvements could be made should the need arise to monitor any similar pesticide application in the future.

Table 11.1

Deposition of Fenitrothion at Ground Level Under Tree Cover and in Open Situations in Sprayed Forest Areas

Forest	*Method of application*	*Sample position No*	*Deposit of Fenitrothion in open situation (g/ha)*	*Deposit of Fenitrothion under tree cover (g/ha)*	*Degree of cover*
Truderscaig	ULV	4	99		
		5	108		
		6	40		
		7	28		
		8	46		
		9	127		
		10	83		
		11	240	104	1
		12	123	69	1
		13	44	175	1
		14	41	130	1
		15	28	10	1
		16	57	78	1
		17	109	46	2
		18	53	40	1
		19	44	13	2
		20	94	7.5	3
		21	19	9.3	1
		22	34	13	1
		23	55	13	2
		24	50	11	2
		25	11	41	2
		26	2	2.5	3
		27	0	145	2
Rosal	LV	9-16	0	0	3-4
		17	132		
		18	85		
		19	206		
		20	64		
		21	82	27	4
		22	256	18	3
		23	8.9	0	3
		24	9.3	101	3
		25-26	0	0	2-3
		27	249	20	2
		28	205	38	3
		29	52	43	2
		30	187	34	3
		31	135	66	3
Strathy	ULV	1	52		
		2	70		
		3	272	2.5	4
		4	-	16	3
		5	124	17	4
		6	64	13	4

Forest	Method of application	Sample position No.	Deposit of Fenitrothion in open situation (g/ha)	Deposit of Fenitrothion under tree cover (g/ha)	Degree of cover
Strathy continued	ULV	7	36	1.8	4
		8	5.3	3.8	4
		9	180		
		10	116		
		11	163		
		12	93	6.5	3
		13	71	16	3
		14	-	38	3
		15	79	9.3	3
		16	47	3.8	4
		17	46	1.8	3
		18	19	9.3	3
		19	-	63	2
		20	80	21	2
		21	11	25	2
		22	61	33	3
		23	5	12	3
		24	3.8	2.5	3
Achrugan	LV	1	89	6	4
		2	116	17	3
		3	108	47	2
		4	121	43	2
		5	12	2.8	3
		6	108	10	2
		7	119	89	1
		8	106	84	2
		9	178	42	3
		10	139	26	2
		11	604	132	2
		12	1.3	0	3
		13	0	0	2
		14	0	0	4
		15	0	0	4
		20	500	89	3
		21	198	2	4
		22	326	19	3
		23	319	10	2
		24	438	34	3
		25	556	61	2
		26	285	61	2
		27	520	15	2
		28	145	40	3
		29	158	20	2
		30	28	13	2

Notes 1. The "open situation" samples were collected at least 2m distant from any tree cover.

2. The degree of cover was assessed on a four-point scale, 0 = No cover; 4 = Dense cover.

3. The limit of detection for the analyses was 0.1 g/ha.

Table 11.2

Deposition of Fenitrothion at Ground Level - Summary of Results

	Truderscaig *ULV*	*Rosal* *LV*	*Strathy* *ULV*	*Achruggan* *LV*
Total No. of samples	41	22	40	52
Range	0-240	0-256	1.8-272	0-604
Mean	59.6	91.8	47.3	116.0
Total No. of open samples	24	13	21	22
Range	0-240	8.9-256	3.8-272	12-604
Mean	64.0	128.6	76.1	235.1
Total No. of covered samples	17	9	19	22
Range	2.5-175	0-101	1.8-63	2.8-131
Mean	53.4	38.6	15.5	39.2
Degree of cover-Range	1-3	2-4	2-4	1-4
Degree of cover-Mean	1.59	2.89	3.16	2.45

Note: This table does not include results from the following positions -

Rosal - Positions 9-16 and positions 25-26
Achruggan - Positions 12-15

The results indicate that these positions either had been missed by the spraying operation or had not been sprayed before the sampling was completed.

Table 11.3

Deposition of Fenitrothion at Ground Level Under Tree Cover
Summary of Results

		Truderscaig *ULV*	*Rosal* *LV*	*Strathy* *ULV*	*Achruggan* *LV*
Tree Cover Degree 1	- Range	9.3-175	-	-	-
	- Mean	69.8	-	-	89*
Tree Cover Degree 2	- Range	11-145	20-43	21-63	10-132
	- Mean	44.8	31.5	36.3	43.5
Tree Cover Degree 3	- Range	2.5-7.5	0-101	2.5-38	2.8-89
	- Mean	5.0	42.8	14.4	34.8
Tree Cover Degree 4	- Range	-	-	1.8-17	2.0-6.0
	- Mean	-	27*	7.0	4.0

* One value only

Note: This table does not include results from the following positions -

Rosal - Positions 9-16 and positions 25-26
Achruggan - Positions 12-15

The results indicate that these positions were either missed by the spraying operation or had not been sprayed before the sampling was completed.

Table 11.4

Deposition of Fenitrothion at Ground Level Outwith the Sprayed Areas

Forest	*Direction of Sample Positions*	*Distance from Forest Edge (m)*	*Sample Position No*	*Deposit of Fenitrothion (g/ha)*
Truderscaig (ULV)	East/North East	20	28	0
		50	29	0
		100	30	0
		200	31	0
		20	35	0.5
		50	34	0
		100	33	0.3
		200	32	0
	West	50	3	15
		100	2	1
		200	1	2.8
		50	38	10
		100	37	1.3
		200	36	2.3
Rosal (LV)	East	20-200	1-8	0
Strathy (ULV)	South East	20	28	36
		50	27	45
		100	26	43
		200	25	16
		20	32	90
		50	31	176
		100	30	35
		200	29	23
Achrugan (LV)	East	20	16	0
		50	17	0
		100	18	0
		200	19	0
		20	31	11
		50	32	2
		100	33	1.8
		200	34	0

Chapter 12

CHEMICAL AND BIOLOGICAL OBSERVATIONS IN STREAMS FOLLOWING AERIAL SPRAYING OF FORESTS WITH FENITROTHION

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INTRODUCTION

The Department of Agriculture and Fisheries for Scotland is responsible, inter alia, for ensuring that stocks of freshwater fish in Scotland are protected and conserved, and the Freshwater Fisheries Laboratory, Pitlochry has had long experience of investigating pesticide residues in fish and fresh waters. The Highland River Purification Board has a statutory responsibility for monitoring the quality of fresh water in the Board's area, and for the prevention of pollution. The two organisations collaborated closely in monitoring the levels of contamination in the aquatic environment, and the consequences of this contamination, during and after the aerial spraying with fenitrothion.

OBJECTIVES

The main objectives were to:

(a) Assess the impact of fenitrothion on the non-target aquatic species, and in particular on the fish and invertebrates of the streams within or adjacent to the treated forests.

(b) Monitor the input of fenitrothion to the water courses, and its fate during the post-spray period.

(c) Compare the results obtained from areas sprayed by low volume (LV) and ultra low volume (ULV) techniques.

(d) Briefly compare the results of the Sutherland treatment with those reported from other forest spraying operations using the insecticide.

MONITORING AREAS

CHOICE OF SAMPLING SITES

As many of the areas to be treated were some distance apart it was necessary to deploy the resources of the laboratory at a limited number of sites. The primary interest was in the areas being treated by ULV spray, a new technique in aerial spraying in this country. However, areas to be treated by the more conventional LV method were also considered for comparative purposes, and because no information was available from previous LV spray treatment in Britain.

Forest areas were selected which contained, or were adjacent to, nursery streams for Atlantic salmon. Where possible the sampling stations were positioned close to the mouth of these streams.

The sampling stations were also located at points which were easily accessible by road, so that sampling equipment could be easily serviced or moved by day or night.

On the basis of this information the Strathy (ULV), Truderscaig (ULV), Rosal (LV) and Fiag (ULV) forests were originally selected for monitoring. However, the Fiag forest was eliminated following extensive fire damage a few weeks prior to the spraying operation.

SAMPLING STATIONS

Strathy Area - Uair Burn (Figure 12.1)

The Uair Burn is the largest tributary of the River Strathy and is almost wholly within the Strathy forest. It has a width of c.3-5m, with a bed of boulders and large stones and occasional patches of smaller gravel. The sampling site was close to the confluence of the stream with the River Strathy.

Strathy Area - River Strathy (Figure 12.1)

The upper reaches of this river were within the ULV treated Strathy forest, and the lower reaches flowed alongside the LV treated Achrugan forest. The width is c.7-8m and the bed consists of medium-sized stones of between 10 and 20 cm with larger stones and boulders throughout its length. The depth at the time of treatment was generally less than 20 cm except for a deeper central channel. The sampling station was just upstream of Strathy village, downstream of the Achrugan forest.

Naver Area - Allt Rosail (Figure 12.2)

The Allt Rosail lies wholly within the forest area and is c.2m broad and averages about 10 cm in depth, with a bed consisting largely of rock with short stretches of gravel and large stones. The sampling site chosen was just downstream of the forest road.

Naver Area - Allt Dalharold (Figure 12.3)

The Allt Dalharold is one of the major streams entering the River Naver in this area. The upper reaches run through the Rosal forest at the boundary with the Truderscaig forest and beyond to open country. The lower reaches run adjacent to the Rosal forest. The stream at the time of sampling was about 4m wide with a bed of stones c.10-20 cm and scattered boulders. The sampling site was at the forest road about 200m above the confluence with the River Naver.

Naver Area - Allt a' Bhealaich (Figure 12.3)

This small stream, which for the most part was a narrow ditch c.30 cm wide with a bottom of peat and silt, was wholly within the Truderscaig forest. The sampling point was about 15m from the confluence with the Mallart River.

SAMPLING PROGRAMME (Figures 12.4 and 12.5)

WATER SAMPLING

Water samples (1 to 2 litres) were taken from each of the sampling sites from the commencement of spraying within that particular area. Samples were initially collected every 2h until 24h had elapsed after the final swath of spraying and then at 48, 72 and 96 h after treatment. Further samples were taken after rainfall and finally 6-7 weeks after spraying. The water samples were used to determine the concentration-time profile within the streams and estimate the total load of pesticide to that water course. This information was then used in conjunction with the biological data collected, to compare these observations with previous published information.

CAGED FISH

Twelve rainbow trout of c.10cm length were placed in cages at each of the main sampling sites. Two fish were removed for chemical analysis at intervals of 6, 12, 24, 48 (72), 96 h after treatment, to determine the uptake/excretion pattern of fenitrothion in relation to the concentrations in the water.

A second smaller cage containing 12 salmon fry was sited at each station. These were not sub-sampled during spraying or in the immediate post-spray period. As most of the streams being monitored served as nursery streams for the native salmon stock a check was made, using the caged fry, on the possible effect of the fenitrothion on wild fish. After the 5 day post-spray period they were killed and analysed for fenitrothion residues.

ELECTROFISHING

In addition to the analyses of captive fish, salmonids and eels were removed by electrofishing from the Strathy sites 24h after treatment, and from the Naver and Strathy sites one month later, to provide information on the fenitrothion concentrations in the resident fish.

DRIFT NET SAMPLING

Drift nets (50 x 20 cm at the mouth, mesh 1.0 x 0.3mm) were placed at the main sampling sites with the surface of the stream below the top of the net, and examined every 6h for a period of 2 days following treatment. For comparative purposes two 6h samples were taken at each site during the week prior to spraying. The drift net samples monitored the effect of the fenitrothion on the stream invertebrates and terrestrial insects floating on the surface. The numbers of invertebrates drifting downstream in any one period can be related to the concentration of the pesticide in the water.

ANALYTICAL PROCEDURE

WATER SAMPLES

Each water sample was collected in an acid-rinsed glass bottle containing 1N sulphuric acid (10 ml) to acidify the contents and prevent hydrolysis of the fenitrothion. The samples were stored in darkness to avoid any photo-decomposition occurring after sampling. The water was transported to the laboratory and extracted with n-hexane (50 ml/litre sample), the organic fraction dried with anhydrous sodium sulphate and analysed using a gas-liquid chromatograph (GLC) with an alkali flame ionisation detector (AFID).

FISH SAMPLES

All fish samples removed from the field stations were killed upon sampling and deep frozen within 6h. The fish were analysed whole and were ground with anhydrous sodium sulphate and exhaustively extracted with n-hexane (100 ml) in a soxhlet apparatus. The fish extracts were then treated in the same manner as the water samples without any clean-up.

DRIFT NET SAMPLES

The drift nets were emptied into a glass jar every 6h and preserved in formalin. The samples were then returned to the laboratory for identification and quantification.

RESULTS - CHEMICAL ANALYSIS

WATER SAMPLES

The pre-spray samples, taken from each sampling station as a background check contained no fenitrothion. A similar sample was taken and spiked with a known quantity of the insecticide formulation to verify the handling, storage and the analytical procedure. There was no evidence of the formation of the main metabolites of fenitrothion (fenitro-oxon, amino fenitrothion, dimethyl fenitrothion), the hydrolysis product, p-nitro cresol or the S-methyl isomer, and the recovery from the spiked water sample was acceptably quantitative (~85 per cent).

During the spray period there was little rainfall in the area (Figure 12.6), which was reflected in the reasonably constant flow (Figure 12.7) in the waters monitored. All the waters sampled during the initial post-spray period contained fenitrothion, which rose to a maximum concentration soon after the application and declined during the following 5 days. There was no evidence of metabolism (less than 2 per cent assuming approximately similar GLC sensitivity of metabolites and fenitrothion) during this period, or after 10 days and up to 40 days, when the fenitrothion levels had declined below the minimum detectable concentration (MDC = 0.003 μg/litre). Therefore the only compound quantified was the active ingredient fenitrothion. The concentration-time profiles obtained from each sampling station over the initial 5 day post-spray period is given in Figures 12.8 - 12.12.

Uair Burn

The initial high concentration (48 μg/litre) obtained during spraying on 13-6-78 was a result of the direct contribution from the spray, which formed a short-lived but highly concentrated slug of fenitrothion which passed along the stream into the River Strathy (Figure 12.8). This high concentration dropped by over an order of magnitude within 4h to 1.5 μg/litre. After 6-8h there was a second much smaller rise in concentration (4 μg/litre) which can best be explained in the light of the profile during the second day.

A second application was made at Strathy after 24h over an experimental block along the upper reaches of the Uair Burn. This second special spray contained a fluorescent dye to enable other observers to obtain information on the droplet size and distribution of the spray. The effect of this application on the concentration-time profile was observed 6-8h after treatment. The concentration of fenitrothion rose to 6.5 μg/litre and subsequently declined to less than 1 μg/litre overnight.

Allt a' Bhealaich (Figure 12.9)

The concentration-time profile obtained from this station was the least complex because the Truderscaig forest received a single ULV spray application. The initial concentration rose to 9.7 μg/litre during spraying and rapidly dropped to 2-2.5 μg/litre during the following 6h. A second peak was observed 14h after spraying, similar to that observed at the Uair Burn and was presumably from the upper reaches of the Allt a' Bhealaich. The increase in the time taken for the peak to emerge is due to the difference in flow (Uair average = 23 litre/second, Bhealaich average = 0.7 litre/second and burn lengths. After 18h the concentration gradually diminished from 1.5 μg/litre to less than 0.05 μg/litre over 5 days.

Allt Dalharold

The most northerly cut-off point for the ULV spraying of the Truderscaig forest was the "narrows" of the forest some 2 km south of the Allt Dalharold. The main stream was in the LV spray treatment block associated with the Rosal forest.

Fenitrothion was detected in this burn (Figure 12.10) prior to any LV spraying of Rosal only 6h after the Truderscaig forest had been treated. It is unlikely that this was due to aerial movement of fenitrothion outwith the prescribed area to the north as the wind direction and speed was 360°, 11 kn respectively on 13-6-78, ie in the opposite direction to the Allt Dalharold. Also in view of the time taken for the fenitrothion to pass along the Uair Burn (6-8h) and the Allt a' Bhealaich (14h) it is unlikely that this contribution was initially from a very small tributary which ran from just inside the Truderscaig ULV area. It does suggest that the upper cut-off boundary for the ULV spray was, in practice, nearer the Allt Dalharold than the "narrows".

The concentration-time profile (Figure 12.10) shows a slow rise from 13-6-78 due to the ULV spraying of Truderscaig forest, followed by a major increase on 16-6-78 to a maximum at 4.2 μg/litre from the LV treatment of the Rosal forest, and a slow decline over the 5 days. The swaths for Rosal were in a N-S direction at approximately 90° to the lower reaches of the Allt Dalharold and the initial application on the 14-6-78 was below the sampling station on this stream.

Less detailed information was obtained at the Allt Dalharold because the auto-sampler was operating at the Allt Rosail and only occasional dip samples were taken.

Allt Rosail

Two initial maxima (6.6 and 8.5 μg/litre) were due to two limited applications on 14-6-78 and 15-6-78 (Figure 12.11). This was followed by a sharp rise on 16-6-78 during spraying and a slow decline upon which was superimposed a series of peaks giving a saw tooth effect. There are two possible explanations for this effect.

Because of the increase in water content of the LV spray formulation compared with the ULV, the area covered per payload is drastically decreased. The saw tooth could be purely a time-lag effect of the swaths due to reloading upstream of the sampling station. Detailed information on the spraying of this block is not available at the time of writing for a correlation to be made.

An alternative suggestion is supported by the pattern found at the Uair Burn and the Allt a' Bhealaich, ie that spraying parallel to the water course deposits a greater burden to the water than spraying at 90°. In each case the upper reaches of the burn or tributaries in the Allt Rosail were approximately parallel to the direction of the swaths.

River Strathy

The concentration of fenitrothion in the River Strathy (Figure 12.12) just above the village of Strathy was very low (maximum 1.1 µg/litre). The contributions from the Strathy forest (ULV) and the possible runoff from Achrugan (LV) were obviously well diluted at this point in the river some 5 km downstream. The small fall and subsequent rise was probably due to the spraying of Achrugan , but, as expected, the concentrations were much lower than at the other sampling stations.

The concentration of fenitrothion in waters associated with the ULV application declined faster than those in the LV areas, although the levels in both types of area were below 0.2 µg/litre after 5 days (Table 12.1). Similar patterns were observed by Peterson and Zitko (1974) for an application rate of 138-275 g/ha. They also found, as in this case, that no measurable traces of fenitrothion were observed after 40 days.

The first significant rainfall within the spray area came 10-12 days after the commencement of operations. Stream waters taken at this time indicated a slight rise in fenitrothion levels due to runoff from the adjacent contaminated land, but were only a little more than at the 5 day post-spray period (Table 12.1). This has also been observed before (Sundaram 1973, 1974).

Eidt and Sundaram (1975) also found that hydrolysis of fenitrothion in water produces p-cresol, but this is only likely to occur to any extent in waters of pH above 7. All the streams studied had pH values below 6.5 and the samples taken were further acidified with sulphuric acid.

Using the flow measurements (Figure 12.7) an estimate was made of the total load of fenitrothion to each stream during the first 5 days post-spray period in which time more than 95 per cent of the fenitrothion entering the water course had been flushed away. The results are given in Table 12.2. The large variation, on a total weight basis, between streams is due to the different sizes of the streams.

CAGED FISH - RAINBOW TROUT

The rainbow trout *(Salmo gairdneri)* were purchased from the Highlands and Islands Development Board fish farms at Moniack near Inverness, transported by road to the sampling sites on 6-6-78 and 12 fish placed in covered handling boxes (70 x 100 cm), one at each site. The original intention of the programme was to install the fish at the sampling points 48h prior to spraying, but due to inclement weather and other operational factors treatment did not commence until 13-6-78. During this period of delay the fish were unable to feed sufficiently from their environment and so were given pelleted fish food.

There was only one mortality from a total of 60 fish. This occurred at Allt Dalharold on 14-6-78 but was not attributed to fenitrothion poisoning, confirmed later by chemical analysis. Apart from this single mortality all the rainbow trout appeared healthy and fed well during the whole operation. The fish at the control site on the River Strathy, approximately 2 km upstream from the spray area, showed no visible signs of stress or abnormal behaviour throughout the whole exercise and there was no trace of fenitrothion (MDC = 0.003 mg/kg) in these fish 5 days after spraying had commenced.

Water temperatures during the actual spraying operations were in the range 14-17°C at Strathy (Uair Burn), and 14-16°C in the Allt Rosail. The overall water temperature ranges recorded for the entire period of operations were 6.5 - 19.5°C in the Uair Burn and 5.0 - 18.5°C in the Allt Rosail, and these are considered not to be abnormal.

The fish at each of the sample sites within the spray areas also showed no signs of abnormal behaviour during the post-spray period (6h-5 days). The fish were not monitored during the spray operation, but observations at the Uair Burn, Strathy, 2h after treatment, when the concentration of fenitrothion in the water was at a maximum, suggested that there was no change in their behaviour.

The rainbow trout were sub-sampled at 6, 12, 24, 48 (72) and 96h periods after spraying by removing 2 fish on each occasion. The chemical analyses for fenitrothion in these fish are given in Table 12.3.

The uptake of fenitrothion by the fish was rapid and in each area, regardless of the method of application (LV or ULV), the maximum concentrations (1.77 - 2.10 mg/kg) were reached within 6-12h from the commencement of the spraying operation. In the case of the samples from the Allt Dalharold and Allt Rosail, the initial pattern was different because of the intermittent nature of the application programme due to inclement weather. However, sampling commenced at the Allt Rosail and Allt Dalharold after the first swath had been flown in the Rosal forest, and the maximum concentration in the fish was observed about 6h after the major part of the block had been treated, giving a similar pattern to the other areas.

The concentration of fenitrothion in the rainbow trout decreased quite markedly over the 5 days after spraying, and clearly followed the concentration-time profile obtained from the water analysis (Figures 12.8-12.11). This indicates the rapid uptake and excretion rate of this material by the trout.

Differences in concentrations in the fish from LV and ULV sprayed areas were not particularly marked, although there was a tendency for the concentrations obtained from the LV areas to remain proportionately higher for a longer period, reflecting the levels in the water at that time.

The results from these field experiments are very similar to those obtained elsewhere. Lockart *et al* (1973) observed no significant biological changes, including those in brain cholinesterase activity, in caged rainbow trout exposed to 275 g/ha spray treatment. Analysis after 24h revealed the average concentration of fenitrothion to be 0.5mg/kg with a maximum of 1.84mg/kg. This declined to less than 0.02mg/kg within 4 days.

The levels found both in the water and in the caged fish in Sutherland were also much lower than the concentrations likely to give rise to any major sublethal effects (cf. N.R.C.C. 1975).

CAGED FISH - SALMON FRY

Salmon fry, reared at the hatchery at the Freshwater Fisheries Laboratory, were transported and installed into the sampling and control burns in a similar manner to the rainbow trout. However, these fry were not sub-sampled like the rainbow trout, but were kept for the duration of the 5 day post-spray exercise.

There were 4 mortalities from the 72 fry (12 at 6 sites): 2 at the River Strathy on 13-6-78 and 16-6-78 and 2 at the Allt Dalharold on 18-6-78 and 20-6-78. None of these deaths were attributed to fenitrothion poisoning. The maximum fenitrothion concentration observed throughout the whole exercise (48 µg/litre) at the Uair Burn is 0.01 of the LD_{50} for salmon fry (4.2 mg/litre) (Wildish 1971). The remaining 68 fry were healthy and appeared to behave normally over the whole period. The concentrations of fenitrothion in the fry (homogenates of the 12 fry from each station) after the 5 days had elapsed are given in Table 12.4.

RESIDENT FISH

Samples of the indigenous population were taken by electrofishing the River Strathy and the Uair Burn on the second day after spraying. Samples from the Allt Dalharold were obtained by the use of the drift net. The concentrations of fenitrothion in the brown trout and eels were no different from those of the caged fish sampled at the same time (Tables 12.3 and 12.5), which suggests that the uptake and excretion rates were similar.

The samples of resident fish obtained one month after treatment contained no detectable fenitrothion.

OBSERVATIONS ON INVERTEBRATE FAUNA

INVERTEBRATE FAUNA

The results of the analyses of drift net samples from four of the main observation sites are given in Figures 12.13 - 12.16. The different species within each order of aquatic insects have been grouped together to make the presentation of the data more concise but, since no attempt was made to identify all the terrestrial insects, this group contains representatives from several orders. The most abundant terrestrial insects in these samples were the Psocoptera (insects related to the book louse), the Diptera or two-winged flies, and the Plecoptera or stoneflies, the juvenile stages of which are aquatic. The first two post-spray samples from the Uair Burn were lost in transit between Sutherland and Pitlochry and the earliest post-spray sample from this burn is therefore one which contains material collected from 6 to 12h after the first spray application.

The figures show that, in almost every case, the number of animals collected in post-spray samples were greater than in samples taken before spraying, and that peak numbers in the drift nets coincided with, or followed shortly after, the peak concentrations of fenitrothion in the water. Although the number of insects belonging to each order varies, there are often close similarities in the pattern of peaks and troughs. This is particularly noticeable in the histograms for Allt Rosail and the Uair Burn. The pattern for the terrestrial insects does not conform so closely with those of the aquatic orders.

In most samples one genus or species within each order was more abundant than any other. *Leuctra* spp. comprised 93 per cent of the stoneflies found in the Uair Burn and 82 per cent in Allt Rosail. By contrast *Chloroperla torrentium* was the most common stonefly in Allt a' Bhealaich. In the Uair Burn, 76 per cent of the mayfly nymphs *(Ephemeroptera)* consisted of *Ephemerella ignita*. In the Allt Rosail samples mayfly nymphs belonging to the families Ecdyonuridae and Baetidae, together with *Ephemerella*, were taken in almost equal proportions, while in the River Strathy only 4 per cent of mayflies were Ecdyonuridae, 38 per cent Baetidae and 55 per cent *Ephemerella ignita*. Of the Diptera or two-winged flies, larvae and pupae of the family Chironomidae far outnumbered the others at all sites.

Because all the streams with the possible exception of the River Strathy were considered unsuitable for Surber sampling, quantitative data on invertebrate numbers before and after spraying are not available, but kick samples taken approximately one month after treatment on 17/18-7-78 made it possible to produce lists of species still alive in the treatment areas (Table 12.6). Not every species taken in the drift nets was collected in the kick samples, although a wide range of species representing several orders was collected from each stream. The kick samples did contain several species not found in the drift net material from the same stream. Larvae of the caddis *Wormaldia subnigra* were present in all the kick samples but were absent from the Allt a' Bhealaich and River Strathy drift nets. None of the drift samples contained larvae of the alder fly *Sialis fuliginosa* found in kick samples from Allt Rosail, and neither adults nor larvae of the beetle *Limnius volkmari* appeared in any of the drift material, but they were taken in kick samples from 3 out of the 4 streams described here.

Only Allt a' Bhealaich was given a single spray treatment and it is therefore difficult to assess the reaction of the invertebrates to the fenitrothion, because it is not known whether the effects were the result of the initial spraying or a combination of two or (for Allt Rosail) three applications. From the close relationship between peak amounts of fenitrothion in the water and peak numbers in the drift nets, it seems that the animal populations reacted within an hour or two of the initial spraying in Allt Rosail and the Uair Burn. (The two missing Uair Burn samples contained large numbers of insects). Reaction at Allt a' Bhealaich was slower, but the sluggish flow probably resulted in a very slow downstream drift of insects into the net. The position at the River Strathy was complicated by the fact that some fenitrothion may have entered the river following the Achruggan forest LV spraying on 12-6-78 and, subsequent to this, fenitrothion may have reached the drift net site after the Uair Burn treatments on 13-6-78 and 14-6-78. The relatively uniform levels of fenitrothion in the water during the observation period, and the similarity in the numbers of aquatic insects in the drift net samples, support this view.

It was not possible to decide what proportion of animals entering the drift nets was alive, and samples of bottom fauna collected the day after the initial spraying showed that live and dead specimens of the same species were present, but that the movements of some individuals were very feeble. The range of species present in the nets indicates that the effect of the fenitrothion was universal and not confined to one or two orders. The differences in the proportions of species between streams are probably a reflection of the character of the streams rather than of the action of the fenitrothion.

Terrestrial insects formed a significant proportion of the catch in most samples in all streams. Since mortalities in this group were independent of fenitrothion concentrations in the water, it is not surprising that the correlation with aquatic insect peaks is not close. The majority of these insects were winged, and although it is likely that they were affected initially by contact with droplets in the air, or on a substrate such as grass or the bark of a tree, it is interesting that as late as 6h after spraying had been completed in the Truderscaig forest, live moths and butterflies were observed flying in clearings between the trees. Allt a' Bhealaich differed from the other streams with respect to captures of terrestrial insects, for here a much higher number was collected in the pre-treatment samples than subsequently. This may have been because dead and dying insects were unable to drop through the vegetation overhanging much of this very narrow stream. The water-cricket (*Velia* spp. - not included in the histograms) was also present in larger numbers in pre-treatment drift samples. This insect, being an inhabitant of the water surface, could easily avoid contact with a water-borne insecticide by taking refuge on the mud at the water's edge. There would be less opportunity to do this in a larger stream, and *Velia* nymphs were taken regularly in drift nets, particularly in the Uair Burn.

In assessing the value of the information contained in Table 12.6, which gives a list of the species taken in the July kick samples, several factors must be considered. Both the Uair Burn and Allt Rosail were very difficult to sample because of the high proportion of boulders in the former and the extent of the rocky substrate in the latter. Also, animals in the drift nets were likely to have come from a very large area of the stream, far greater than would be covered in the course of kick sampling, and in addition, several of the species represented in the drift nets were taken in very small numbers over a period of up to two days. If these species were in fact very sparsely distributed, it is unlikely that they would have been collected by a few minutes of kick sampling. Nevertheless, the absence of *Ephemerella ignita* from the Uair Burn kick samples and the absence of mayfly nymphs from the Allt Rosail may be significant. This may also be true of caddis larvae of the family Polycentropidae, which were taken in drift samples at all 4 sites but were not found in any of the kick samples.

The information obtained during these observations is in general comparable to that given in published accounts of similar work. Flannagan (1973) noted an increase of 700-800 per cent in the number of chironomids in his drift nets a few hours after spraying and a large increase also in the number of terrestrial invertebrates captured. Eidt and Sundaram (1975) and Peterson and Zitko (1974) found that numbers taken in drift samples returned to normal after the pulse of fenitrothion had cleared. Similar observations were made on the invertebrates in Allt a' Bhealaich (the beetles were an exception here) and the Uair Burn. The position at Allt Rosail was not so obvious but a general decrease in numbers was recorded following the third application. Changes in biomass were not studied in the course of the present work but information in the literature on this matter is not always relevant; firstly because much of the data on concentrations is based on an applied dose and not on the fenitrothion content in the water and, secondly, because the application method quoted is in most cases the LV or standard spray technique. Biomass studies are difficult to undertake, primarily because of the difficulty of obtaining adequate controls, but also because of the problem of recolonisation from untreated areas, and the rapid development from egg to winged adult undergone by some species of insect.

CONCLUSIONS

The main objectives of the investigation were achieved.

A maximum concentration of 48 µg/litre fenitrothion was found in one of the streams immediately after spraying but, in the others, the maximum was less than 18 µg/litre. The decline in concentration was more rapid after the ULV spray than after the LV treatment, but in every case levels were well below 1 µg/litre after 5 days. Since several of the streams received more than one application only a general assessment of the decline in concentration could be made. Concentrations in the water increased after rain, presumably due to runoff from foliage and the soil, but the raised levels were never more than were found in the streams 5 days after treatment. The fenitrothion produced no detectable concentrations of metabolites.

There were no mortalities among caged rainbow trout and salmon fry. The concentrations of fenitrothion in the trout followed closely the patterns in the water, indicating that the fish were able to excrete the chemical very quickly. Concentrations of fenitrothion in resident brown trout and eels were no different from caged rainbow trout sampled at the same time. Samples of resident fish obtained one month after treatment contained no detectable amounts of fenitrothion.

A sharp increase in the number of invertebrates taken in drift nets was observed within a few hours of application. This decreased rapidly as the fenitrothion concentration in the water fell. A wide range of invertebrate species was affected. Although it was not possible to take quantitative samples, kick samples taken a month after spraying showed that representatives of many of the species had survived treatment.

The results obtained correspond closely to the findings of Canadian workers who have studied the effects of fenitrothion. It is not possible to assess the long-term effects on fish stocks of individual treatments of this type as a result of this investigation, since no detailed history of the fish populations at these sites is available. No short-term effects have been observed on the fish.

ACKNOWLEDGEMENTS

We would like to thank the staff of the Highland River Purification Board for assisting in this investigation, and we would also like to acknowledge the help given by Mr G. Reid and other Forestry Commission staff at Bettyhill for technical assistance with radio communications. Other members of staff at the Freshwater Fisheries Laboratory assisted in the collection of samples and subsequent analyses.

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Table 12.1

Concentration of Fenitrothion in Water After Spraying (µg/litre)

Sample Station	*Spray Method*	*1 Day Little*	*5 Days Rain*	*10 days After Rain*	*40 Days*
Uair Burn	ULV	2.03	0.031	0.12	ND*
Allt a' Bhealaich	ULV	1.61	0.14	0.15	ND
Allt Dalharold	LV	2.64	0.12	0.21	ND
Allt Rosail	LV	6.60	0.17	0.36	ND
River Strathy	ULV + LV	1.16	ND	0.02	ND

*ND = Not Detected (minimum detectable level = 0.03 µg/litre)

Table 12.2

Input of Fenitrothion to Streams Monitored as Percentage of Total Load to Forest Area. Application Rate - 300g Active Ingredient per ha.

Forest Area	*Stream*	*Area (ha)*	*Total load (kg)*	*Input to Stream (g)*	*% of Total*
Strathy	Uair Burn (ULV)	236	710	19.4	0.028
Truderscaig	Allt a' Bhealaich	772	232	0.26	0.00001
Rosal	Allt Rosail (LV)	675	202	1.4	0.00007
Rosal	Allt Dalharold (LV)	675	202	1.78	0.00009

Table 12.3

Concentration of Fenitrothion in Whole Rainbow Trout (mg/kg)

Sample Station	*Spray Method*	*Concentration of Fenitrothion* 6h	*12h*	*24h*	*48h*	*72h*	*96h*
Uair Burn	ULV	1.91	1.24	1.33	0.217	0.031	0.004
Allt a' Bhealaich (mouth)	ULV	0.58	0.97	0.46	0.32	0.24	0.011
Allt a' Bhealaich (road)	ULV	1.77	1.78	0.51	0.14	-	0.04
Allt Dalharold	LV	0.30	2.1	1.28	0.86	0.20	0.050
Allt Rosail	LV	0.34	0.37	1.58	1.71	-	0.08

Minimum Detectable Concentration 0.003 mg/kg

Table 12.4

Concentration of Fenitrothion in Salmon Fry, 5 Days after Spray Commencement (µg/g)

Sample Station	*Spray Method*	*Concentration*
Uair Burn	ULV	0.003
Allt a' Bhealaich (mouth)	ULV	0.006
Allt Dalharold	LV	0.010
Allt Rosail	LV	0.017
River Strathy	ULV + (LV)	0.004

Table 12.5

Concentration of Fenitrothion in Indigenous Population of Salmonids and Eels In the Spray Area (µg/g)

Station	*No of Fish Analysed*	*Species*		*2 Days Post-Spray*	*1 Month Post-Spray*
Uair Burn	6	Brown Trout	Mean	1.07	
			Range	1.48-0.78	ND*
	6	Eels	Mean	0.36	
			Range	0.59-0.19	ND
River Strathy	6	Brown Trout	Mean	-	
			Range	-	ND
	6	Eels	Mean	0.032	
			Range	0.053-0.03	ND
Allt Dalharold	5	Brown Trout	Mean	0.267	
			Range	0.48 -0.053	ND
		Eels	Mean	-	
			Range	-	ND

*ND = Not Detected. Minimum Detectable Concentration = 0.003 µg/g.

Table 12.6

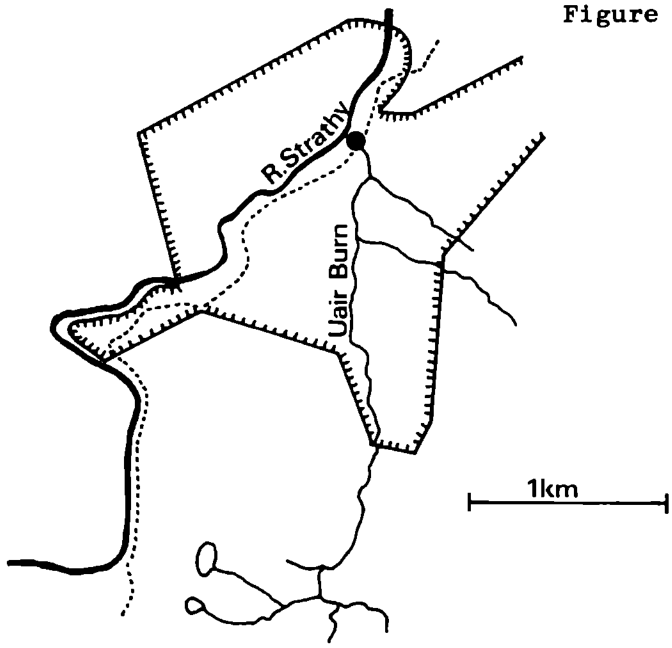
Invertebrate Samples (kick samples) Taken on 18 July 1978

+ = *Species Present in Kick Sample*
O = *Species Taken in Drift Net but Absent from Kick Sample*

Taxa	*Uair Burn*	*Allt a' Bhealaich*	*Allt Rosail*	*River Strathy*
OLIGOCHAETA	+	+	+	+
EPHEMEROPTERA				
Ecdyonuridae	+		O	+
Baetidae	+	+	O	+
Ephemerella ignita	O		O	+
Paraleptophlebia sp.	O		O	
Caenis	O			
Siphlonurus lacustris		+		
PLECOPTERA				
Leuctra spp.	+	+	+	+
Amphinemoura sulcicollis	+	O	O	O
Protonemoura sp.	O			
Isoperla grammatica	O		O	
Chloroperla torrentium	O	O	O	
Diura bicaudata	O			
Dinocras cephalotes				+
HEMIPTERA				
Velia spp.	O	+	O	O
TRICHOPTERA				
Rhyacophila spp.	+		O	+
Hydropsyche spp.	+		O	+
Hydroptila sp.	+		O	+
Polycentropidae	O	O	O	O
Wormaldia subnigra	+	+	+	+
Other caddis	O	+	O	O
MEGALOPTERA				
Sialis fuliginosa			+	
DIPTERA				
Chironomidae	+	+	+	+
Simuliidae	+	O	+	+
Tipulidae	+	+	+	+

Taxa	*Uair Burn*	*Allt a' Bhealaich*	*Allt Rosail*	*River Strathy*
COLEOPTERA				
Oreodytes rivalis (a)	O	O	O	O
Hydroporinae (l)	O		O	O
Hydroporus spp. (a)		O	O	
Platambus maculatus (a)		+		
Haliplus lineatocollis	O	O	O	
Oulimnius tuberculatus (a)	+	+	O	+
Oulimnius tuberculatus (l)	+	+	O	+
Elmis aenea (a)	+	O	O	+
Elmis aenea (l)	+	O	+	+
Esolus parallelopipidus	O		O	
Limnius volkmari (a)	+			+
Limnius volkmari (l)	+	+		
Hydraena gracilis (a)	+		+	O
Helodidae (l)	O	+	+	
HYDRACARINA	O			
MOLLUSCA				
Limnaea pereger		+	+	+

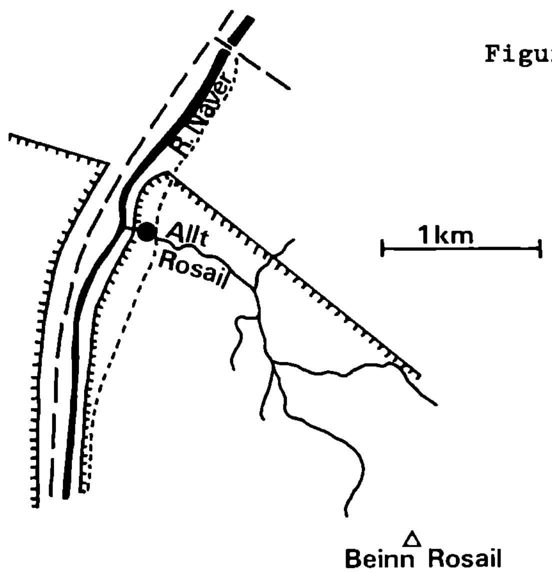
Figure 12.1



Stream sampling sites

Strathy, Rosal and Truderscaig

Figure 12.2



Forest Boundary

Main road

Forest road

Sampling site

Figure 12.3

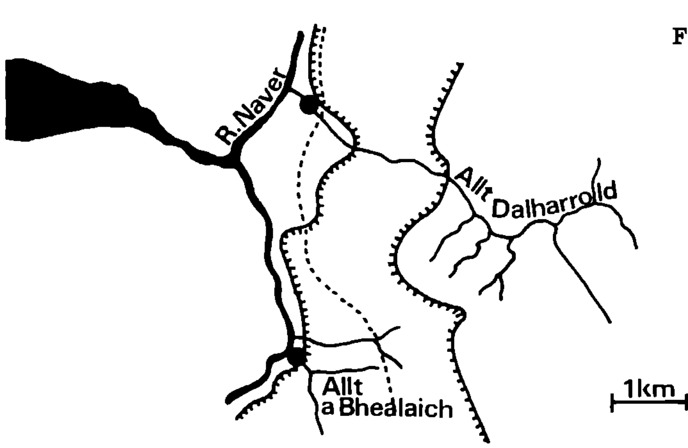


Figure 12.4 Sampling Programme - Naver Forest
13-20 June 1978

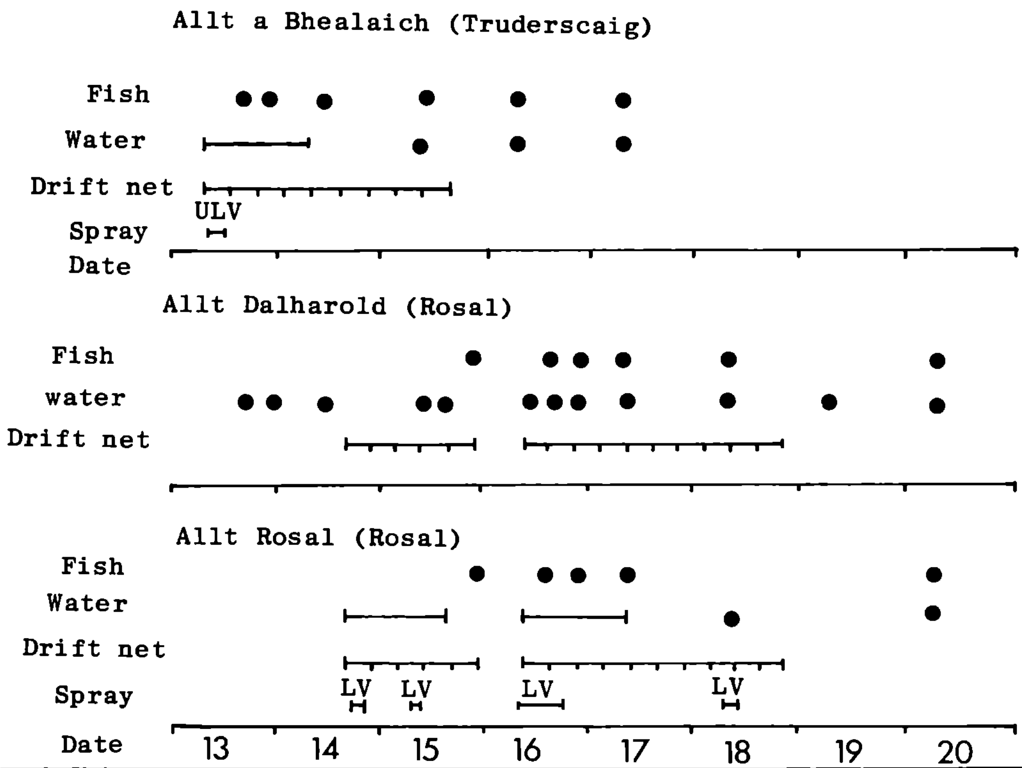
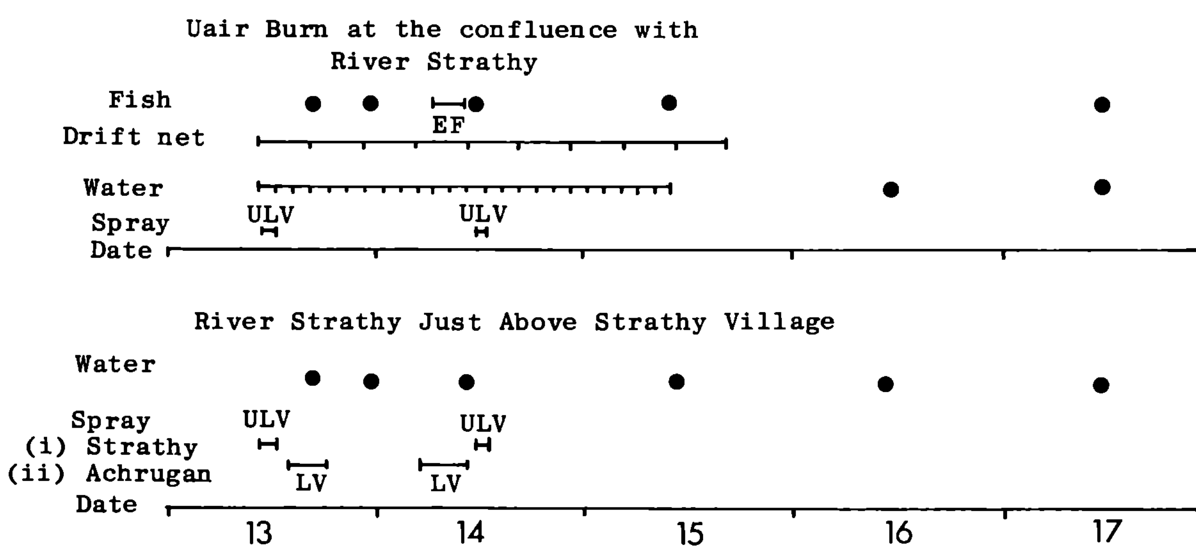


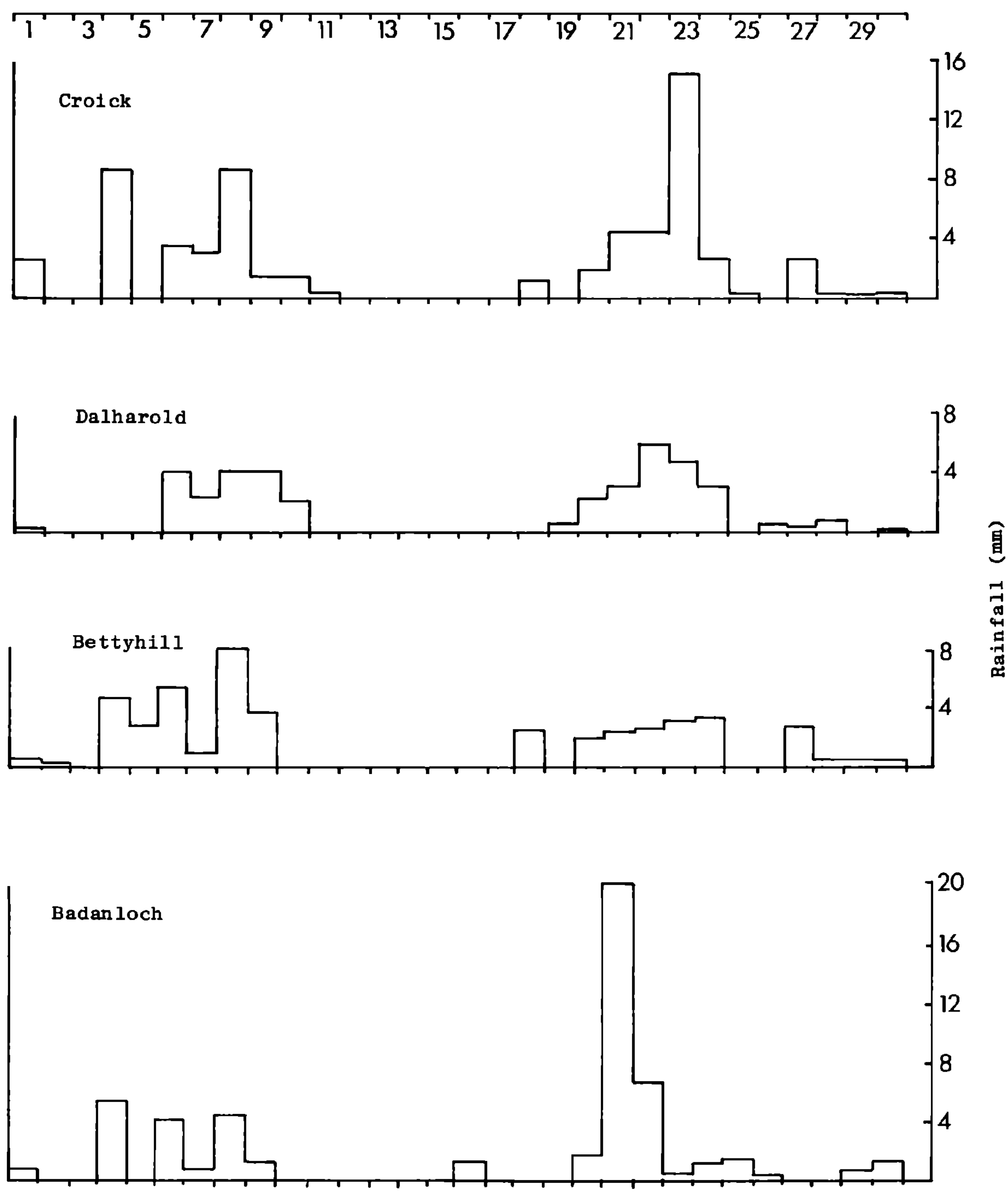
Figure 12.5

Sampling Programme - Strathy Forest
13-17 June 1978



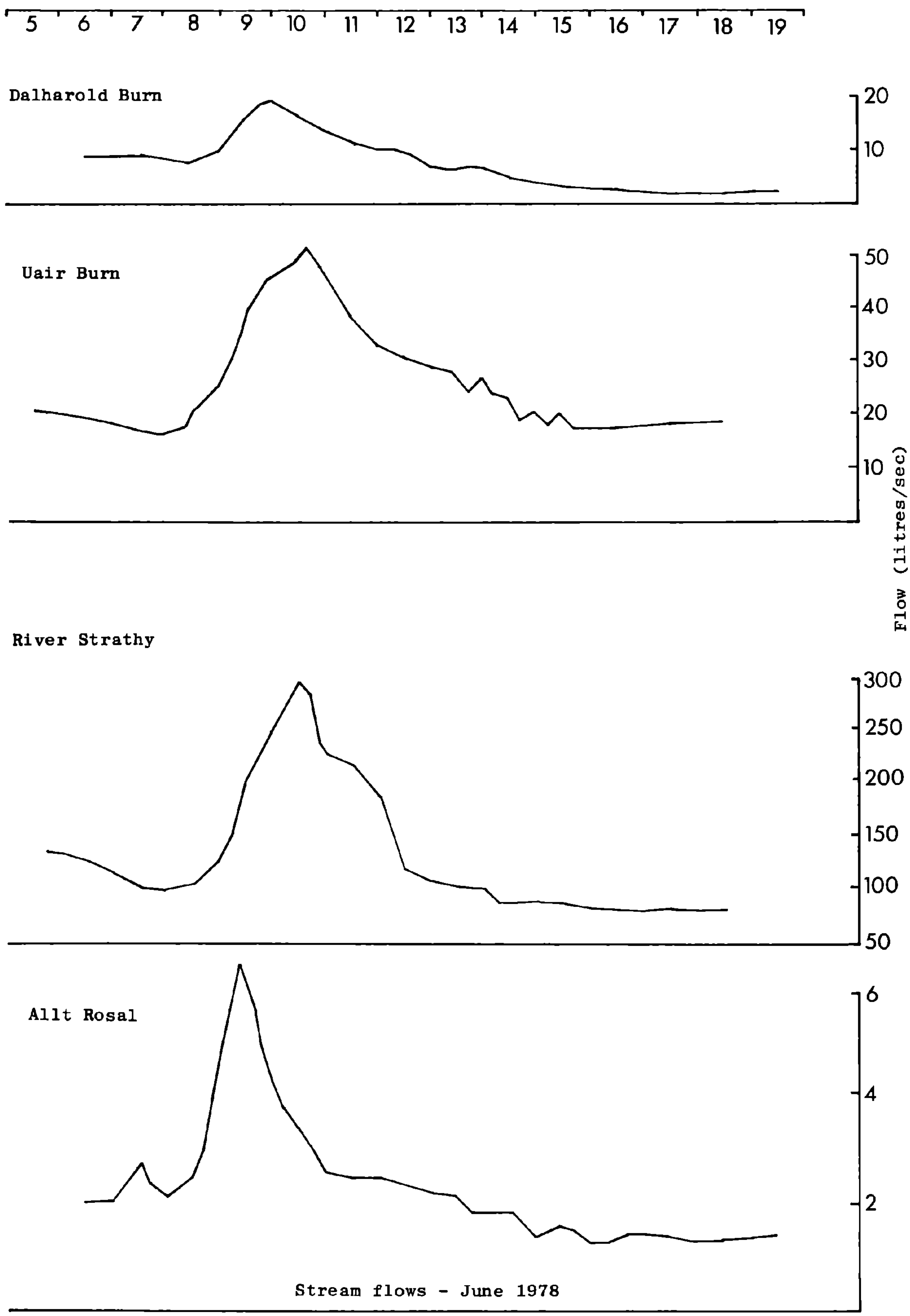
* EF = Electrofishing

Figure 12.6



Daily Rainfall June 1978

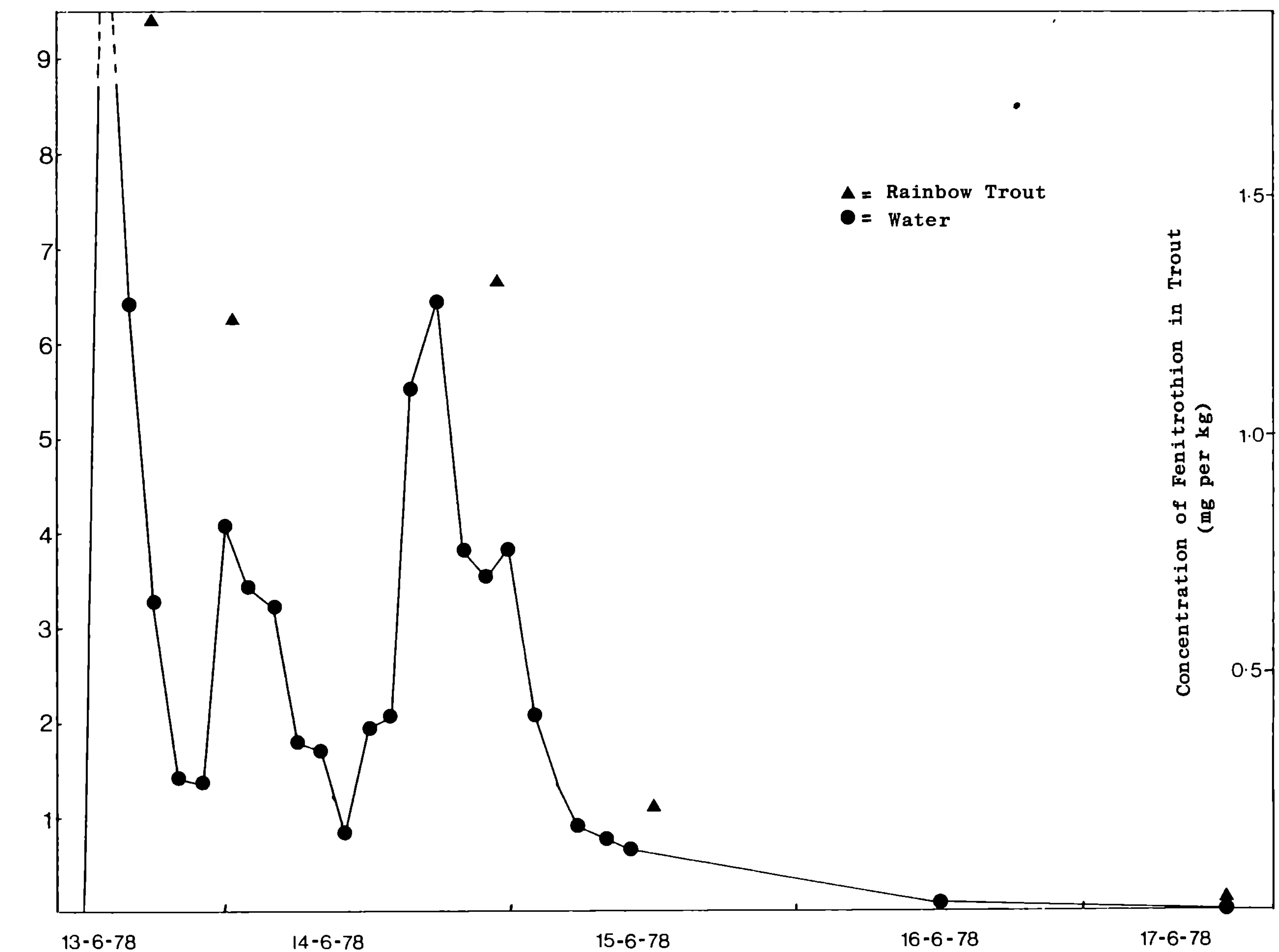
Figure 12.7



Stream flows - June 1978

Figure 12.8

Uair Burn



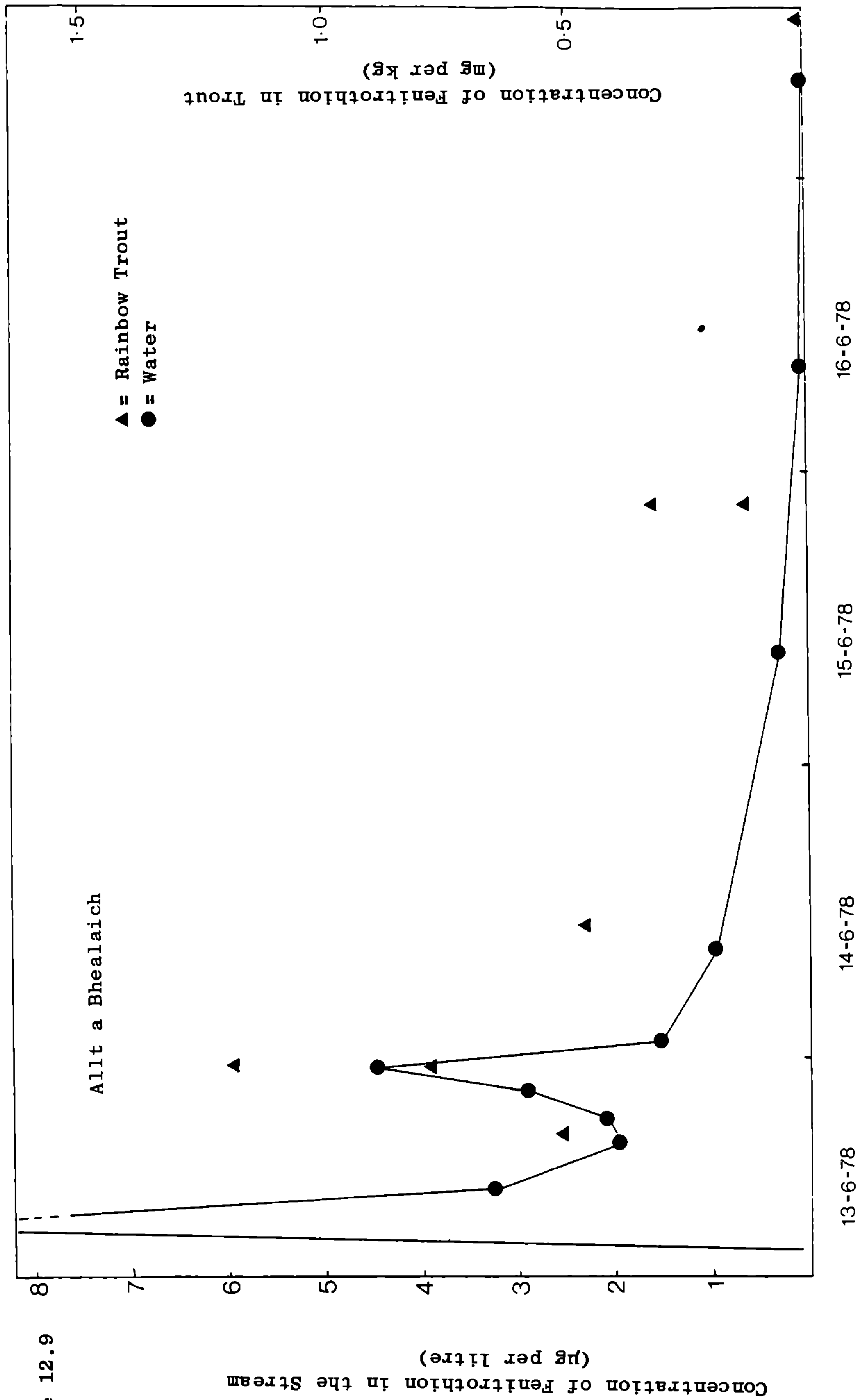

Allt a Bhealaich
▲ = Rainbow Trout
● = Water
Concentration of Fenitrothion in Trout
(mg per kg)
1·5
1·0
0·5
Concentration of Fenitrothion in the Stream
(μg per litre)
8
7
6
5
4
3
2
1
13-6-78
14-6-78
15-6-78
16-6-78

Figure 12.9

Figure 12.10

Allt Dalharold

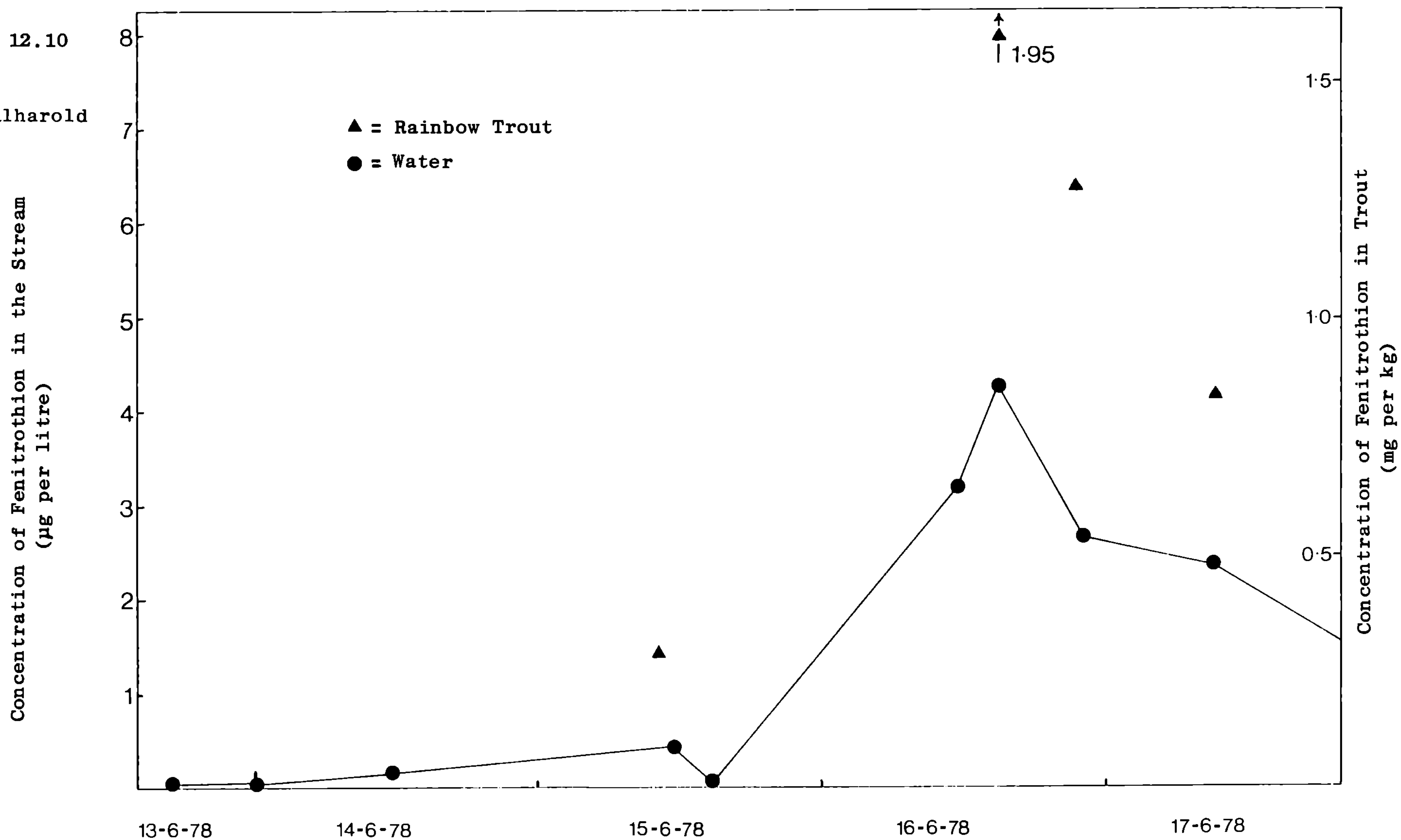


Figure 12.11

Allt Rosal

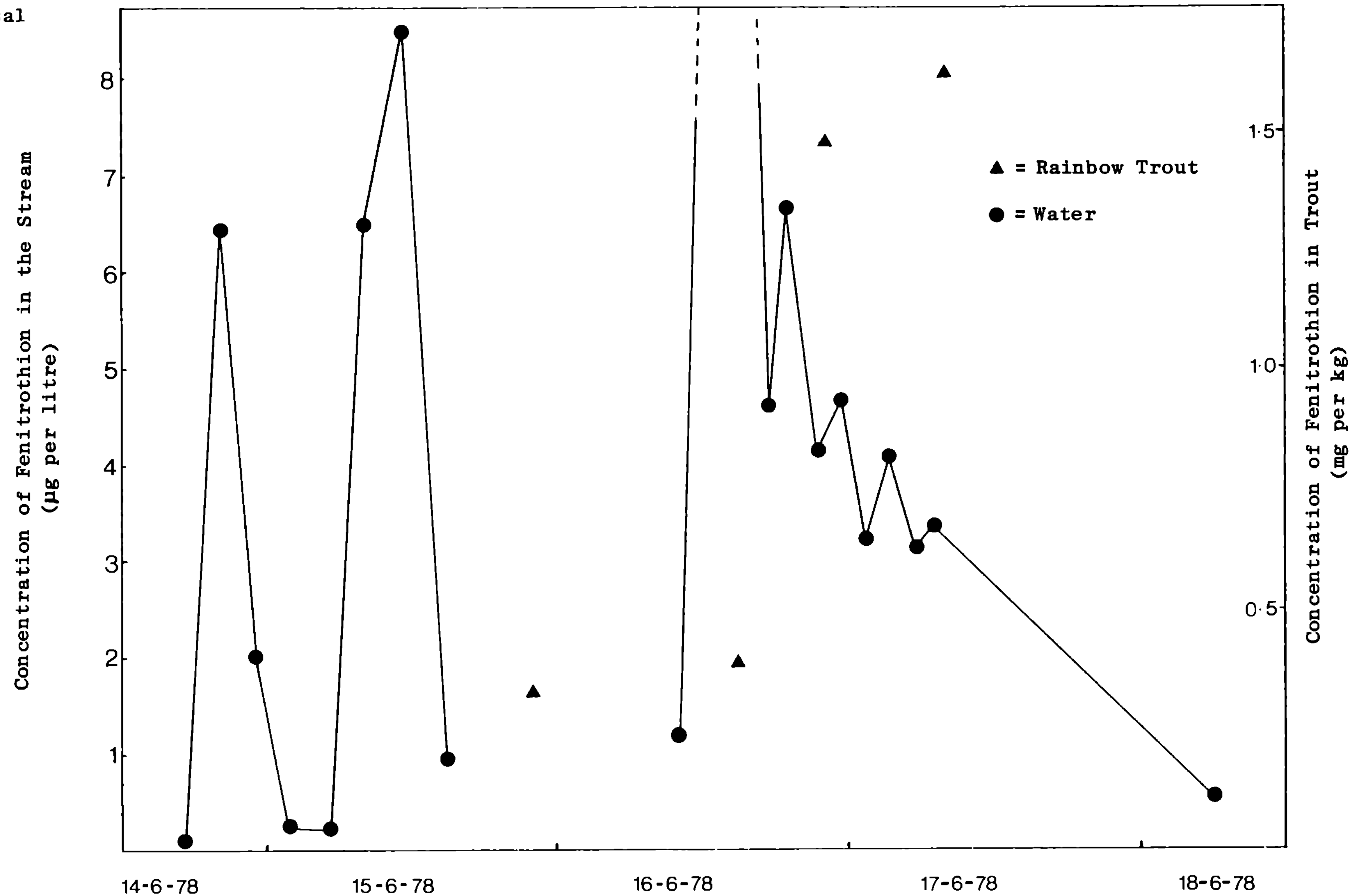


Figure 12.12

River Strathy

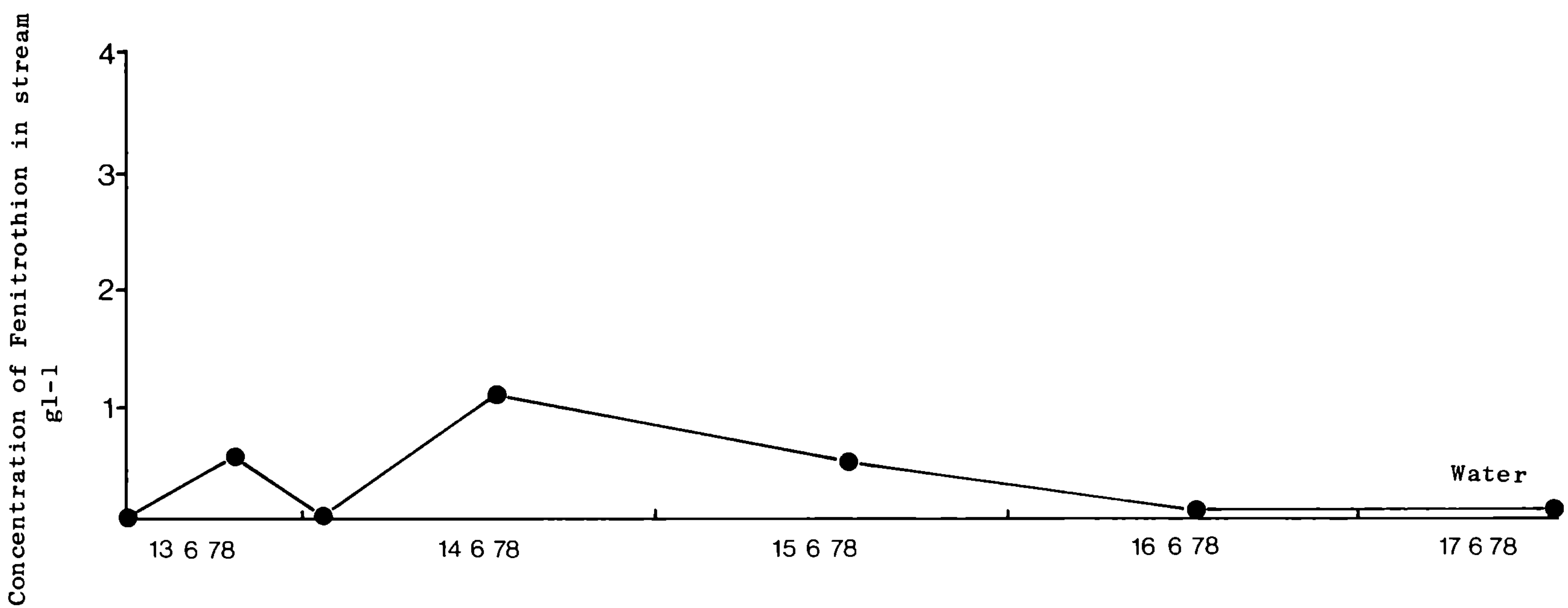


Figure 12.13

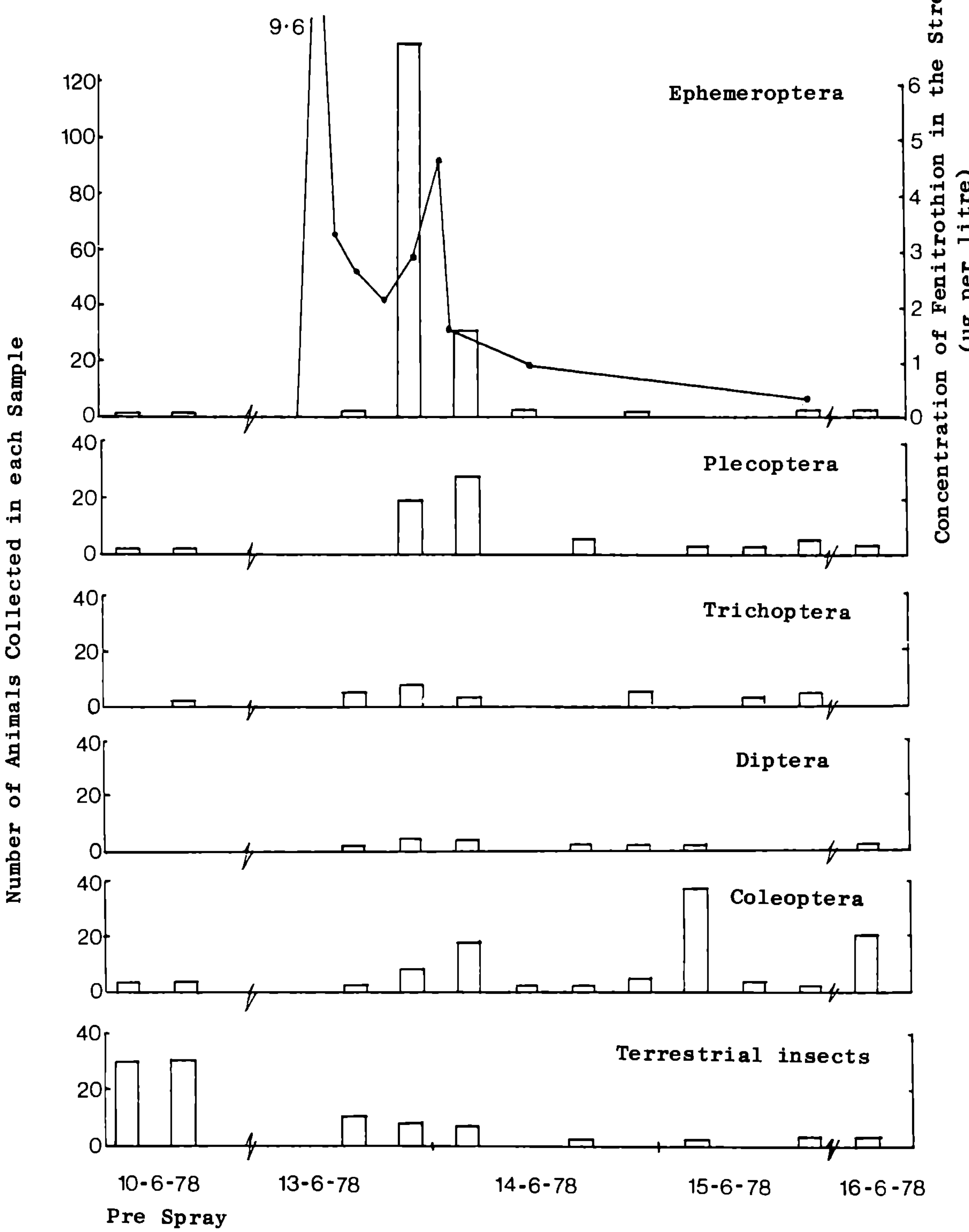

9·6
Ephemeroptera
Plecoptera
Trichoptera
Diptera
Coleoptera
Terrestrial insects
Number of Animals Collected in each Sample
Concentration of Fenitrothion in the Stream (µg per litre)
120
100
80
60
40
20
0
6
5
4
3
2
1
0
10-6-78
Pre Spray
13-6-78
14-6-78
15-6-78
16-6-78

Figure 12.14

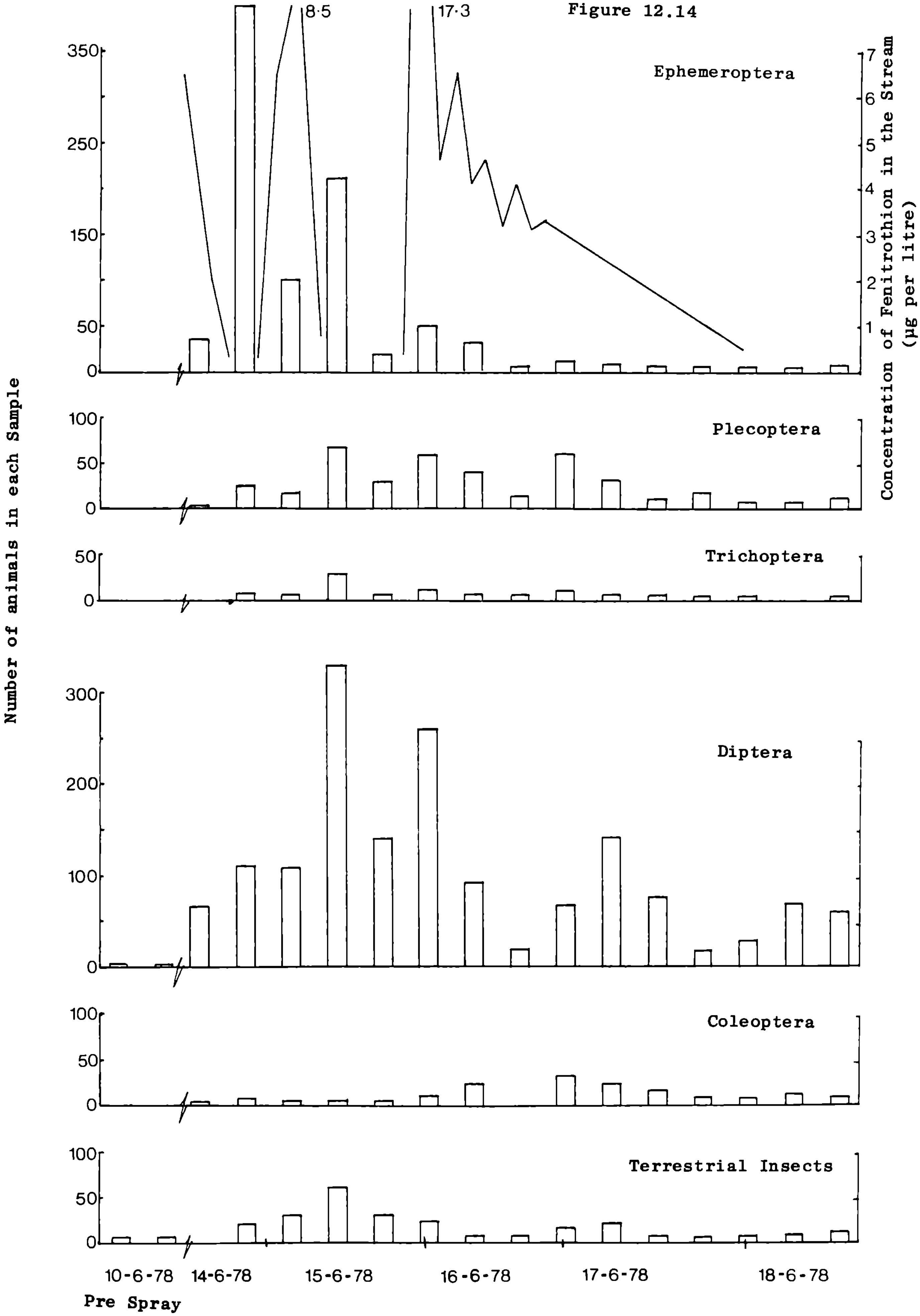

8·5
17·3
Ephemeroptera
Plecoptera
Trichoptera
Diptera
Coleoptera
Terrestrial Insects
Number of animals in each Sample
Concentration of Fenitrothion in the Stream (µg per litre)
350
250
150
50
0
100
50
0
50
0
300
200
100
0
100
50
0
100
50
0
7
6
5
4
3
2
1
10-6-78
14-6-78
15-6-78
16-6-78
17-6-78
18-6-78
Pre Spray

Figure 12.15

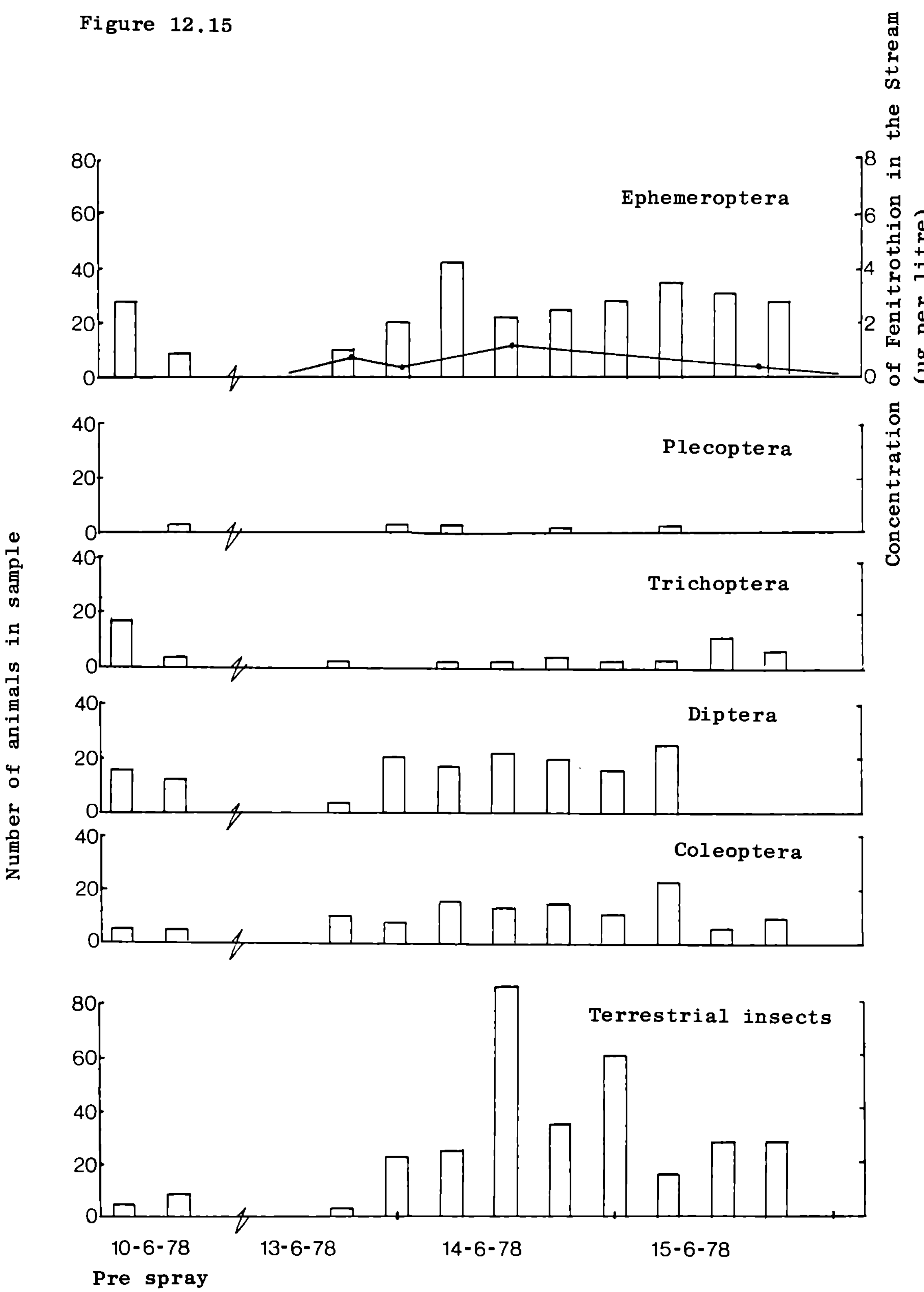
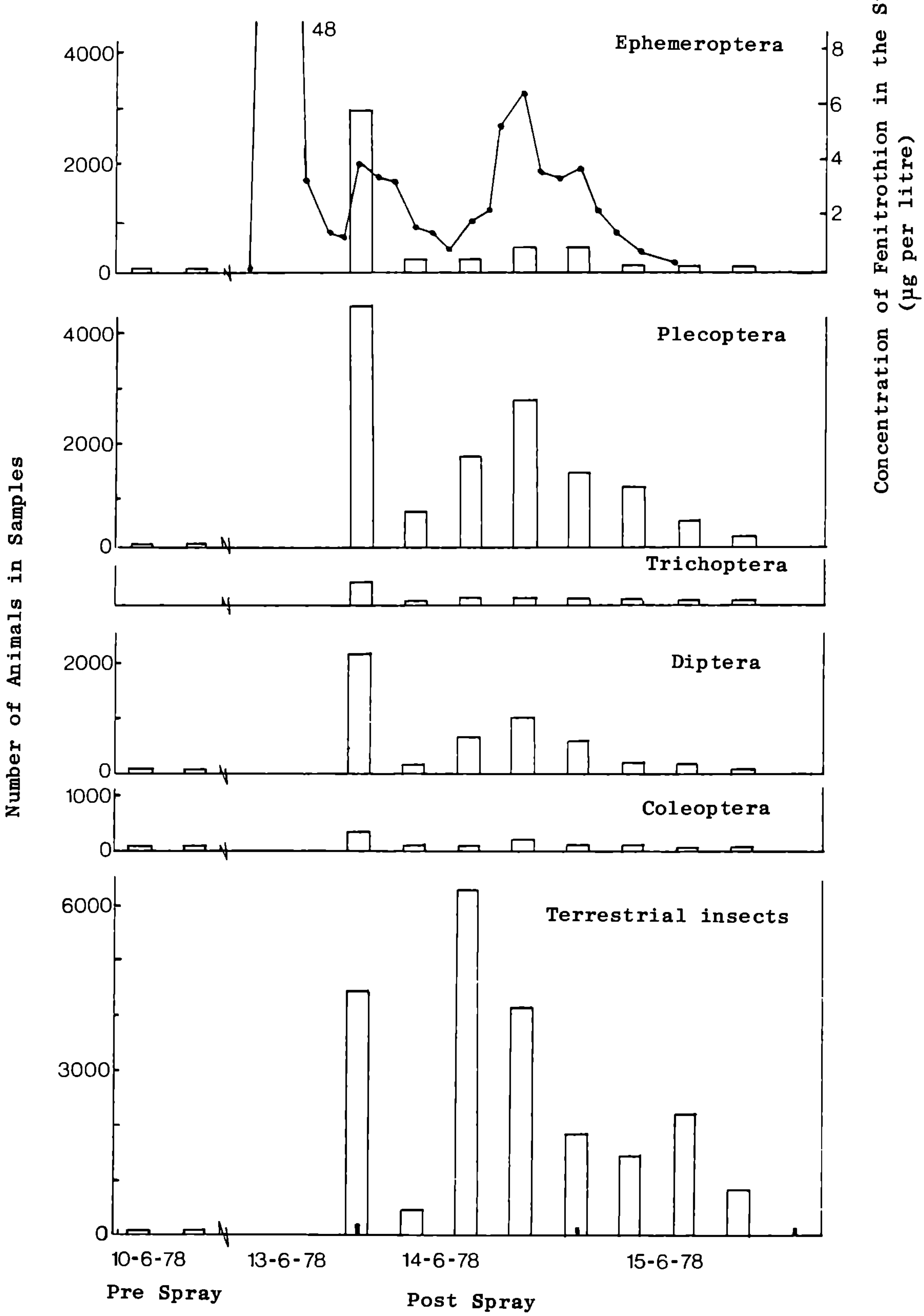

Number of animals in sample
Concentration of Fenitrothion in the Stream (µg per litre)
Ephemeroptera
Plecoptera
Trichoptera
Diptera
Coleoptera
Terrestrial insects
0
20
40
60
80
0
2
4
6
8
10-6-78
Pre spray
13-6-78
14-6-78
15-6-78

Figure 12.16


Ephemeroptera
Plecoptera
Trichoptera
Diptera
Coleoptera
Terrestrial insects
48
4000
2000
0
6000
3000
1000
8
6
4
2
Number of Animals in Samples
Concentration of Fenitrothion in the Stream (µg per litre)
10-6-78
13-6-78
14-6-78
15-6-78
Pre Spray
Post Spray

Chapter 13

THE EFFECTS ON WILDLIFE OF FENITROTHION APPLICATION TO FORESTRY COMMISSION PLANTATIONS IN SUTHERLAND

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It must be emphasised that the Nature Conservancy Council monitoring programme detailed in this report was, of necessity, very limited in scope and superficial in treatment. The report is included in the absence of other observations the groups covered, but the information presented here must be viewed with the above limitations in mind.

INTRODUCTION

In late March 1978 the Nature Conservancy Council learnt of the Forestry Commission's intention to carry out a large scale spraying operation at selected Lodgepole pine plantations in Sutherland and Caithness, by the application of the non-selective organophosphorous compound fenitrothion using both low volume (LV) and ultra low volume (ULV) techniques from a fixed wing aircraft.

Because of their statutory obligations over the conservation of wildlife, the NCC expressed concern over this operation as did a number of other agencies. A meeting was held at the DAFS laboratory at Pitlochry on 10 May between representatives of some of the agencies who intended to undertake some form of monitoring, and this meeting and subsequent discussions resulted in some integration of the monitoring effort. The major benefits of this were the elimination of unnecessary duplication of effort, co-ordination of sampling sites and procedures, thus avoiding experimental disturbance, and co-operation over certain logistic arrangements.

When framing their contribution to the monitoring programme, the NCC took the following points into consideration:-

1. That freshwater monitoring, including the effects on vertebrate and invertebrate organisms, was being adequately covered by the Freshwater Fisheries Laboratory, Pitlochry, in conjunction with the Highland River Purification Board.

2. Results of extensive monitoring of the use of fenitrothion in Canada had seemed to indicate that the effects on terrestrial wildlife were relatively small.

3. Staff resources and time available would limit the scope of any monitoring exercise.

4. Any effects on animal groups potentially at risk would in most cases be extremely difficult to establish with any scientific reliability. This would apply particularly to invertebrate populations where no base line data existed. The detection of direct effects on such organisms, particularly if they are sub-lethal, would require reliable information on normal population levels and range of variation. Where indirect effects are concerned, a knowledge of inter-relationships within communities, especially the food web, would also be necessary.

5. With two or three exceptions the spraying operation did not directly threaten any sites already identified as of special scientific interest.

This report describes the monitoring effort undertaken or initiated by the NCC during this spraying operation. Chemical analysis was undertaken by the Department of Agriculture and Fisheries for Scotland (See Chapter 12) at their East Craigs Laboratories and a bird census study, before and after spraying, was carried out by the Royal Society for the Protection of Birds commissioned by the NCC (See Chapter 14).

OBJECTIVES

The groups which seemed to be at greatest risk from pesticide application were invertebrates, particularly flying forms or those using the canopy, and birds. In both cases effects may be due to direct contact with the chemical or indirectly through food supply reduction and/or contamination. Other animal species such as those living on the ground should have been less susceptible to direct contact but may have been affected by intake of contaminated food.

Because of the great problems associated with studies of invertebrate populations and the general lack of knowledge of the invertebrate species and numbers in the area, it was decided to concentrate on the bird populations. Birds are an important and conspicuous component of the forest system, much is already known of their ecology, fairly reliable estimates of their numbers can be made in a short period and, depending on feeding habits, they can act as indicators of fluctuations in numbers of other groups.

Accordingly the major objective of the monitoring programme was to determine whether the spraying had any identifiable effect on the bird population. A subsidiary objective was,by collections and observation, to establish any significant effects on other groups, such as small mammals and the larger invertebrates.

Monitoring sites would be selected to enable a comparison of the effects of LV and ULV spraying techniques.

METHODS

Two pairs of adjacent plantations were chosen as study areas in conjunction with the other monitoring agencies. Each pair had one plantation subjected to LV spraying and the other to ULV spraying. The areas were Achrugan (LV) Strathy (ULV), and Rosal (LV) Truderscaig (ULV).

BIRDS

A census of song birds within each block was carried out before and after spraying in each plantation (See Chapter 14). Specimens of some of the commoner species were shot from Achrugan and Strathy plantations (licence issued under the Protection of Birds Acts 1954 to 1976) for chemical analysis. Collection was, of necessity, opportunistic so a range of species was represented.

Some specimens were taken shortly after spraying to establish the levels of pesticide carried by birds due to direct contact during application. A second sample was taken between 48 and 60 hours after spraying to determine what levels still persisted. It was assumed that these pesticide figures would reflect any build up in the gut or body tissues due to ingestion of contaminated food. Chemical analysis was of whole birds including plumage.

MAMMALS

A series of 24 Longworth traps was positioned in two different areas in both Achruggan and Strathy plantations. They were set to operate during the 12-24 hours after spraying. Representative specimens were killed for subsequent chemical analysis.

INVERTEBRATES

One light trap was positioned at each of the four locations (2 in Strathy and 2 in Achrugan) chosen for mammal trapping and operated during the night following spraying in each case. Control trapping was undertaken on the night prior to spraying but unfortunately this was only possible at one location. Specimens of the larger flying insects and pond skaters were collected from both plantations within a few hours of spraying for chemical analysis. Direct observations were made of the effects of the spray on the more conspicuous invertebrates.

Locations of mammal and light traps are marked on Figure 14.1.

RESULTS

BIRDS

Bird census results are given in the RSPB Report (Chapter 14). The specimens taken for analysis, together with their whole body residue levels are given in Table 13.1. By bulking data from both forests, mean values for each species on each sampling occasion are given in Table 13.2.

MAMMALS

Details of the specimens trapped are given in Table 13.3. Analysis of each of the whole bodies of the animals collected showed no detectable fenitrothion residue. The limit of detection for the analysis was 2 µg/animal which is approximately equivalent to 0.2 mg/kg.

INVERTEBRATES

Except for 2 or 3 very small dipterans, no specimens were collected in any of the light traps including the control occasion before spraying. The specimens taken for analysis, together with their whole body residue levels, are given in Table 13.4.

The following observations were also made:-

a) Effects on Odonata. Two areas in Strathy Forest were examined for Odonata immediately after spraying and 24 hours later. Weather conditions were similar on both occasions. The number of insects obtained were as follows:-

Species	*Area 1* *50m Length Open Ride*		*Area 2* *75m x 30m Glade Around Stream*	
	13 June	*14 June*	*13 June*	*14 June*
Libellula quadrimaculata	8	0		
Pyrrhosoma nymphula	12	1	15	8

The sprayed area was examined on 27 August (nearly 10 weeks later) and many *Sympetrum scoticum* were observed, indicating that spraying had not resulted in mortality of the aquatic stage of this species.

b) As well as good control of the target species, the pesticide seemed to kill almost all the sawfly larvae which were heavily infecting the pine trees.

c) Other non-target insects affected by the spray were aphids and lepidoptera. Nevertheless, many day-flying geometrid moths, bumble bees, diptera, mayflies stoneflies and dragonflies were all flying in the forests shortly after spraying.

DISCUSSION

Because of the limited monitoring programme carried out, only the more dramatic effects of the pesticide application would have been discernible.

BIRDS

Previous monitoring of the effects of fenitrothion application to forests in Canada suggested that at the concentration used in this current exercise, direct contact during spraying was unlikely to be lethal to birds. Even if some individuals had died during the first few days after spraying, however, it is most unlikely that their bodies would have been found. Nevertheless, it seems from the evidence of the song bird census that little or no immediate mortality occurred in the species registered. Levels of fenitrothion measured on birds collected immediately after spraying indicated body burden compared to similar measurements made in Canada. Much of this must have been due to pesticide coating the plumage and the large variation in fenitrothion levels on the first sampling date may therefore reflect the degree of exposure of individual birds during spraying.

In spite of the sample being small and of mixed species, it is evident that there was a decrease in pesticide levels during the following 2-3 days. What is not known, however, is whether the fenitrothion still present after this time was the remains of that trapped in the plumage and/or that taken into the gut or body tissuesthrough feeding or preening. If the latter, it is, once again, not possible to say whether higher levels had proved lethal to other individuals as only live specimens were collected for analysis. Nevertheless, the song bird census data again indicate little or no effect on populations in the days following spraying, with the possible exceptions of robin and Willow warbler.

The same is true of longer term indirect effects on birds such as may be caused by a reduction or alteration in food supply. Eradication of the invertebrate population would be expected to result in a reduction in breeding success and a decline in population levels. During the period of monitoring, however, no such effect was evident, either from bird census data (again with the possible exceptions of robin and Willow warbler) or fledgling success from those nests and family groups observed (Chapter 14).

It is clear that more detailed longer term monitoring would have been required to determine the precise ecological effects on bird species.

MAMMALS

Trapping of small mammals showed marked variation in densities between the two sample plantations. This suggested that numbers were much higher in the more mature Strathy Forest. There was no evidence that any pesticide had reached these ground-living mammals either directly or indirectly. Because of the short duration of sampling, however, it is not possible to comment on whether there was any build up of residue in insect eaters, such as shrews, due to subsequent ingestion of contaminated larvae dropping from trees above.

INVERTEBRATES

As well as a dramatic reduction in the larvae of the target species, *Panolis,* as well as Pine sawfly, it was obvious that many other invertebrates, particularly flying insects, were killed by the spray. Many of the more conspicuous species were active immediately after spraying but some of these contained measurable quantities of fenitrothion which may subsequently have killed them or produced sub-lethal effects. Observational evidence, however, indicates that many groups survived. Without knowing more about the normal composition of the invertebrate fauna, however, and the biology and ecology of individual species it is not possible to speculate on the long term effects.

There was no evidence of any differential effects on wildlife between the LV and ULV treatments but it is unlikely that the monitoring carried out would have been sensitive enough to detect this.

CONCLUSION

Within the animal groups monitored there was no firm evidence of any major immediate effects caused by fenitrothion application.

The Lodgepole pine environment is too new and artificial for the animal community to be stable or balanced. Nonetheless it is important to know what influence such large scale pesticide application will have, both within the newly created forest ecosystem and on the surrounding countryside. More information is particularly important if the area and/or frequency of such spraying is to increase. To establish more precisely the effects of such treatment, however, will require a much greater input of resources into the monitoring effort over a longer period.

Table 13.1

Whole Body Levels of Fenitrothion in Live Birds
Taken at Intervals After Spraying

A. Strathy Forest (Sprayed by ULV on 13.6.78)

Date of Sampling	*Species*	*Body Weight (g)*	*Fenitrothion (mg/kg)*
13.6.78	Chaffinch - male	18.1	0.36
"	Chaffinch - female	19.2	3.52
"	Chaffinch - male	19.6	1.48
16.6.78	Chaffinch - male	22.6	1.37
"	Wren	7.0	0.40
"	Coal tit	8.3	0.59
"	Chaffinch - male	20.2	1.23
"	Coal tit	8.7	1.45
"	Coal tit	8.4	0.56
"	Willow warbler (nestling)	10.2	$<$0.05

B. Achrugan Forest (Sprayed by LV on 13 and 14.6.78)

Date of Sampling	*Species*	*Body Weight (g)*	*Fenitrothion (mg/kg)*
13.6.78	Chaffinch - male	20.0	9.32
"	Meadow pipit	18.2	9.47
"	Willow warbler	10.5	1.62
16.6.78	Meadow pipit	18.3	0.14
"	Willow warbler	9.3	1.02
"	Chaffinch	16.9	0.56
"	Chaffinch	21.7	0.98
"	Meadow pipit	18.0	0.32
"	Coal tit	8.7	1.25

Table 13.2

Mean Values for Body Weights and Fenitrothion Residues
from both Strathy and Achrugan Data on the Two Sampling Occasions

	Immediately After Spraying			*2-3 Days After Spraying*		
Species	*Number*	*Mean Body Weight (g)*	*Mean Fenitrothion (mg/kg)*	*Number*	*Mean Body Weight (g)*	*Mean Fenitrothion (mg/kg)*
Chaffinch	4	19.2	3.67	4	20.4	1.04
Meadow pipit	1	18.2	9.47	2	18.2	0.23
Willow warbler	1	10.5	1.62	2	9.8	0.54
Coal tit	0			4	8.5	0.96
Wren	0			1	7.0	0.40

Table 13.3

Small Mammals Collected During the Night After Spraying

A. Strathy Forest (Sprayed by ULV on 13 June 1978)

Night of Sampling	*Location*	*Species*	*Sex* *	*Body Length (cm) To base of Tail*	*To tip of Tail*	*Body Weight (g)*
13/14.6.78	South	*Apodemus sylvaticus*	♂	7.5	15.0	15.0
"	"	" "	♂	6.5	12.5	11.0
"	"	** " "	♀	9.0	18.0	22.0
"	"	** " "	♂	7.5	15.0	15.0
"	"	*Sorex araneus*	♀	5.5	9.5	9.5
"	North	*Microtus agrestis*	♀	7.5	9.5	11.0
"	"	" "	♀	10.5	14.0	32.0
"	"	" "	♂	6.5	9.5	8.5
"	"	** " "	♂	7.0	9.5	14.0
"	"	*Apodemus sylvaticus*	♂	7.0	12.0	8.5
"	"	*Sorex araneus*	♂	6.5	11.0	9.0

B. Achrugan Forest (Sprayed by LV on 13 and 14 June 1978)

14/15.6.78	East	None
"	West	None

* There is some doubt as to the sex of some individuals.

** These specimens were released and the remainder taken for chemical analysis.

Table 13.4

Whole Body Levels of Fenitrothion in Live Insects Taken After Spraying

A. Strathy Forest (Sprayed by ULV on 13.6.78)

Time and Date of Sampling	*Number and Species in each Sample*	*Total Weight of Sample (mg)*	*Total Amount of Fenitrothion in Sample (µg)*
17.00 - 13.6.78	2 Lepidoptera	12.9	1.06
17.00 - 13.6.78	1 Hymenoptera Apidae 1 Diptera	150	2.00
17.45 - 13.6.78	8 Hemiptera	32.7	0.28
17.45 - 13.6.78	3 Ephemeroptera	15.3	0.11
11.30 - 14.6.78	4 Odonata	188	0.24

B. Achrugan Forest (Sprayed by LV on 13 and 14.6.78)

Time and Date of Sampling	*Number and Species in each Sample*	*Total Weight of Sample (mg)*	*Total Amount of Fenitrothion in Sample (µg)*
14.00 - 14.6.78	1 Hymenoptera Apidae	610	< 0.02
14.00 - 14.6.78	1 Ephemeroptera 1 Plecoptera 1 Odonata	71.5	0.04
14.00 - 14.6.78	1 Lepidoptera 1 Diptera	13.9	0.46
14.00 - 14.6.78	8 Hemiptera	121.6	< 0.02

Chapter 14

THE EFFECTS OF FENITROTHION ON THE BIRD POPULATIONS

R.A. Broad and R.H. Dennis
Royal Society for the Protection of Birds

INTRODUCTION

The Royal Society for the Protection of Birds was concerned about the toxicity of fenitrothion and the possible effects of large scale spraying on the bird populations of the woodland areas and the surrounding important lochs and bogs. The timing of the spraying at the height of the breeding season was felt to be particularly sensitive. Following discussion with the Nature Conservancy Council, the Forestry Commission and colleagues in the RSPB, we accepted the need for a one-off spray programme.

SELECTION OF STUDY AREAS

Of the areas to be sprayed, Strathy, Achrugan , Truderscaig and Rosal plantations were selected as the most suitable for monitoring the effects of the aerial application of fenitrothion on the bird populations. The woodland blocks could be conveniently grouped in 'pairs' (Strathy-Achrugan and Truderscaig-Rosal), in which the first mentioned was to have fenitrothion applied by ultra low volume (ULV) technique and the second by the more conventional low volume (LV) technique. Further, each of the pairs could be monitored with the greatest economy of effort and time by 1-2 observers working independently. Unfortunately it proved impractical to monitor an unsprayed control area of similar woodland.

METHODS

MONITORING OF BIRD POPULATIONS

Strathy - Achrugan

The number of singing birds, supplemented by sight observations, was recorded within 100 metres either side of pre-determined 'walks'. Each 'walk' began and ended at a fixed point and was of approximately 30 minutes duration. The 'walks' (See Figure 14.1) were chosen to include a representative sample of habitats, different age groups of trees and, where present, all stages of defoliation resulting from the depradations of the Pine beauty moth. Four 'walks' were selected in Strathy and three in Achrugan and these were monitored by R. Broad in the same sequence and at the same time of day, each visit commencing at 0515 hours. Every effort was made to ensure that each 'walk' was monitored in the same way on each visit.

After the initial pre-spray counts had been completed it was learnt that the spray programme was to be varied in part of Strathy (Strathy special). This area, just entered by 'walk' number 4, was to be sprayed (ULV) with a day's separation between two half doses of fenitrothion. At this stage it was not possible to make special provision for monitoring this area.

Truderscaig - Rosal

The number of singing birds, supplemented by sight observations, was recorded at a predetermined number of 5-10 minute 'stops' (see Figure 14.2) along the road. The road conveniently ran the length of both woodland blocks and spanned a representative selection of different areas. These 'stops', six in Truderscaig and twelve in Rosal, were monitored by E. and F. Bartlett, and where possible were censused in sequence at the same time, each visit commencing at 0730 hours.

In order to standardise the results, the number of birds recorded are the number of singing birds for song birds plus any additional family parties which were counted as one, irrespective of the size of the family. Two exceptions were made for crossbill and Hooded crow. Family parties and larger flocks of the former species were recorded regularly feeding in areas where the trees were too small for them to have nested. This species was, however, included among the breeding species as it was obviously an important constituent of the avifauna at the time of the spraying. As they were not in song the figures shown for crossbills are the actual number of birds seen. Similarly, for the larger breeding species of non-song birds (and the Hooded crow) the figures recorded were the total number of birds seen.

It had been intended to census all four woodland blocks on two consecutive mornings pre-spraying, immediately post-spraying and again ten days after spraying. However, the dictates of the weather on the spray programme led to modifications of the monitoring programme. Also on some count mornings inclement weather, especially high winds, heavy precipitation and poor visibility, led to further modifications of the monitoring. The final timings of the counts in relation to the spraying are shown in Table 14.1 and relevant notes on the weather are shown after each census.

When time permitted the bird censuses were supplemented by records from other areas of the four woodland blocks and included observations on bird behaviour and breeding success. During the course of the monitoring a number of nests were located and their success was recorded post-spraying.

RESULTS

MONITORING OF BIRD POPULATIONS

The number of breeding birds on each 'walk' (Strathy - Achrugan) and at each 'stop' (Truderscaig - Rosal) are given in full in Table 14.4. A number of additional species were found breeding in areas of the woodland blocks away from the census areas and these species are tabulated in Table 14.5. Similarly, in order that a complete picture of the birds affected by the spraying may be presented, observations of non-breeding species are recorded in Table 14.6.

In each of the forest blocks the total number of breeding birds decreased after spraying and there was some indication of a slight recovery 1-2 weeks post-spray (Figure 14.3). The results for the two census techniques compared favourably and showed a similar pattern despite the discrepancy in the sample sizes. Further, a comparison of the two areas sprayed by ULV with the two sprayed by LV technique indicates little overall difference between the effect of the two techniques.

The number of breeding species recorded in Strathy, Achrugan , Truderscaig and Rosal Forests was 23, 30, 21 and 19 respectively with an additional 7 species monitored at Rosal on adjacent farmland. Overall, the species composition pre-spray was broadly similar in each block with only minor variations in the order of the leading 6-8 species (Table 14.2).

These variations could be related to the different habitats provided by the varied age classes of trees in the individual blocks. During the period monitored post-spray (maximum 15 days at Strathy and Truderscaig) the order of the most important species changed very little. It is clear, however, that the overall decrease in the total number of breeding birds is not due to a decrease in all species, indeed the decrease mainly reflects the decrease of two species - Willow warbler and robin (Figure 14.5). Most other species show little overall change (eg wren and chaffinch) (Figures 14.4/14.5) while a few (eg Coal tit, goldcrest, and Meadow pipit in Truderscaig) even appear to show small increases post-spray (Figure 14.6). This is apparently the case in both LV and ULV areas alike.

The decrease in the number of robins in Strathy post-spray would have been greater had the figures included only those birds in full song. On 14, 15 and 16 June, immediately post-spraying, only 2-3 full song phrases were heard in Strathy. The majority of robins were recorded on the strength of a few brief, quiet sub-song phrases, in contrast to those recorded immediately post-spraying in Achrugan on 15 and 16 June which were still in full song.

A more detailed examination of the Willow warbler decline indicates that the post-spray decrease was patchy throughout the forests, varying considerably from area to area even within one woodland block (Table 14.3). This variation appeared to be linked to the age of the trees. It was most readily seen in Truderscaig and especially in Rosal where Willow warblers decreased at several 'stops', in trees mainly 8-15 feet high, yet in adjacent 'stops' where the trees were a few feet taller and had grown much closer together, they almost totally disappeared. This was also reflected in Strathy where the overall decrease was greatest on 'walk' number 3. This 'walk' most consistently followed older blocks of trees where the canopy had already closed and where the ground vegetation beneath the trees was much reduced. No dead birds were found in any forest block and, apart from the robins in sub-song in Strathy immediately post-spraying, no obvious changes in behaviour or activity of the living ones were observed.

THE EFFECT OF SPRAYING ON NESTING BIRDS

In Strathy (ULV) two Great tits' nests were located but in neither case could the contents be accurately seen. In the first, incubation had begun before spraying and the young had hatched by 27 June. At a second nest, food was being carried in on 15-16 June immediately post-spraying and the young had apparently fledged before 27 June. A Willow warbler's nest, also in Strathy, had young more than half-grown on the day of spraying. These chicks subsequently fledged successfully despite being fed in part on Pine beauty moth caterpillars immediately post-spraying. All three nests were well concealed, one of the Great tit's in a natural rock crevice and the other in an ancient wall, and the Willow warbler with its domed nest was tucked well under a tussock on the ground. It seems highly improbable that the nest contents received a full dose of fenitrothion.

In Truderscaig (ULV) a Hen harrier's nest found on a pre-spray visit had an incomplete clutch. The female completed the clutch and was still incubating ten days post-spraying. At another Hen harrier's nest in Truderscaig it was estimated that the young began to hatch around the date of spraying - all three young were growing normally on 27 June. A buzzard's nest in Achrugan (LV) had three large young in the nest at the time of spraying and these were almost ready to fledge on the last visit on 27 June. A Short-eared owl was also feeding young in Achrugan at the time of the spraying and although the nest was not located the adults were still feeding the young in the same area ten days post-spraying. The three nests and presumably the Short-eared owl nest too,were all in an open situation and would have received a full dose of the spray.

Pre-spray observations in the woodland blocks indicated that the number of family parties of fledged song birds was small, although some species were actively feeding large young in the nest (eg Coal tit's nest in Strathy on 3 June had young ready to fledge). Post-spray visits, particularly on 26-27 June in Strathy and Achruggan indicated that fledged family parties, particularly of Coal tit, wren, goldcrest and chaffinch, were widespread.

For the small sample of nests found it would appear that the effect of spraying, whether by LV or ULV technique, was minimal having no disturbing effect on the females still laying or incubating, and no deleterious effect on young being fed in the nest at the time of spraying. This was apparently equally true of the small song birds and of a number of the larger predators.

DISCUSSION

For the majority of species present in each forest block the spraying, whether by LV or ULV, appears to have had little effect on the number of adult birds present. Despite an extensive search no mortality was recorded but it should be remembered that the chance of finding the bodies of small song birds would be minimal. Thus it is difficult to be certain that a decrease in the number of song birds after spraying is due to mortality or to dispersal away from the area. A small and gradual reduction of the singing birds over the monitoring period could be explained by the progress of the breeding season - birds spending less time in song and more time in feeding young as the season progressed.

Any birds feeding principally on Pine beauty moth caterpillars (and other invertebrates affected by the spray) might also be expected to spend proportionately less time in song and more time in searching for food after spraying. The success of a number of nests after spraying and sight records of family parties of a number of different species of song birds up to 10 days after spraying, suggested that the availability of food was not critical. Nevertheless, as it proved impractical to monitor a similar tract of unsprayed woodland, it was not possible to compare the size and number of family parties in sprayed and control unsprayed areas.

Although the majority of species showed little decrease, the numbers of both Willow warblers (which was the most abundant or the second most abundant species in all the forests studied) and robins showed relatively large overall decreases post-spraying, in the order of 57 per cent and 50 per cent respectively. It should be borne in mind that any reduction in the singing birds may well be minimal because removal of birds from close to, may increase the audibility of more distant birds at the limits of the transect. These changes seem unlikely to have been related to other variables. It is known that the weather is among the variables likely to influence the number of singing birds but it seems improbable that Willow warblers and robins should be influenced to the exclusion of the other species. The decrease in the robins may in part have been apparent rather than real, resulting from a behavioural change particularly evident in the ULV area of Strathy with numbers of birds reduced to sub-song, which could well have led to under-recording in the denser forest areas.

With the Willow warblers the observed reduction seemed to be real. However, the decrease post-spray was patchy and there was some evidence to show that the decrease was related to the age and size of the trees. In Truderscaig and Rosal the greatest decrease was recorded in the extremely young forests, where the trees were small and well-spaced with a considerable growth of ground vegetation. In Strathy, which had an older age structure than Truderscaig and

Rosal, the greatest decrease was among the oldest group of tightly-packed trees with little ground cover. The reasons for this patchiness remain conjectural but whatever the reasons, the uniformity, both in terms of age and species in large tracts of these plantations have undoubtedly exaggerated the effect.

CONCLUSIONS

The effect of this single large-scale spraying, both by LV and ULV, on the bird populations of the woodland blocks appears to have been relatively small. Without reference to control unsprayed areas, detectable changes giving cause for caution were recorded in only two species of commonly occurring song birds. There was no positive evidence to show whether the decrease was due to direct lethal effects on the birds themselves, or to dispersal away from the sprayed areas following a reduction of the invertebrate food available.

It may be anticipated that regular or repeat large-scale spraying with fenitrothion (or allied compounds) would have far greater effects on the bird populations and give considerable cause for concern. Spraying programmes to control pest species may be self-perpetuating, reducing the likelihood of biological control and thus necessitating further applications of pesticides and exposing the bird populations to long-term effects which are quite unknown.

In the future, planting programmes designed to reduce the monoculture effect in plantations would be welcomed by the RSPB. A greater mixture of tree species and age groups within forests would not only seem to go a long way to preventing a recurrence of such devastating outbreaks and thus preclude the widespread, large-scale application of pesticides, but would also be considerably beneficial to the bird populations.

ACKNOWLEDGEMENTS

We are particularly grateful for the help of Lt Col and Mrs F.W. Bartlett who conscientiously carried out the field work in Truderscaig and Rosal and also for the co-operation of Mr G.W.M. Reid, Head Forester (Naver Forest) at a particularly busy time.

ABSTRACT

The bird populations of four woodland areas in Sutherland were monitored before and after the aerial application of fenitrothion against the defoliating Pine beauty moth. The results presented indicated that with the exception of robin and Willow warbler, most species were apparently unaffected by fenitrothion applied in low volume or in ultra low volume at the rate of 300g/ha. However, the results must be regarded as tentative as it was not possible to compare these figures with those from an untreated control area. The success of a number of nests after spraying was not impaired. Of the two species apparently reduced after spraying, the decrease in the number of robins may have been due in part to a change in behaviour. An overall reduction in the number of Willow warblers was shown to vary from area to area and there was some evidence to show that this was related to the age of the trees. These findings are discussed and the future use of large-scale spraying aginst similar outbreaks considered.

Table 14.1

Timing of Bird Counts in Relation to Spraying

Forest	*Pre-Spray Counts*	*Completion of Spray Application*	*Post-Spray Counts*
Strathy	2 and 3 June	ULV 13 June (* special 14 June)	a) 14, 15 & 16 June b) 27 & 28 June
Achrugan	2 and 3 June	LV 14 June	a) 15 & 16 June b) 27 & 28 June
Truderscaig	2 and 3 June	ULV 13 June	a) 14 & 15 June b) 19 & 20 June c) 27 & 28 June
Rosal	2 and 3 June	LV 17 June	a) 19 & 20 June b) 27 & 28 June

Table 14.2

The Five Most Abundant Song Bird Species, Pre- and Post-Spraying

A. ULV Spraying

	Strathy		*Truderscaig*	
	Pre-Spray	*Post-Spray*	*Pre-Spray*	*Post-Spray*
1.	Chaffinch	Chaffinch	Willow warbler	Meadow pipit
2.	Willow warbler	Willow warbler	Chaffinch	Willow warbler
3.	Robin	Wren	Meadow pipit	Chaffinch
4.	Coal tit	Coal tit	Skylark	Skylark
5.	Wren	Robin	Wren/Robin	Wren

B. LV Spraying

	Achrugan		*Rosal*	
	Pre-Spray	*Post-Spray*	*Pre-Spray*	*Post-Spray*
1.	Willow warbler	Chaffinch	Willow warbler	Willow warbler
2.	Chaffinch	Willow warbler	Chaffinch	Chaffinch
3.	Wren	Wren	Robin	Song thrush
4.	Meadow pipit	Meadow pipit	Coal tit	Robin/Coal tit
5.	Robin	Robin	Song thrush	

Table 14.3

The Number of Willow warblers Recorded Pre- and Post-Spray
in Each Forest Area
(The figures are average figures, expressed to the nearest whole number)

Strathy

	Pre-Spray	*Post-Spray*		
		Date		
'Walk'	*2 - 3/6*	*14 - 16/6*	*19 - 20/6*	*27 - 28/6*
1	22	14		9
2	18	14		9
3	8	3		1
4	10	8		4

Achrugan

'Walk'	*2 - 3/6*	*15 - 16/6*	*19 - 20/6*	*27 - 28/6*
1	17	16		14
2	16	9		8
3	18	11		9

Truderscaig

'Stop'	*2 - 3/6*	*14/6**	*19 - 20/6*	*27 - 28/6*	*Estimated height of trees in feet*
1	4	1	1	1	
2	5	2	1	1	Less than 8
3	3	1	0	1	
4	3	2	2	1	
5	6	4	3	2	6 - 11
6	2	1	2	2	

(* Average of 2 counts on same morning)

Rosal

'Stop'	*2 - 3/6*	*14/6*	*19 - 20/6*	*27 - 28/6*	*Estimated height of trees in feet*
1	1		0	0	15
2	0		0	0	1
3	4		4	3	
4	4		3	2	Mainly 8 - 15
5	5		2	3	
6	4		2	3	
7	2		0	1	
8	2		1	0	
9	3		0	0	Mainly 12 - 20
10	3		0	0	
11	4		1	0	
12	2		0	0	

Table 14.4

Counts of Breeding Birds in Strathy, Achrugan , Truderscaig and Rosal Forests Pre- and Post-Spraying with Fenitrothion

(for an explanation of the figures refer to the text)

** Crossbill - this species is unlikely to have been a breeding species in any of the areas, but it has been included in the following tables as parties were regularly seen feeding in the areas.

+ - Indicates presence of distant birds but numbers uncertain.

( ) - Species included in brackets in the Rosal counts were breeding just outside the woodland areas.

Table 14.4 (contd)

Strathy

Species	2 June 1978 Walk 1	2	3	4	Total	3 June 1978 Walk 1	2	3	4	Total
Woodpigeon	1		3	5	9			2	1	3
Skylark	1	1			2			1		1
Hooded crow		1			1				1	1
Great tit			3	2	5			1		1
Blue tit										
Coal tit	8	2	9	6	25	6	5	5	12	28
Wren	1	7	4	6	18	6	4	6	8	24
Mistle thrush	1				1				1	1
Song thrush		1	1	3	5	1		3	4	8
Robin	2	2	7	12	23	13	5	11	7	36
Willow warbler	25	20	4	9	58	19	16	11	11	57
Goldcrest		2	2	3	7	7	1	1	5	14
Spotted flycatcher										
Dunnock				1	1					
Meadow pipit	1	1			2	1				1
Siskin			2		2					
Redpoll			2		2	1				1
**Crossbill		4	6	2	12		3			3
Chaffinch	14	7	28	14	63	11	14	18	19	62
Reed bunting						1	1			2

Weather notes:	Bright and sunny, light wind, hot.	Overcast, hazy sun, warm.

Table 14.4 (contd)

Strathy

	14 June 1978					*15 June 1978*					*16 June 1978*				
	Walk					*Walk*					*Walk*				
Species	*1*	*2*	*3*	*4*	*Total*	*1*	*2*	*3*	*4*	*Total*	*1*	*2*	*3*	*4*	*Total*
Woodpigeon								4	1	5				2	2
Skylark				1	1	1	2			3	2	1		2	5
Hooded crow	1	1	1	2	5		1	1		2	1	1			2
Great tit		1	1	1	3		1	3		4		2	2		4
Blue tit			1		1										
Coal tit	3	2	6	6	17	2	5	6	4	17	1	4	5	8	18
Wren	6	4	9	6	25	6	5	8	10	29	5	4	9	8	26
Mistle thrush															
Song thrush	1	1	2	2	6		2	3	3	8	1		4	1	6
Robin	4		7	5	16	4	5	6	6	21	7	3	4	3	17
Willow warbler	11	15	2	8	36	13	13	4	12	42	8	14	2	5	29
Goldcrest	2		2	4	8	2	3		3	8	4	1	2	5	12
Spotted flycatcher															
Dunnock	1				1	1				1	1				1
Meadow pipit		1			1		1	1		2	1		1		2
Siskin														2	2
Redpoll															
Crossbill**			10	10	20				1	1			16	30	46
Chaffinch	12	7	17	11	47	13	19	16	9	57	14	13	12	13	52
Reed bunting															
Weather notes:	Mist clearing by Walk No.2 to give bright sun. Wind moderate.					Dense mist clearing by 0500 hours. Hazy sun. Moderate wind.					Dull and overcast, wind light but increasing.				

Table 14.4 (contd)

Strathy

	27 June 1978					*28 June 1978*				
	Walk					*Walk*				
Species	*1*	*2*	*3*	*4*	*Total*	*1*	*2*	*3*	*4*	*Total*
Woodpigeon			2	1	3			1		1
Skylark								1	1	2
Hooded crow		2			2	1	1	2	1	5
Great tit		1			1		1	1		2
Blue tit										
Coal tit	5	6	7	4	22	7	5	11	8	31
Wren	4	4	3	10	21	7	3	3	10	23
Mistle thrush				1	1				1	1
Song thrush	1		2	2	5	1		2	2	5
Robin	3	1	6	2	12	5	4	6	5	20
Willow warbler	10	9	1	4	24	7	8		5	20
Goldcrest	4	2	2	6	14	4	2	2	5	13
Spotted flycatcher										
Dunnock										
Meadow pipit		3			3			2		2
Siskin				1	1				1	1
Redpoll				1	1					
**Crossbill			5		5			3		3
Chaffinch	10	18	17	17	62	16	17	18	20	71
Reed bunting										

Weather notes:	Dull and overcast, occasional sunny intervals. Wind light.	Overcast. Wind light becoming moderate. Occasional drizzle.

Table 14.4 (contd)

Achrugan

	2 June 1978				*3 June 1978*			
	Walk				*Walk*			
	1	*2*	*3*	*Total*	*1*	*2*	*3*	*Total*
Species								
Mallard								
Buzzard								
Kestrel								
Pheasant	1			1	1			1
Woodpigeon	2		2	4				
Cuckoo	1	1	1	3	1	1	1	3
Short-eared owl	1			1				
Skylark		1		1		1		1
Hooded crow		2		2				
Great tit	1			1				
Blue tit					2			2
Coal tit	1		2	3	1	1	3	5
Wren	10	7	9	26	11	4	11	26
Mistle thrush								
Song thrush								
Robin	7		8	15	7	1	6	14
Willow warbler	21	16	16	53	13	16	19	48
Goldcrest	1	1		2	4	1	1	6
Dunnock					1		1	2
Meadow pipit	6	19	3	28	8	12	1	21
Twite	1			1				
Redpoll	1	6	3	10	2	3	5	10
**Crossbill								
Chaffinch	9	8	11	28	14	6	14	34
Reed bunting	3	3	3	9	3	4	2	9
Weather notes:	Bright and sunny, light wind, hot.				Overcast, hazy sun, warm.			

Table 14.4 (contd)

Achrugan

Species	*15 June 1978* Walk *1*	*2*	*3*	*Total*	*16 June 1978* Walk *1*	*2*	*3*	*Total*
Mallard					1			1
Buzzard	1			1				
Kestrel							1	1
Pheasant		2		2		1		1
Woodpigeon			2	2	1		4	5
Cuckoo	1			1	1		1	2
Short-eared owl	1			1	1			1
Skylark		2	1	3		1	1	2
Hooded crow	2	15*		17*	2	11*	2	15*
Great tit							2	2
Blue tit							1	1
Coal tit	1	1	3	5	6	1		7
Wren	9	2	11	22	8	5	9	22
Mistle thrush								
Song thrush					1	1		2
Robin	6	1	5	12	8	1	9	18
Willow warbler	16	10	10	36	15	8	11	34
Goldcrest	3	2	3	8	2		3	5
Dunnock			1	1		1		1
Meadow pipit	5	11	4	20	5	11		16
Twite								
Redpoll	3	4	3	10	2		3	5
**Crossbill			1	1				
Chaffinch	12	11	16	39	9	8	15	32
Reed bunting		2	3	5	1	4	3	8

* Single flock included in total - not breeding birds.

Weather notes:	Dull, moderate wind increasing made counts difficult on exposed rides in Walk No.2.	Dull and overcast, wind light - moderate.

Table 14.4 (contd)
Achrugan

Species	*27 June 1978* Walk 1	2	3	Total	*28 June 1978* Walk 1	2	3	Total
Mallard						1		1
Buzzard								
Kestrel								
Pheasant							1	1
Woodpigeon								
Cuckoo			1	1	1			1
Short-eared owl	1			1				
Skylark	1	1	1	3		2	1	3
Hooded crow		3		3	2	33*		35*
Great tit								
Blue tit								
Coal tit	5	1	5	11	3		9	12
Wren	8	3	6	17	7	5	8	20
Mistle thrush					1			1
Song thrush	1		1	2			1	1
Robin	3	1	3	7	5	2	5	12
Willow warbler	11	6	10	27	16	9	8	33
Goldcrest	4		4	8	5	4	3	12
Dunnock		1		1				
Meadow pipit	8	9	4	21		12	3	15
Twite								
Redpoll	2	2	1	5	4		2	6
**Crossbill								
Chaffinch	13	6	16	35	17	7	14	38
Reed bunting	5	2	5	12	5	4	4	13

* Flock of 32, included in total - not breeding birds.

Weather notes:	27 June 1978	28 June 1978
	Dull and overcast, occasional sunny intervals. Wind light.	Overcast. Moderate wind but walks sheltered. Occasional drizzle at first then continuous light rain on Walk No.3.

Table 14.4 (contd)

Truderscaig

	2 June 1978							*3 June 1978*						
	'Stop'							*'Stop*						
Species	*1*	*2*	*3*	*4*	*5*	*6*	*Total*	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
Red-breasted merganser													1	1
Hen harrier						1	1						1	1
Black grouse	10						10			1				1
Snipe								1						1
Curlew	+	+		2			+		+	+	+			+
Greenshank				+		+	+				+			+
Cuckoo	1		1	1	1		4		1	1	1	1		4
Short-eared owl										2				2
Skylark	6				1	1	8	4					1	5
Hooded crow	1						1	1						1
Coal tit				1	2	1	4					1		1
Wren				2	1	1	4		1		1		1	3
Song thrush									1					1
Winchat	1			1		1	3	2						2
Robin				2	1	1	4		1		1		1	3
Willow warbler	4	3	1	2	5	1	16	4	6	4	4	6	2	26
Meadow pipit	1	3	1	1		1	7	2	1	2	2			7
Redpoll					1		1					1		1
Chaffinch				2	4	2	8	1	1	1	1	2	2	8
Reed bunting														
Weather notes:	Anticyclonic mist clearing later. Hot.							Overcast, anticyclonic mist clearing early. Warm.						

Table 14.4 (contd)

Truderscaig

Species	*14 June 1978 (0715 - 0830 hours)* 'Stop' 1	2	3	4	5	6	Total	*14 June 1978 (0840 - 1000 hours)* 'Stop' 1	2	3	4	5	6	Total
Red-breasted merganser														
Hen harrier	2						2							
Black grouse														
Snipe								1						1
Curlew			+				+	+		+				+
Greenshank														
Cuckoo		1		1	1		3	1		1				2
Short-eared owl								1			1			2
Skylark	2	1					3	4						4
Hooded crow	1						1							
Coal tit												1		1
Wren				1	1	1	3						1	1
Song thrush														
Winchat														
Robin												1		1
Willow warbler	1	1	1	1	4		8		2	1	2	3	2	10
Meadow pipit	5	2	2			1	10	4	3	2	1	1	3	14
Redpoll												1		1
Chaffinch			1	2	2	2	7				2	1	2	5
Reed bunting				1	1		2				1	1		2
Weather notes:	Clear and sunny, but cool in wind.							Clear and sunny, but cool in wind.						

Table 14.4 (contd)

Truderscaig

	19 June 1978							*20 June 1978*						
	'Stop'							*'Stop'*						
Species	*1*	*2*	*3*	*4*	*5*	*6*	*Total*	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
Red-breasted merganser														
Hen harrier						1	1	1						1
Black grouse	1						1							
Snipe														
Curlew	+				+		+	+					+	+
Greenshank														
Cuckoo	1	1					2							
Short-eared owl											2			2
Skylark	4	2				1	7	3				1		4
Hooded crow	1			1			2							
Coal tit														
Wren				1	1	1	3				1	2	1	4
Song thrush												1	1	2
Winchat	1						1							
Robin														
Willow warbler	1	1		2	3	2	9		1		2	2	1	6
Meadow pipit	6	1	1	1	1	1	11	3	1	2		1	1	8
Redpoll														
Chaffinch			1	3	2	2	8				1	1	2	4
Reed bunting					1		1							

Weather notes:	Low cloud, overcast, visibility moderate, cold, strong wind.	Low cloud, overcast, visibility good. Wind moderate.

Table 14.4 (contd)

Truderscaig

	27 June 1978							*28 June 1978*						
	'Stop'							*'Stop'*						
Species	*1*	*2*	*3*	*4*	*5*	*6*	*Total*	*1*	*2*	*3*	*4*	*5*	*6*	*Total*
Red-breasted merganser														
Hen harrier											1			1
Black grouse											1			1
Snipe	1						1							
Curlew														
Greenshank														
Cuckoo			1				1							
Short-eared owl	1						1							
Skylark	4	1					5	5					1	6
Hooded crow								1						1
Coal tit												1		1
Wren				1	1	1	3				2	1		3
Song thrush														
Winchat	1	1					2	1						1
Robin				1			1							
Willow warbler	1		2		1	1	5		1		2	2	2	7
Meadow pipit	6	4	3	3		2	18	4	2	1	2	1	2	12
Redpoll														
Chaffinch			1	2	1	1	5				4	1	3	8
Reed bunting			1				1				1			1

Weather notes:

27 June 1978: Rain at first clearing to give sunny periods. Cold moderate wind.

28 June 1978: Overcast, occasional showers

Table 14.4 (contd)

Rosal

2 June 1978

Species	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Total*
	'Stop'												
Hen harrier		1											1
(Oystercatcher)													
(Lapwing)	4												4
(Curlew)													
(Greenshank)		1											1
Woodpigeon						2			3	1			6
Cuckoo							1						1
Short-eared owl													
Skylark		2					1						3
Hooded crow													
Coal tit				1		1		1	1			1	5
Wren	1										1		2
Mistle thrush	1					1						1	3
Song thrush	2			1									3
(Wheatear)													
Robin				1				1	2			1	5
Willow warbler	1		4	6	6	5	1		2	4	3	2	34
Goldcrest													
Meadow pipit		2	1										3
(Pied wagtail)	1												1
(Starling)													
Redpoll										1			1
Bullfinch													
Crossbill**													
Chaffinch	7		1	3	2	2	2	1	2	1	1	3	25
Reed bunting					1								1

Weather notes: Anticyclonic mist clearing later.
Hot.

Table 14.4 (contd)

Rosal

3 June 1978

Species	*'Stop'* 1	2	3	4	5	6	7	8	9	10	11	12	*Total*
Hen harrier		1		1									2
(Oystercatcher)	1												1
(Lapwing)	1												1
(Curlew)											+	+	+
(Greenshank)		+					+						+
Woodpigeon									2			1	3
Cuckoo						1	1						2
Short-eared owl													
Skylark		1									1	1	3
Hooded crow													
Coal tit			1	1	2	1							5
Wren												1	1
Mistle thrush	1					1							2
Song thrush	2			1		1							4
(Wheatear)													
Robin	1		1	1		1	1	2	1		1		9
Willow warbler			4	2	4	3	2	3	3	1	4	2	28
Goldcrest					1								1
Meadow pipit		1	2										3
(Pied wagtail)	1												1
(Starling)													
Redpoll										1			1
Bullfinch													
Crossbill**													
Chaffinch	5		2	3	3	1	2	1	1	1	1	2	22
Reed bunting				1									1

Weather notes: Overcast, anticyclonic mist clearing early. Warm.

Table 14.4 (contd)

Rosal

19 June 1978

Species	*'Stop'* 1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Total*
Hen harrier													
(Oystercatcher)	1												1
(Lapwing)	1												1
(Curlew)													
(Greenshank)	2												2
Woodpigeon						2						1	3
Cuckoo													
Short-eared owl													
Skylark		1											1
Hooded crow									1				1
Coal tit						1							1
Wren						1						1	2
Mistle thrush													
Song thrush									1	1			2
(Wheatear)													
Robin				1	1	1					1		4
Willow warbler			3	2	2	3		1			1		12
Goldcrest													
Meadow pipit		1											1
(Pied wagtail)													
(Starling)													
Redpoll													
Bullfinch													
**Crossbill													
Chaffinch	2		1	3	2	2	2	1	1	1	2	1	18
Reed bunting													

Weather notes: Low cloud, overcast, visibility moderate, cold strong wind.

Table 14.4 (contd)

Rosal

20 June 1978

Species	*'Stop'* 1	2	3	4	5	6	7	8	9	10	11	12	*Total*
Hen harrier						1			1				2
(Oystercatcher)	1												1
(Lapwing)	3												3
(Curlew)													
(Greenshank)													
Woodpigeon	1							2					3
Cuckoo						1							1
Short-eared owl													
Skylark													
Hooded crow													
Coal tit									1				1
Wren					1					1			2
Mistle thrush	1												1
Song thrush					1	1		1				2	5
(Wheatear)	1												1
Robin					1			1	1				3
Willow warbler			4	3	1								8
Goldcrest													
Meadow pipit	1												1
(Pied wagtail)	1												1
(Starling)	2												2
Redpoll													
Bullfinch													
**Crossbill											12		12
Chaffinch	3		2	1	2	2	2	1	1		1		15
Reed bunting													

Weather notes: Low cloud, overcast, visibility good. Wind moderate.

Table 14.4 (contd)

Rosal

27 June 1978

	'Stop'												
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*Total*
Species													
Hen harrier		1		1				1		1			4
(Oystercatcher)													
(Lapwing)	2												2
(Curlew)	1												1
(Greenshank)													
Woodpigeon						1							1
Cuckoo													
Short-eared owl													
Skylark	1												1
Hooded crow													
Coal tit				1	2			1			1		5
Wren			1	1	2							1	5
Mistle thrush	1												1
Song thrush	1		1		1	1	1					1	6
(Wheatear)	1												1
Robin													
Willow warbler			3	4	2	2	1						12
Goldcrest													
Meadow pipit	1	1											2
(Pied wagtail)	2												2
(Starling)	2												2
Redpoll													
Bullfinch					5								5
**Crossbill			18										18
Chaffinch	2			2	3	3	2	1	2	2	2	1	20
Reed bunting													

Weather notes: Rain at first clearing to give sunny periods. Cold moderate wind.

Table 14.4 (contd)

Rosal

28 June 1978

Species	*'Stop'* 1	2	3	4	5	6	7	8	9	10	11	12	*Total*
Hen harrier				1						1			2
(Oystercatcher)													
(Lapwing)													
(Curlew)													
(Greenshank)		+								+			+
Woodpigeon	3						5		2	2			12
Cuckoo													
Short-eared owl												1	1
Skylark		3											3
Hooded crow		1					1						2
Coal tit							1						1
Wren			1	1	1								3
Mistle thrush													
Song thrush		1					1					1	3
(Wheatear)													
Robin					1								1
Willow warbler			3		3	3							9
Goldcrest													
Meadow pipit	1	5											6
(Pied wagtail)													
(Starling)													
Redpoll													
Bullfinch													
**Crossbill											2		2
Chaffinch	5			3	2	5	2	1		1	2	1	22
Reed bunting													

Weather notes: Overcast, occasional showers.

Table 14.5

Additional Breeding Species Recorded in Woodland Blocks Away From Census Area

	Pre-Spray	*Post-Spray*
A. *Strathy*		
Mallard		+
Cuckoo		+
Bullfinch	+	+
B. *Achrugan*		
Hen harrier	+	+
Red grouse		+
Stonechat	+	+
Blackcap		+
Spotted flycatcher		+
C. *Truderscaig*		
Mistle thrush		+
D. *Rosal*		
-		

+ = Species present in suitable breeding habitat

Table 14.6

Supplementary List of Species Recorded in Woodland Areas

+ = Species recorded

B = Breeding referred to in appropriate section of Table 14.4

S = Strathy
A = Achrugan
R = Rosal
T = Truderscaig

Species	*S*	*A*	*T*	*R*	*Remarks*
Red-throated diver	+	+	+		Seen and heard regularly overhead, breeding on nearby lochs.
Heron		+	+	+	Occasional birds feeding in pools and water-courses.
Buzzard		B	+	+	Occasionally seen overhead, probably breeding nearby.
Sparrowhawk			+		One sighting.
Osprey	+				One fishing in river.
Merlin			+		One sighting, probably breeding nearby.
Red grouse	+	B			Heard regularly around margins of forest.
Golden plover	+				Recorded overhead.
Lapwing		+		B	Recorded overhead.
Curlew	+	+	B	B	Recorded regularly especially in fringing areas. Possibly breeding in more open forest.
Greenshank	+	+	B	B	
Great black-backed Gull		+			Seen overhead, mainly following water-courses. Possibly using larger lochs for bathing.
Herring gull		+			
Common gull		+			
Black-headed gull		+			
Short-eared owl	+	B	B	B	Recorded once, but not thought to be breeding - possibly breeding nearby.
Collared dove				+	Seen once near farmhouse.
Swift		+			Occasional sightings overhead.
Swallow		+		+	
Raven	+	+			Occasional sightings. Probably bred nearby.

Figure 14.1

Map showing bird census walks and other sampling locations

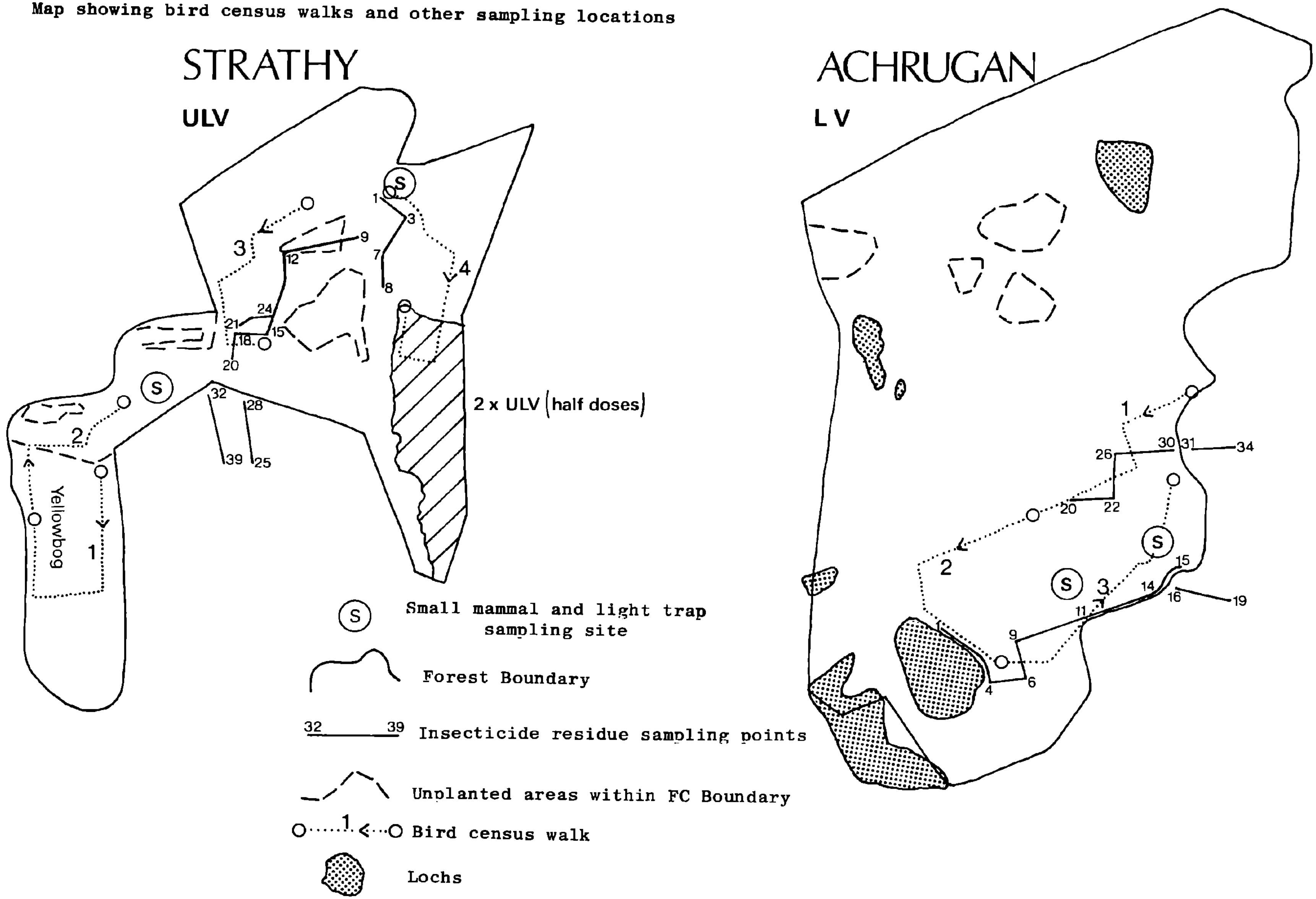
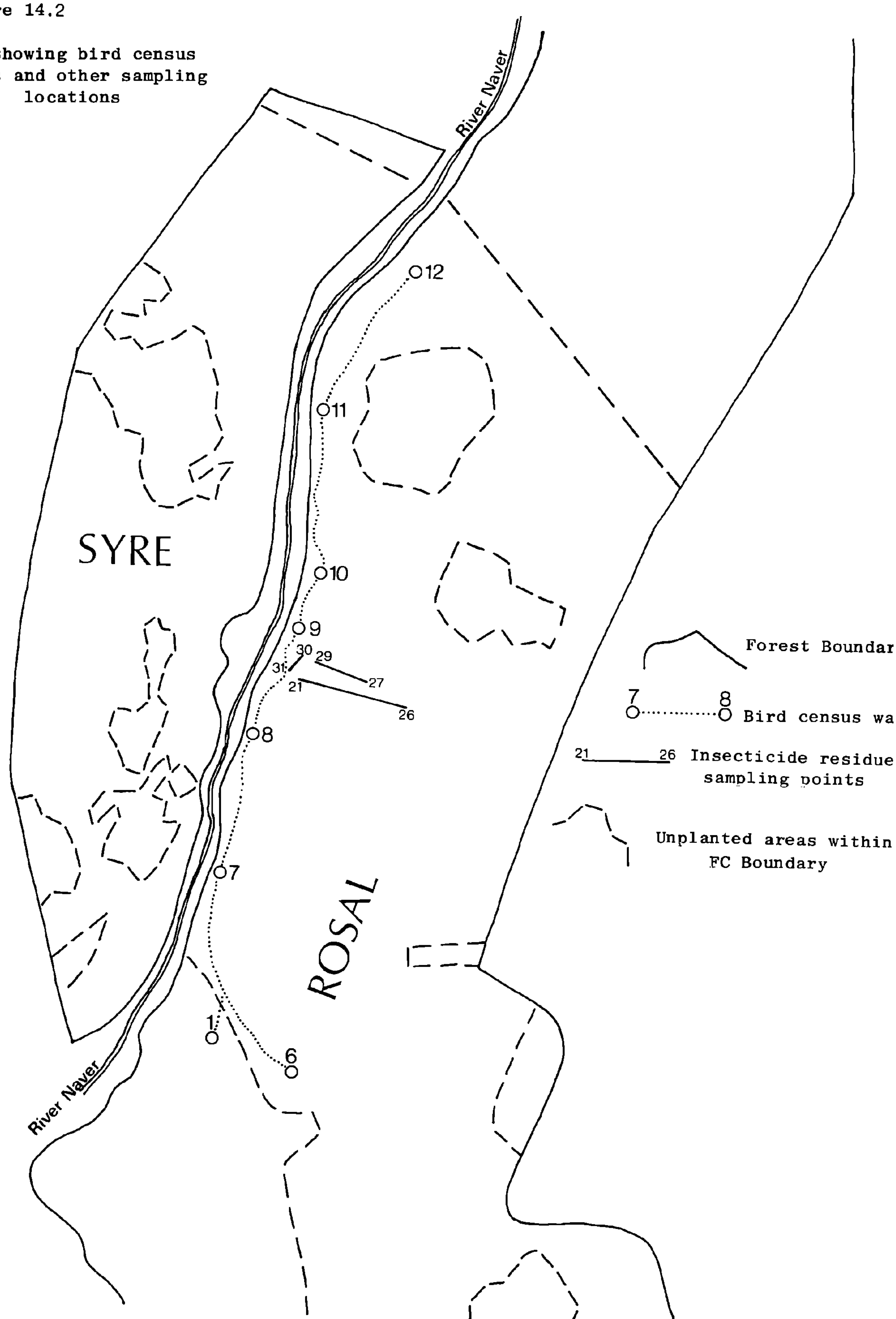


Figure 14.2

Map showing bird census stops and other sampling locations



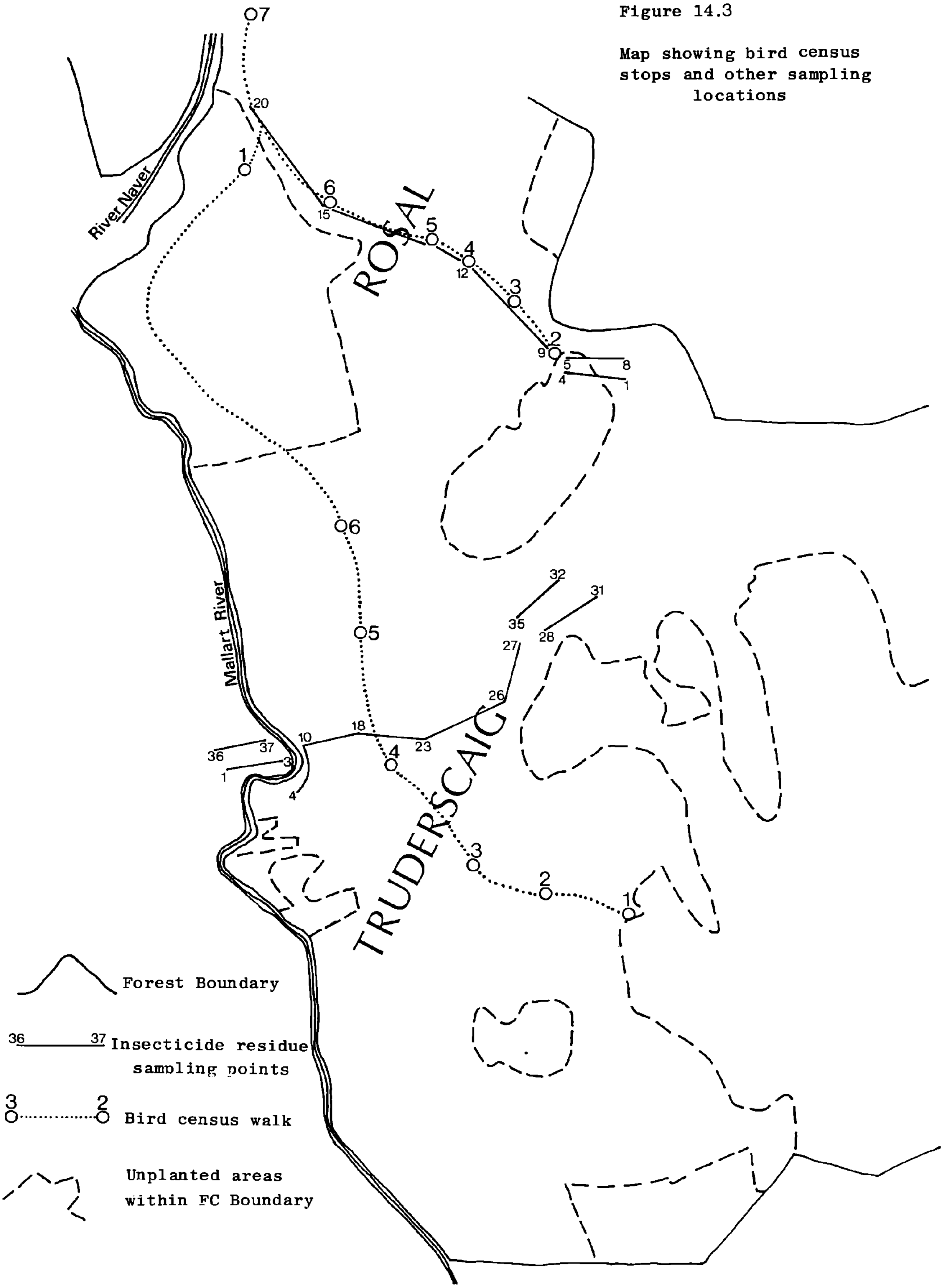


Figure 14.3

Map showing bird census stops and other sampling locations

Figure 14.4

Comparison of total number of breeding birds after spraying in Naver Forest

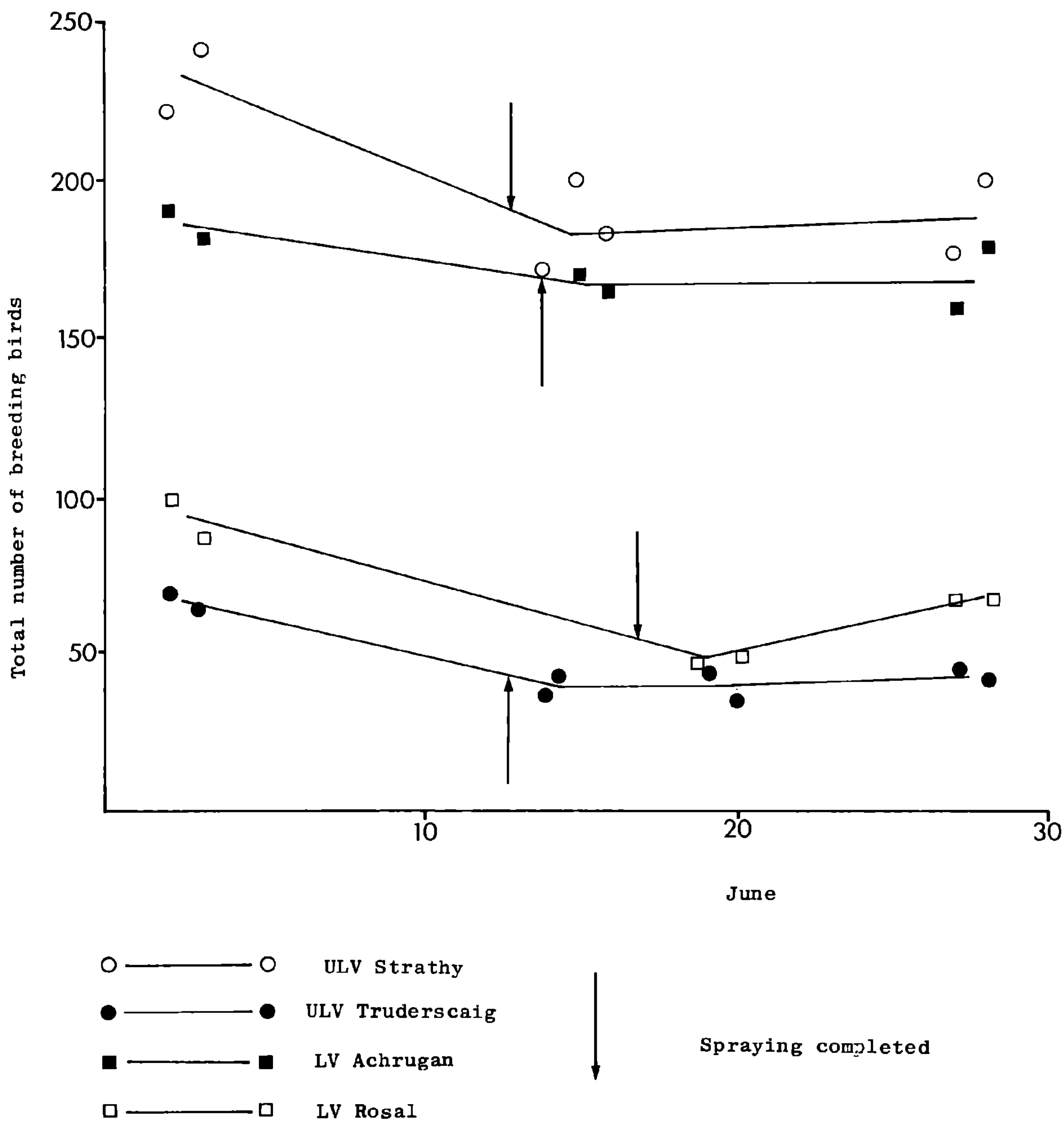


Figure 14.5

Changes in the numbers of birds after spraying

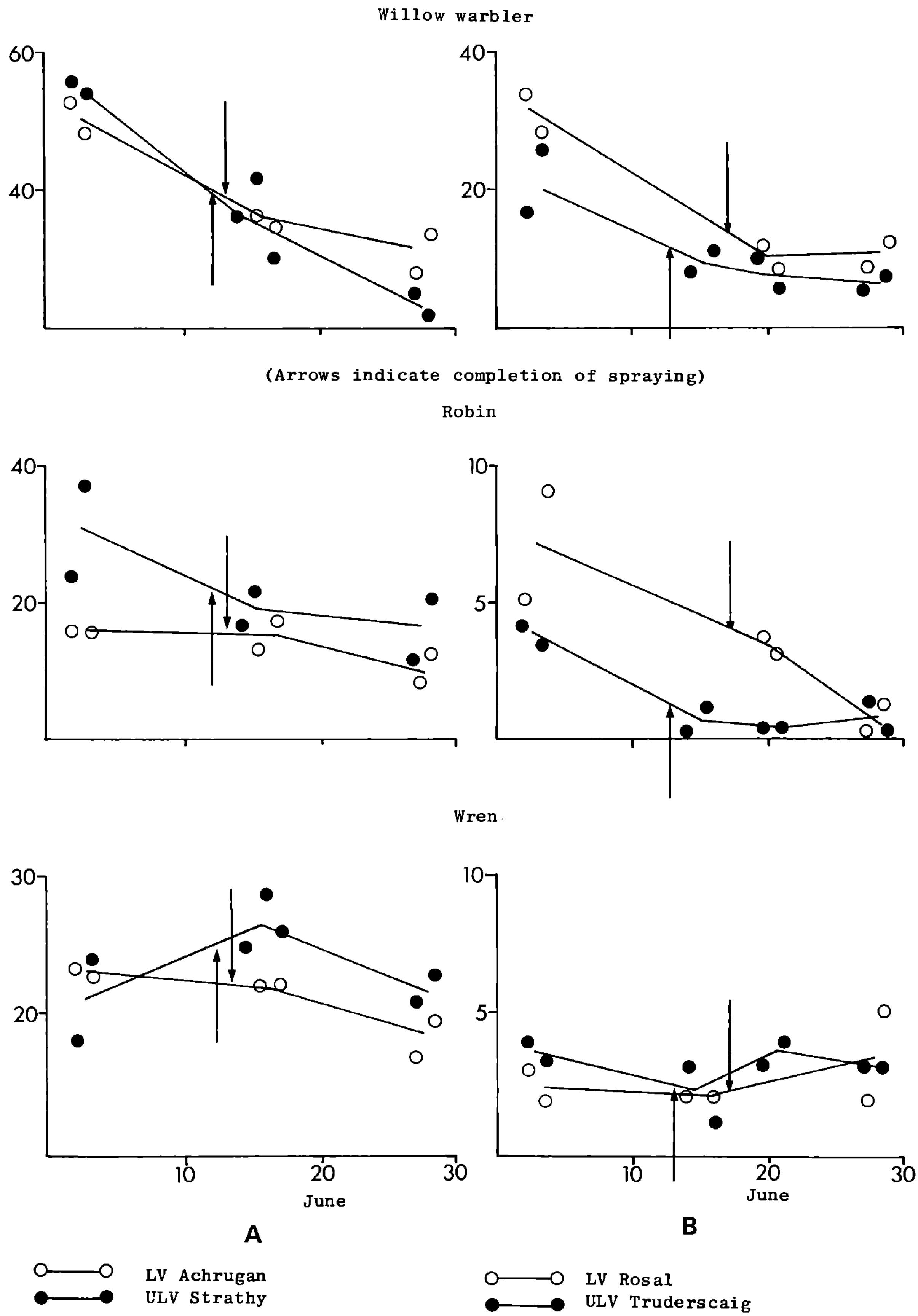
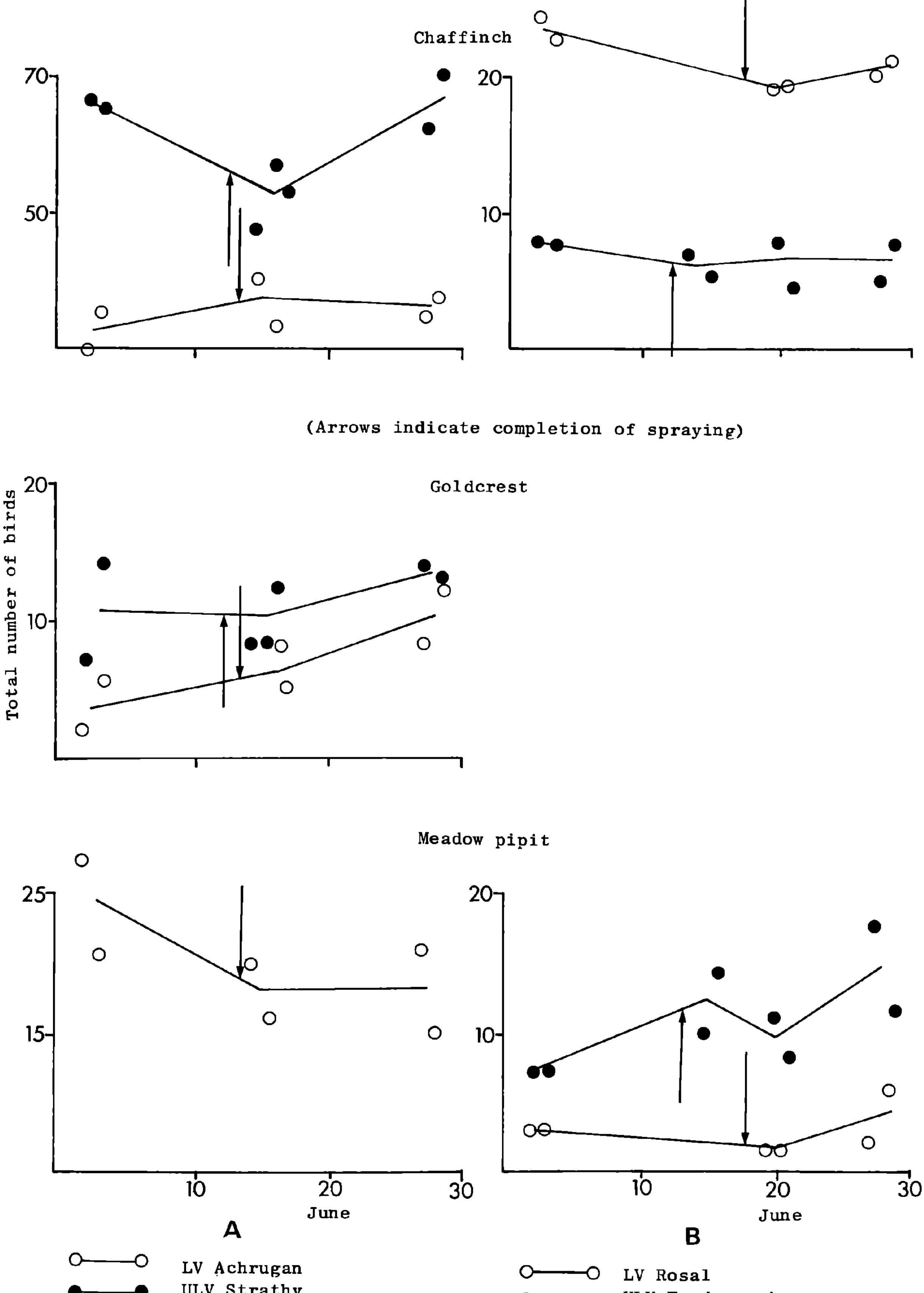


Figure 14.6

Changes in the numbers of birds after spraying



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