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Environmental impact of pesticide drift

Aerial spraying

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Environmental Impact of Pesticide Drift: Aerial Spraying

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SUMMARY

1 **Insecticide drift and impact from aerial spraying.**
Six field trials are described in which aerial applications were made to field crops during 1992 and 1993. Deltamethrin (under experimental permit), triazophos (under off-label approval) and fenitrothion (two applications) represented compounds considered to pose relatively high drift hazards to non-target invertebrates; phosalone was chosen to represent moderate hazard, and pirimicarb chosen for low hazard. The severity and extent of drift effects were measured by bioassays using young cabbage white caterpillars and three aquatic invertebrates.

The deltamethrin trial was conducted at Holme Lacey, Herefordshire. It involved the comparison of drift from a helicopter and a hydraulic ground-based sprayer, and also cooperation with MAFF Central Science Laboratory in direct chemical measurements of within-crop deposition and drift. The bioassay results gave safe distances of about 90 m for *Pieris brassicae* and 30 m for aquatic invertebrates. However, the chemical assays showed that the helicopter had applied about 41% of the intended dose and so these values must be considered low estimates.

The triazophos, fenitrothion and pirimicarb trials were carried out on adjacent fields in the Fens near Chatteris. They included worst case conditions with mean wind speeds of 3.5 to 4 m s^{-1}, and also near calm conditions in which wind direction changed by 180° after setting out the targets. *P.brassicae* showed downwind drift effects from triazophos and fenitrothion up to at least 150 m while obvious effects on aquatic fauna were recorded up to 75 - 120 m. The phosalone trial was carried out at Abbots Ripton and involved studies of over-spraying as well as drift. Toxic effects were again recorded up to 100-150 m from three edges of the experimental area, although they occurred more slowly. There were no effects on *P. brassicae* from pirimicarb.

Chemical validation of spray rates and the use of water-sensitive papers are discussed, as well as the value of complementary bioassay results from terrestrial and aquatic species.

2 **Use of bioassay techniques to assess the effects of asulam when applied from helicopters.**
The potential damage from asulam drift is assessed by using common sorrel *Rumex acetosa* and non-native ferns in bioassays. Three previous experiments are reviewed and augmented with data from two studies, in 1992 and 1993. Drift deposition measurements and comparisons with damage to bioassay plants were made in all cases using water-sensitive papers, and more accurately in one experiment by adding a lithium tracer to the spray.

The combined results of all studies shows that bioassays are generally sensitive and can be used to determine or detect:
i) Safe distances downwind from a sprayed patch, ie buffer zones,
ii) Differential windward and leeward damage,
iii) Overspray damage,
iv) Damage in different micro-habitats within a sprayed area.

A first buffer zone estimate of 161 m was based on a single trial in a high wind. A study in 1992 gave poor and conflicting results, at

least partly because of the poor efficacy of the asulam spray. The 1993 study found damage to bioassay plants at the maximum distance tested of 180 m downwind. It was estimated that this damage was brought about by 8% deposition of the nominal dose applied.

3 **Ancillary studies on aerial spraying and insecticides**

Brief reviews are made on techniques for reducing drift hazards from aerial spraying and on the long term effects of pyrethroids on insects. The fixed-wing spraying equipment and procedures used by the contractor in the field trials were fairly standard. However, there may be a case for setting practical routines for leaving unsprayed headlands. Pyrethroids have relatively short field persistence, and the field bioassays for deltamethrin (and organophosphorus compounds) were found to give stable mortality results after 6-7 days. Unpublished studies suggest that there may be sublethal effects.

A collation of environmental risks from insecticides is made by considering the relative extent of use of 25 compounds, their spectrum of activity against insect orders, their toxicity to *P. brassicae* and hazard ratings for bees and fish.

4 **Buffer zones and recommendations to protect conservation interests**

The definition and purpose of buffer zones are considered with special reference to aerial spraying. It was concluded that setting buffer zones could not realistically hope to protect sensitive sites totally. The aim should therefore be to try to ensure that unacceptable effects are avoided. A statutory buffer zone of 250 m around SSSIs should provide acceptable protection from downwind drift and over-spraying in the vast majority of cases. For protection of the wider countryside from pesticide drift, opportunities should be taken at the regulatory stage to revoke aerial uses or to set statutory buffers consistent with recent precedents.

BACKGROUND AND ORGANISATION

ITE was commissioned by the Nature Conservancy Council in 1986 to carry out a desk study on the impact of pesticide drift. Following the report in 1987, ITE undertook a five year programme for the Department of Environment and NCC to study the effects of herbicide and insecticide drift on plants and invertebrates, mainly from ground sprayers. These involved subcontracts to the Institute of Freshwater Ecology on aquatic invertebrates, and to the Institute of Arable Crop Research at Long Ashton on herbicide vapour drift and dose response of plants.

A further two year contract was then commissioned by English Nature to quantify the impact of drift from aerial spraying of insecticides on field crops and asulam on bracken, and to advise on buffer zones to protect SSSIs. Studies on insecticides have involved joint work between ITE, IFE and Dr Cooke on secondment from English Nature. Studies on asulam have involved joint work between ITE and Professor Marrs at Liverpool University (under subcontract). This report concludes the programme.

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INSECTICIDE DRIFT AND IMPACT FROM AERIAL SPRAYING

1 INSECTICIDE DRIFT AND IMPACT FROM AERIAL SPRAYING

B N K Davis, L C V Pinder, A S Cooke & A J Frost

1.1 INTRODUCTION

Williams *et al* (1987) reviewed the extent of aerial spraying in Britain and (mainly) overseas data on drift from both fixed-wing aircraft and helicopter. They assessed the available information on drift with respect to different types and orientation of nozzles, down-draft, flying height, site variables such as field width and 'roughness length' of the crop, and meteorological variables.

Deposition data compiled in the review were subsequently used to estimate the distances at which honeybees might be at risk from aerial spraying of 20 insecticides under unstable, neutral and stable atmospheric conditions (Davis & Williams 1990). These showed, for example, that the 'LD_{50} distance' for honeybees receiving triazophos spray drift could be 21, 65 and 135 m respectively.

In 1989 the NCC expressed concern over the potential drift hazards to nearby SSSI from triazophos and the pyrethroids that were currently applied by air to pea crops. Efforts were therefore made in 1990 to locate pea crops that were to be sprayed with these compounds in Norfolk, Suffolk, Cambridgeshire and Lincolnshire through ADAS and FWAG officers, the Processors and Growers Research Organisation (PGRO) and by direct contact with aerial spray contractors. However, these efforts were unsuccessful and so in 1991, a local spray operator was contracted to spray an area near Chatteris with deltamethrin under experimental control and with the agreement of a local farmer. The bioassay results indicated effects on *Pieris brassicae* larvae and aquatic invertebrates up to 250 m downwind of the sprayed area (Davis & Pinder 1992; Davis *et al* 1993a; Pinder *et al* 1993). English Nature then contracted ITE to undertake further studies specifically on aerial spraying, to include three field trials with insecticides in both 1992 and 1993.

These six trials are summarised in chronological order in Table 1.1. The first trial was in Herefordshire and differed from all the others in the use of a helicopter; spraying details are given in Table 1.2. The remaining five were all in Cambridgeshire using the same spray contractor (Table 1.3, Section 1.4), and four of them on the same farm as the original deltamethrin trial in 1991.

This report describes these six trials in the most logical sequence for assessing the results.

1.2 METHODS: OVERVIEW

General features of the organisation of these field studies are described here, together with general descriptions of sites and methods. Specific details for the individual trials are described separately. Trial 1 with deltamethrin was distinctive and is considered first. The other five are then considered in

Table 1.1 Observations made for six aerial spray drift trials in 1992 and 1993.

Trial Date	1 8 July 1992	2 29 July 1992	3 26 August 1992	4 2 June 1993	5 15 June 1993	6 7 July 1993
Site	Holme Lacey	Chatteris	Chatteris	Chatteris	Abbots Ripton	Chatteris
Aircraft	Helicopter (+ ground sprayer)	Fixed wing	Fixed wing	Fixed wing	Fixed wing	Fixed wing
Pesticide	Deltamethrin	Triazophos	Pirimicarb	Fenitrothion (1)	Phosalone	Fenitrothion (2)
Bioassays						
Caterpillars						
Pieris brassicae	✓	✓	✓	✓	✓	✓
Aquatic invertebrates						
Gammarus pulex	✓	✓	-	✓*	✓*	✓*
Asellus aquaticus	✓	✓	-	✓	✓	✓
Centroptilum sp	✓	-	-	-	-	-
Baetis sp	-	✓	-	-	-	-
Zygoptera	-	-	-	✓	-	-
Dytiscidae	-	-	-	-	✓	-
Culex torrentium	-	-	-	-	-	✓
Deposition measurements	A	-	-	-	-	WSP

* = including animals exposed in the field A = chemical analyses WSP = water-sensitive papers

descending order of drift effects ie triazophos, fenitrothion (2), phosalone, fenitrothion (1) and pirimicarb.

1.2.1 Organisation

The first trial was designed to compare drift from a helicopter and from a tractor-mounted hydraulic sprayer. Mr M T Davies (M D Air Services) proposed this comparison and made initial contacts with Holme Lacey Agricultural College, near Hereford. This college provides training courses and certificates for spraying. Detailed arrangements were made with Mr Gwyn (Arable Farm Manager). Mr Savourey obtained the necessary experimental permit for aerial application of deltamethrin to sugar beet for which there was no current approval.

Trials 2, 3, 4 and 6 were carried out at Curf Fen north of Chatteris by agreement with the farmer Mr C Childs who was originally contacted through FWAG. Trial 5 was on the Abbots Ripton Estate by agreement with Lord de Ramsey and by arrangement with the Farm Manager Mr R Pickard. Aerial spraying for all five trials was done by Apple Aviation under contract. Sites, dates and pesticides were agreed well in advance but the precise time of spraying and position of swaths were confirmed by telephone on the morning in question, depending on wind direction. Mr A Penniston directed the flight paths himself for Trials 2 and 6. On the other occasions, a radio telephone was used to maintain contact with the office at Sibson Airfield, and fluorescent marker flags were placed at about 16 m intervals to indicate the swaths.

1.2.2 Site descriptions

Holme Lacey

The western half of a long rectangular sugar beet field (c. 100 x 680 m) near the top of a hill was chosen for the trial (grid reference 32/3552334, altitude 120 m). It was bounded by grass fields to north and south with a small copse midway along the northern boundary and a low intermittent hedge and a few trees on the southern boundary. The land fell away evenly towards the south up to about 85 m beyond the field edge and then more steeply (Figure 1.1).

Chatteris

Three adjacent fenland fields were used during 1992 and 1993 (grid reference 52/4088, altitude 10 m) (see Figure 1.32). These all bordered on a concrete farm track which provided access, and were surrounded by other arable fields (wheat, sugar beet, potatoes and peas) without any hedges or trees. Where there was no boundary ditch, the crop boundaries themselves could vary from year to year.

Abbots Ripton

Oil seed rape was needed for the phosalone trial. A large field of spring-sown rape was chosen on the clay lands north of Kings Ripton (grid reference 52/259780, altitude 125 m).

1.2.3 Bioassays and spray validation

Two- to four-day-old larvae were used for bioassays of drift effects in all six trials. Aquatic invertebrates were used in all except Trial 3 with pirimicarb though the species varied depending on availability (Table 1.1).

The caterpillars were reared from batches of freshly laid eggs obtained for each trial from a commercial breeder, "Pieris" at Grantchester. The egg batches were kept in petri dishes on fresh cabbage leaves for about five days and then pinned to young cabbage plants in 7 x 7 cm pots. Day-old larvae were transferred with a paint brush to other potted cabbage plants a day or so before they were to be used. These potted plants were placed directly on the ground in fallow fields, short grass or stubble, or on upturned buckets in longer grass or sugar beet, or were suspended from canes so that they were just above tall crops such as wheat and oilseed rape.

After exposure to spray drift, the potted plants with the caterpillars were immediately placed in larger pots (ca 17 x 17 x 13 cm) with sealed drainage holes and nylon gauze cylinders taped around the rim. The open ends of the gauze cylinders were then tied and held above the plants by 40 cm split canes sunk into the potting compost. The larvae were thus brought back to a shaded room and survival recorded generally for 6-10 days.

The standard procedure for aquatic invertebrates was to expose targets consisting of a rectangular photographic developing tray, 46 cm x 57 cm and 8 cm deep, containing 2 cm of pond water that had been filtered through a 60 μm mesh net, to remove coarse particles and macro-invertebrates. The trays were lined with aluminium foil to prevent adsorption of pesticide onto the plastic surfaces. The trays were generally placed on the ground with their long sides at right angles to the anticipated direction of drift. However, in wheat and rape crops the trays were supported at the height of the crop using bamboo canes with adjustable hooks which attached to the lip of the tray. In some cases, invertebrates (*Gammarus pulex*) were added to the water trays for direct exposure in the field (Table 1.1), but in all trials the water samples were returned to the laboratory where subsamples were placed in 250 ml washed glass beakers. Animals were exposed to the undiluted water from each tray and in some cases to samples that were diluted to simulate contamination of water bodies that were 25 cm, 50 cm or 100 cm deep ie dilution by 12.5, 25 and 50 times respectively. Replicate controls of each species were also established and all were maintained over a minimum period of four days during which mortality was assessed.

Chemical analyses of deltamethrin in the helicopter and tractor sprayer tanks in Trial 1, and of the spray deposition and drift from both sprayers, were made by the Central Science Laboratory of the Pesticides and Contaminants Group from Harpenden, under the direction of Dr A J Gilbert.

1.3 TRIAL 1: DELTAMETHRIN

1.3.1 Methods

Spraying and field bioassays
A 300 m x 50 m area was marked out with flags along the top western end of the sugar beet field, and divided into two plots 200 m and 100 m long for helicopter and tractor spraying respectively (Figure 1.1).

Three parallel lines of bioassay targets were set out 5 m apart downwind of both plots starting on the southern boundary near the middle of the helicopter plot, but near the western end of the tractor plot to minimise shelter and turbulence effects from trees to north and south. Within each line, the targets were placed at 0, 10, 20, 30, 40, 50, 75, 100, 125 and 150 m from the boundary of the helicopter plot, and at 10 m intervals from 0-60 m from the boundary of the tractor plot. The 50 m position fell just within the grass field for the helicopter plot while the 60 m position fell just within the sugar beet field for the tractor plot owing to variations in the width of the field.

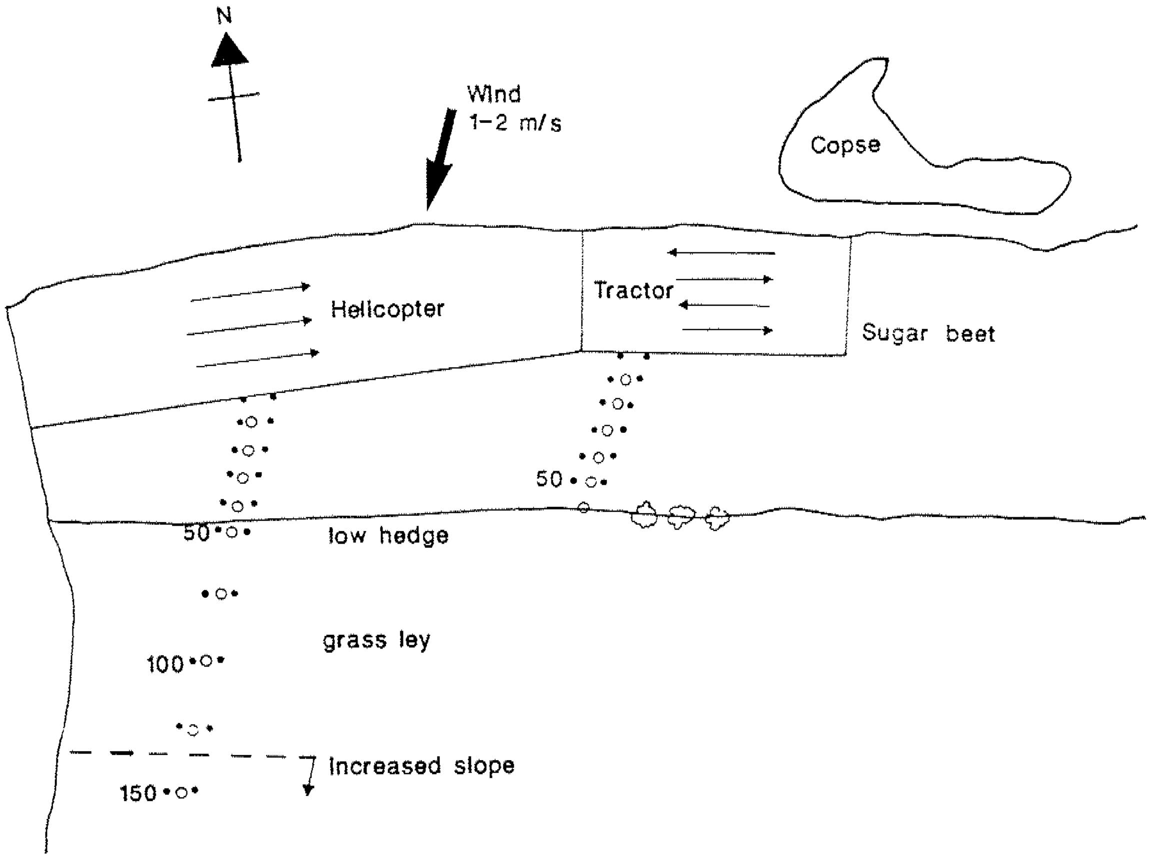
At each distance, the inner line of targets consisted of a water tray placed on the ground. Sugar beet leaves that overhung the trays were removed. The outer pair of targets each consisted of two young cabbage plants, each with about twelve 3-day-old *P. brassicae* larvae. There were no caterpillar targets at 60 m for the tractor plot, only a water target.

Spraying was done on the evening of 7 July between 2100 and 2140. It was brought forward from 8 July because of prevailing favourable weather conditions and a forecast of less settled conditions. Because of the late hour and the time needed to set up the deposition and drift targets by Dr Gilbert, it was necessary to put out all the caterpillar targets at the same time, and to follow the helicopter spraying immediately by the tractor spraying. Water targets downwind of the area sprayed by tractor were, however, only exposed when helicopter spraying had been completed.

The quantities of spray made up for the helicopter and ground sprayer were calculated to apply the standard application rate for deltamethrin, ie 7.5 g ai ha^{-1}. The actual levels of spray deposition were measured by Dr Gilbert using 8.7 cm diameter chromatography papers, placed horizontally in Petri dishes at crop height at 1.5 m intervals across the first (downwind) swath and last (upwind) swath. Drift was measured with similar papers placed at 1 m intervals downwind of the treated areas, and with vertical and horizontal polythene lines and sets of horizontal pipe cleaners at 8 m and 20 m downwind.

The helicopter sprayed three swaths 200 m long by 15 m wide from west to east in each case, starting c. 10 m from the southern edge of the plot and working upwind. The tractor sprayed four swaths 100 m long by 12 m wide on tramlines starting 6 m up from the south east corner of the plot. The spray was shut off when the

Figure 1.1. Area sprayed with deltamethrin at Holme Lacey by helicopter and tractor with positions of spray drift bioassay targets
● *P. brassicae* ○ water trays.



tractor entered the helicopter plot and restarted when it re-entered the plot on the return run after turning at the end of the field. The wind was light and steady (Table 1.2).

After spraying, the cabbage plants and water samples were all collected in by 2230 and transported back to Monks Wood the same night. The cabbages were kept for a week and checked regularly for larval mortality. Surviving larvae were then ten days old and entering their fourth instar. Subsamples of water were transferred to cleaned, 250 ml glass beakers. Invertebrates - *Asellus aquaticus*, *Gammarus pulex*, and *Centroptilum* (mayfly) nymphs - were exposed to undiluted water samples, and *A. aquaticus* and *Centroptilum* exposed to water diluted to simulate the effect of contaminating a pool 25 cm deep. In all cases two replicates, each containing 10 individuals, were established together with two controls for each species which used water that had not been exposed to possible contamination by drift. Mortality was then assessed over a period of four days.

Table 1.2. Spraying details for Holme Lacey using deltamethrin. Data from Glass (1993) except wind speed.

	Helicopter	Ground sprayer
Model/type	Hiller 12E	hydraulic
Swath width (m)	15	12
Boom length (m)	9.75	12
Nozzles	29 D645 cone	24 Hardy 4 110-20 fan
Pressure/flow (bar/l min^{-1})	2/2.3	2.5/1.38
Speed (km h^{-1})	64	8
Height above crop (m)	2	0.6
Intended application rate (g ai ha^{-1})	7.5	7.5
Measured " " "		
(downwind swath)	2.9	9.8
(upwind swath)	3.2	9.2
Wind speed at 2 m height (m s^{-1})	1-1.5	1-2

Figure 1.2. Cumulative mortality among *Pieris brassicae* larvae exposed to deltamethrin drift at different distances downwind following helicopter spraying.

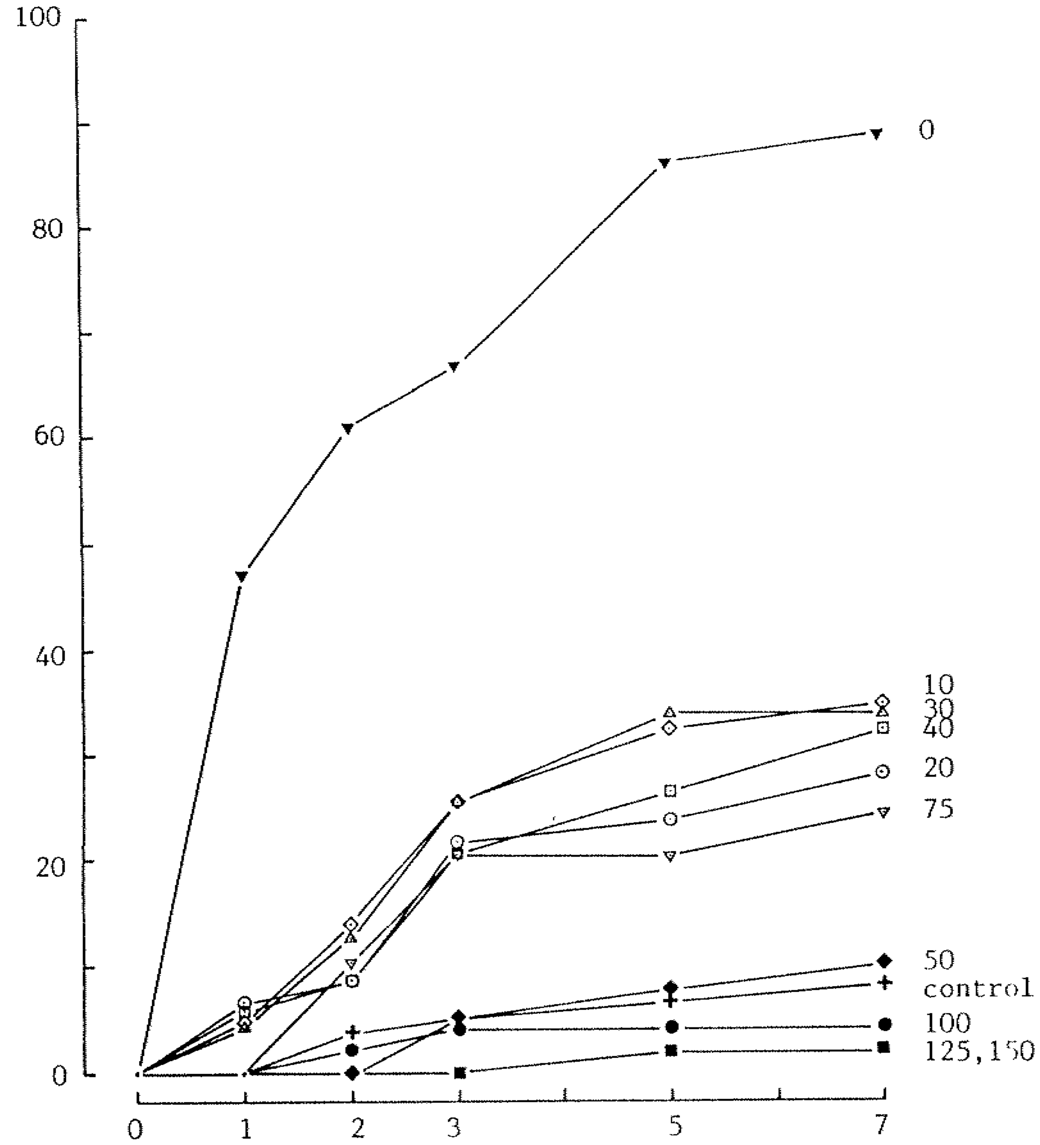
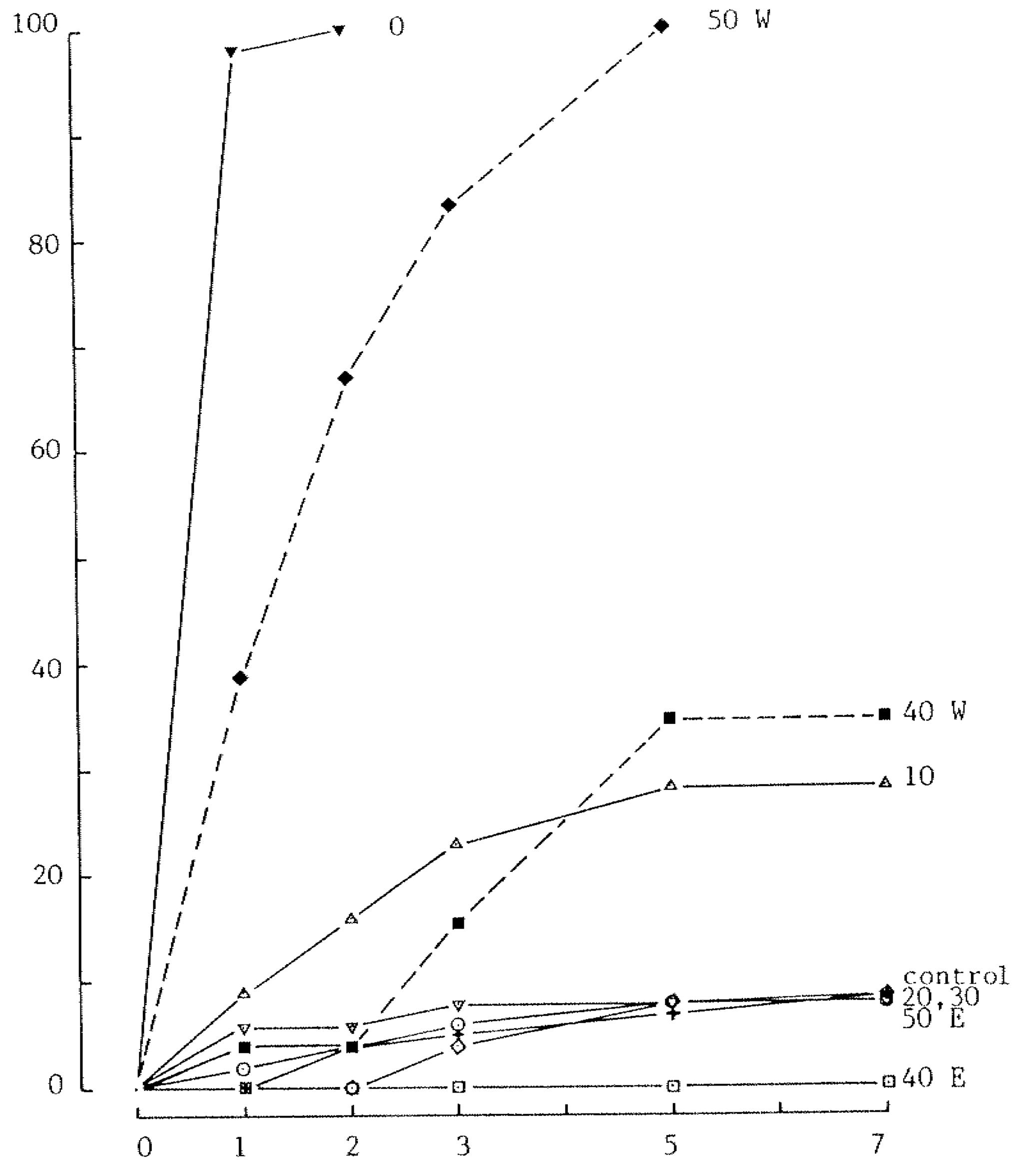


Figure 1.3. Cumulative mortality among *Pieris brassicae* larvae exposed to deltamethrin drift at different distances downwind following tractor spraying. East and west replicates for 40 m and 50 m shown separately.



1.3.2 Results

Caterpillars

Helicopter spraying

The mortality figures for *P. brassicae* were combined for the pair of targets (4 plants) at each downwind distance, and plotted to give cumulative mortality curves (Figure 1.2). There was a high initial mortality at the nominal edge of the sprayed area rising to 89% after seven days. Mortalities at 10, 20, 30, 40 and 75 m were all very similar, rising quite quickly up to day 3 and then more slowly to between 25 and 35% after seven days. The mortality at 50 m was 10.3%, only slightly above that for controls but rose again at 75 m. Mortality at 100 - 150 m was below that for controls (8.3%), reaching 2-4% after seven days.

Tractor spraying

The mortality curves again fell into three groups (Figure 1.3). At the edge of the sprayed plot, 98% of larvae died within one day and 100% within two days of spraying. At 10 m, the mortality rose gradually to 28% after five days with no further deaths, and thus equalled that for 20 m from the helicopter spraying. The results at 20-30 m were similar to controls reaching a mean of 8% mortality but those for 40 m and 50 m differed greatly between replicates. The eastern replicate in each case was again very low (0-8%) but the more western replicates had anomalous high mortality rising to 35% at 40 m and 100% at 50 m (Figure 1.3). (The 7-day mortality profiles for helicopter and tractor are compared with the results for aquatic invertebrates in Figures 1.10-1.13).

Aquatic invertebrates

Helicopter spraying

No mortality occurred in any of the controls during the period of the experiments. Mortality figures for each pair of replicates were combined and the cumulative mortality curves using the undiluted target water are shown in Figures 1.4, 1.6 and 1.8. At the edge of the crop mortality was high in all three species, reaching 100% after three days in *A. aquaticus* and by four days in the other two species. Initial mortality was also high at a downwind distance of 10 m in both *A.aquaticus* and *G. pulex* but after day 1 the mortality rate declined resulting in a final mortality after four days of 50% and 70% respectively. In contrast, in the case of *Centroptilum* nymphs, mortality rates at 10 m were virtually the same as those at the edge of the sprayed area throughout the experiment. Beyond 10 metres mortality rates generally declined rapidly with distance with the anomaly that in the case of the two crustaceans there was a higher than expected mortality at 100 metres.

When diluted target water was used there was no mortality beyond 10 m and 30 m in *A. aquaticus* and *Centroptilum* respectively.

Tractor spraying

Combined results from the two replicates for each distance are shown in Figures 1.5, 1.7, 1.9. Both *A. aquaticus* and *G. pulex* (Figures 1.5, 1.7) showed anomalously high mortality at 50 m and 60 m but this was not the case with *Centroptilum* in which mortality declined more or less steadily with distance from the sprayer; after four days mortality was 100% at all distances up to 30 m but only attained 20% at 60 m. In *A. aquaticus* a marked reduction in rate of mortality occurred between 10 m and 20 m while in *G. pulex* a similarly strong reduction in death rate occurred between 20 m and 30 m.

In water diluted to simulate a depth of 25 cm all animals were killed in the edge and 10 m treatments. Beyond this no mortality was observed in *A. aquaticus*, except at 50 m where it reached 30%. In the case of the mayfly nymphs (*Centroptilum*) deaths declined progressively to zero at 50 m.

Figure 1.4. Cumulative mortality among *Asellus aquaticus* exposed to deltamethrin drift at different distances downwind following helicopter spraying.

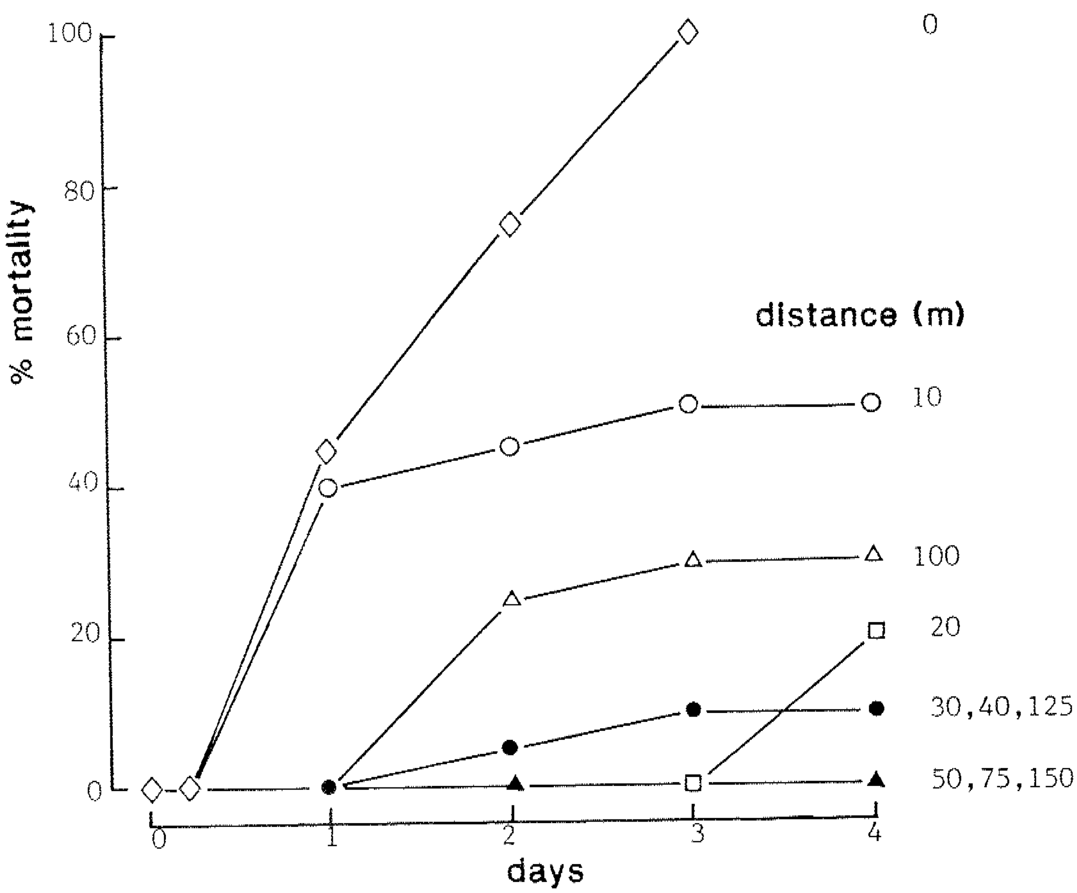


Figure 1.5. Cumulative mortality among *Asellus aquaticus* exposed to deltamethrin drift at different distances downwind following tractor spraying.

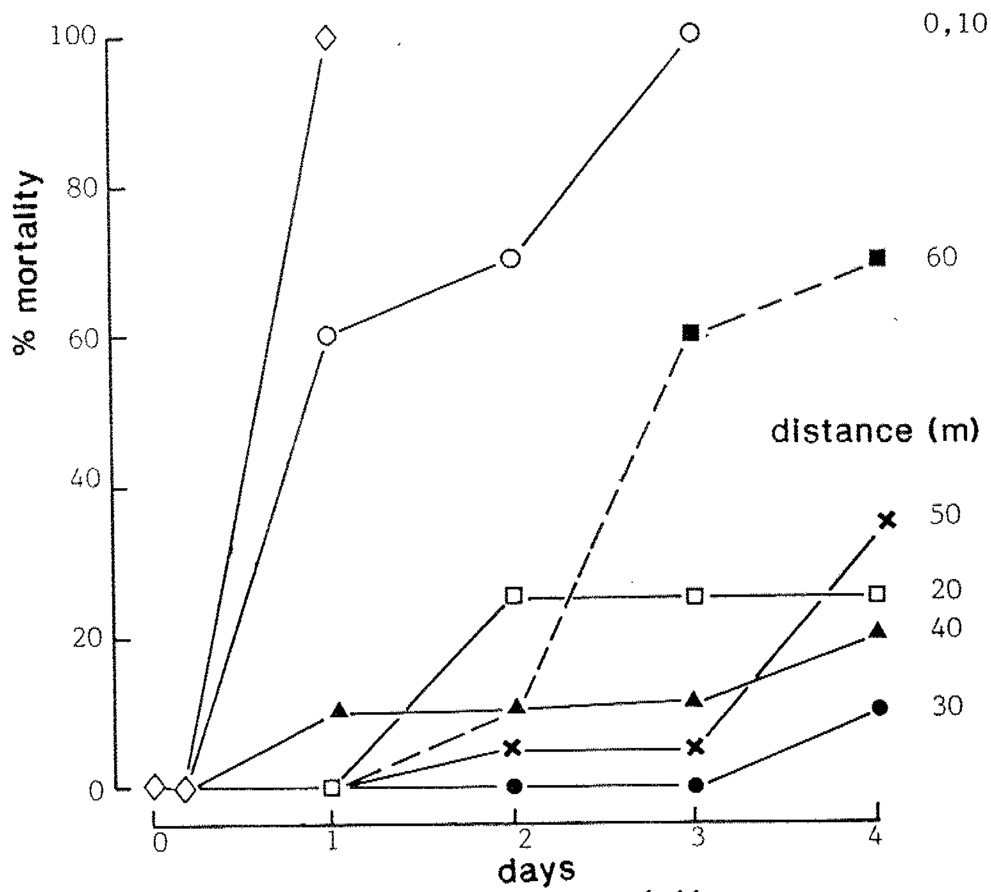


Figure 1.6. Cumulative mortality among *Gammarus pulex* exposed to deltamethrin drift at different distances downwind following helicopter spraying.

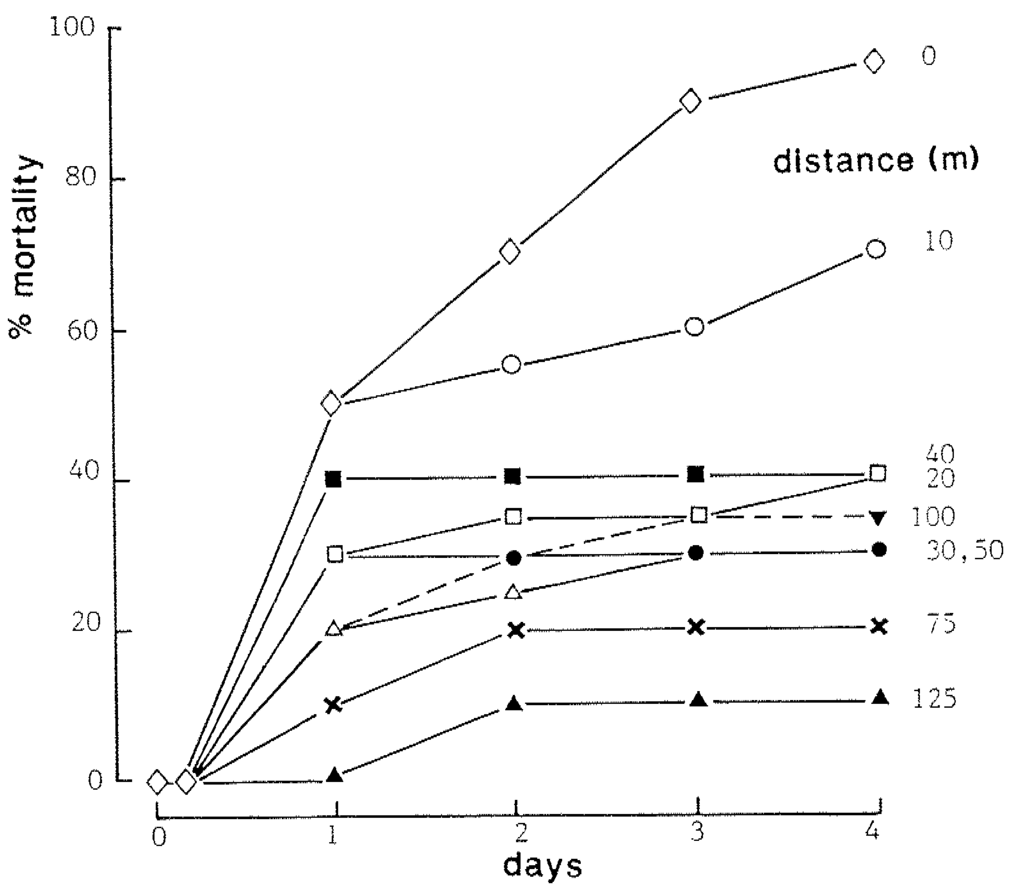


Figure 1.7. Cumulative mortality among *Gammarus pulex* exposed to deltamethrin drift at different distances downwind following tractor spraying.

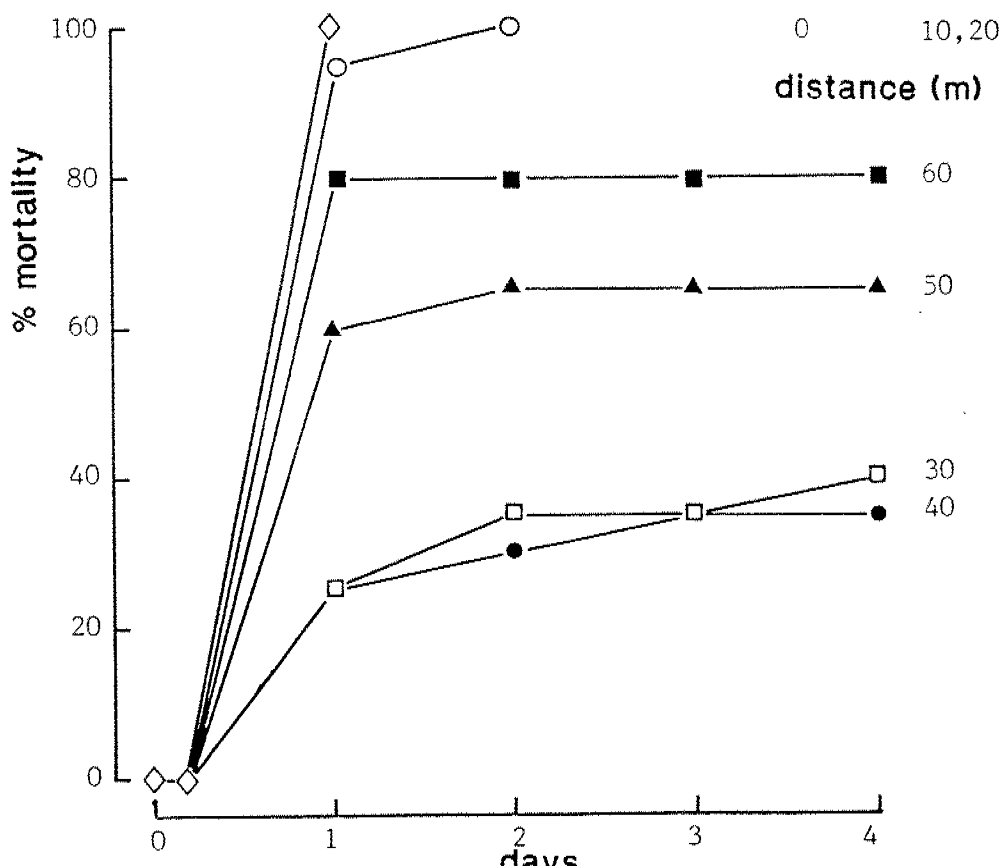


Figure 1.8. Cumulative mortality among *Centroptilum* nymphs exposed to delatmethrin drift at different distances downwind following helicopter spraying.

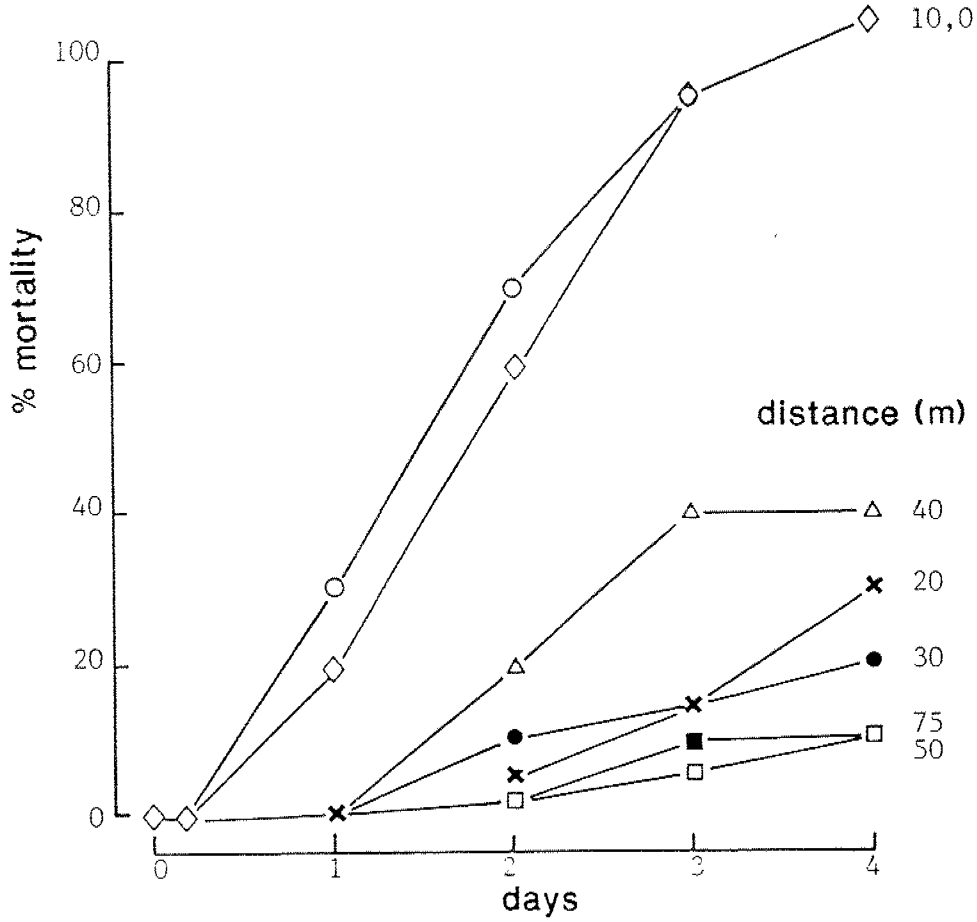
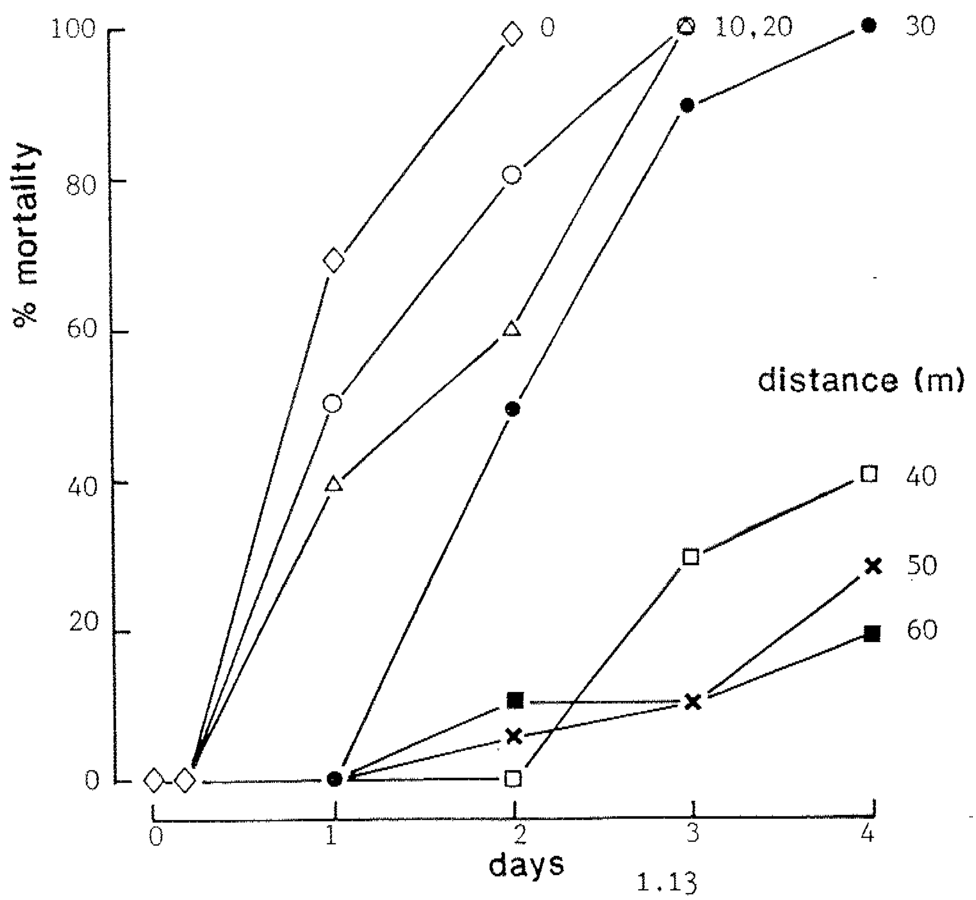


Figure 1.9. Cumulative mortality among *Centroptilum* nymphs exposed to deltamethrin drift at different distances downwind following tractor spraying.



Comparison of helicopter and tractor spraying
The drift effects from the helicopter and tractor are compared directly in Figures 1.10-1.13, after seven days for caterpillars and four days for aquatic invertebrates. In all species mortality was greater close to the crop in the case of ground spraying, remaining at 100% up to 30 m in the case of *Centroptilum*. At 20-30 m mortality was distinctly lower in *Pieris* from ground spraying but beyond this the western replicate and both crustaceans showed strongly increased mortality again.

Deposition and drift measurements
The intended application rate of deltamethrin was 7.5 g ha^{-1} for both helicopter and tractor. The measured deposition on Petri dishes placed within the downwind and upwind swaths was 2.9 and 3.2 g ha^{-1} for the aerial application and 9.8 and 9.2 g ha^{-1} respectively (Table 1.2). These mean values were obtained from dishes that had received the 'full dose', and do not include low or zero values; such low values were attributed to partial coverage by crop leaves during the application. They indicate that the helicopter applied about 41% of the intended dose and the tractor about 127%, ie a 3-fold difference.

The analysis from the helicopter spray tank gave a concentration of 63.2 μg/ml instead of the intended 130 μg/ml, ie about half the intended concentration, while the tractor spray tank had a concentration of 51.2 $\mu g\ ml^{-1}$ instead of 38.0, ie about one and a third times the intended concentration. These values are not considered entirely reliable because of precipitation in the sealed tubes before the extraction solvent was added and analyses made (R Glass pers. comm.) but they nevertheless reinforce the relative deposition results from the Petri dishes.

The only air sampling media found to have detectable deposits of deltamethrin from aerial application were at the 8 m downwind stations for the vertical polythene lines and at 8 m and 20 m downwind for the ground lines. None of the airlines from the ground based application had detectable deposits.

Figure 1.10. Mortality among *P. brassicae* larvae (mean and range) after 7 days following spraying with deltamethrin by helicopter and tractor. East and west replicates for tractor plot at 40 m and 50 m shown separately.

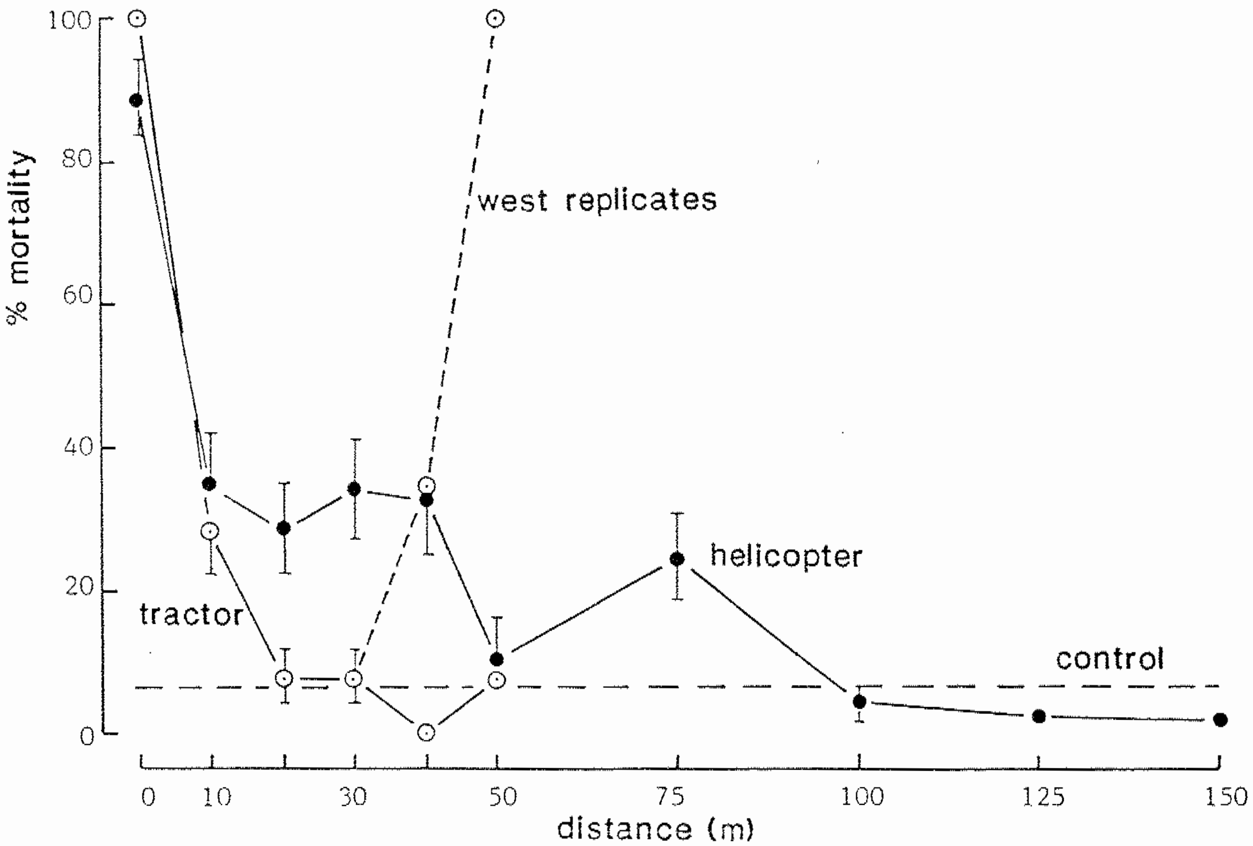


Figure 1.11. Mortality among *Asellus aquaticus* after 4 days following spraying with deltamethrin by helicopter and tractor. Target water 2 cm deep, undiluted.

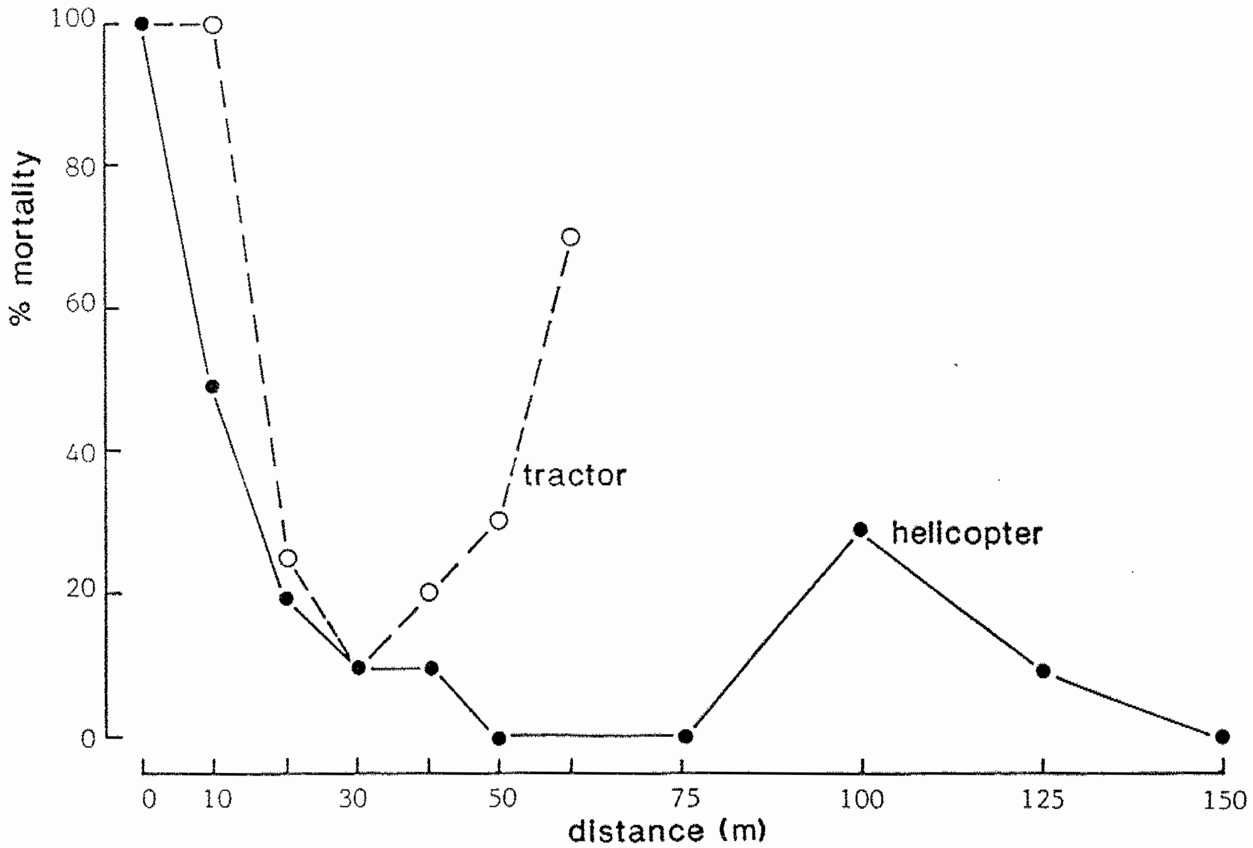


Figure 1.12. Mortality among *Gammarus pulex* after 4 days following spraying with deltamethrin by helicopter and tractor. Target water 2 cm deep, undiluted.

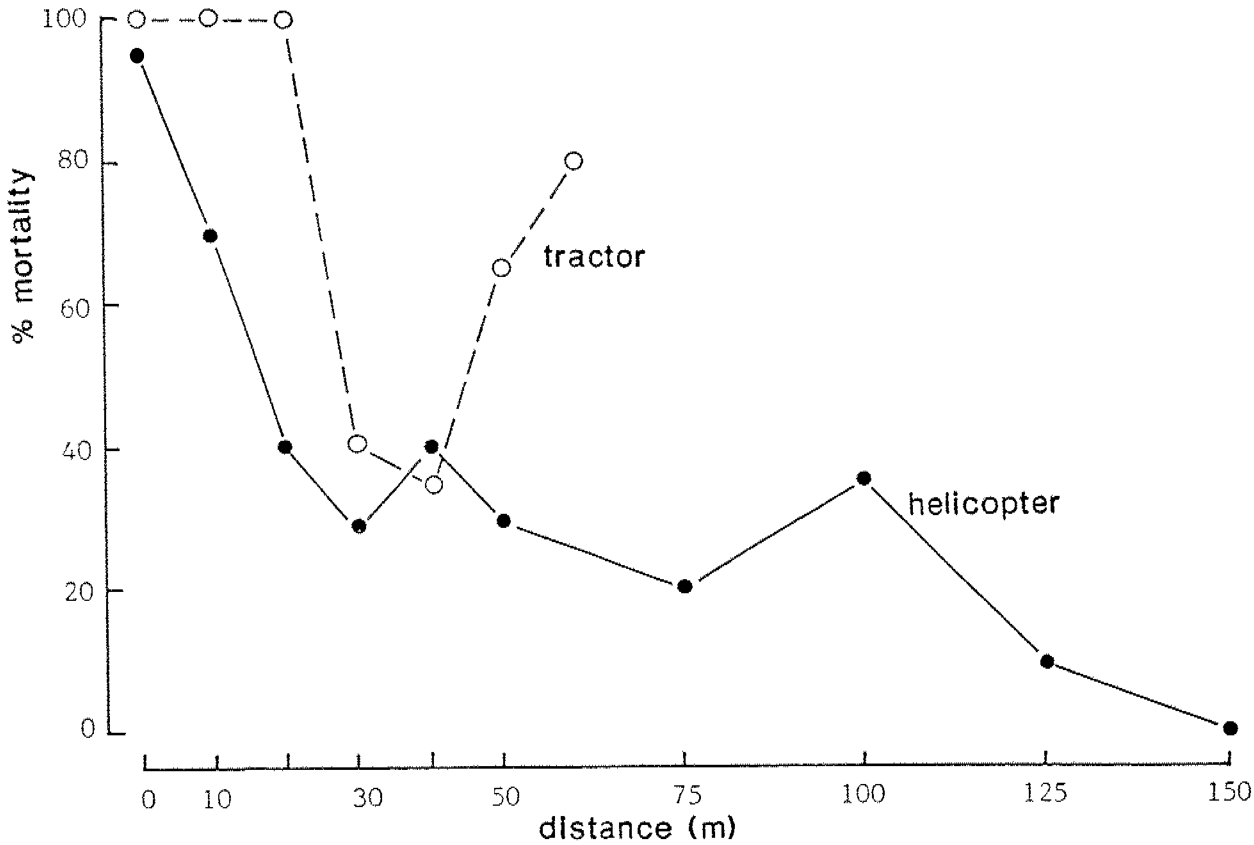
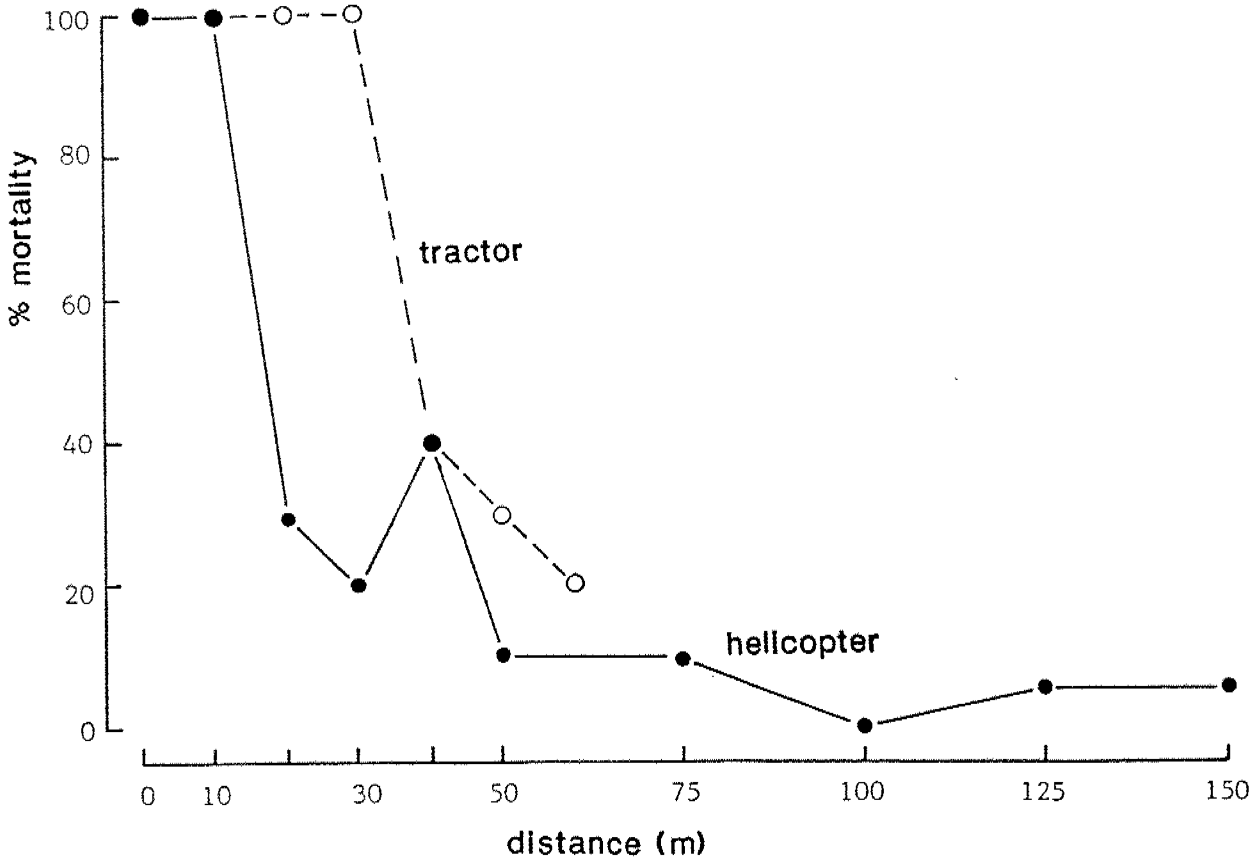


Figure 1.13. Mortality among *Centroptilum* nymphs after 4 days following spraying with deltamethrin by helicopter and tractor. Target water 2 cm deep, undiluted.



1.3.3 **Discussion**

The *Pieris brassicae* bioassay results from aerial spraying with deltamethrin spanned a useful wide range of effects from 89% at the edge of the sprayed plot to negligible mortality at 100+ m downwind. The edge of the plot was about 5 m from the end of the helicopter spray boom to allow for displacement of spray by the wind into the intended target area. The rapid decrease in drift-induced mortality between 0-10 m indicates that the spray swath was applied reasonably accurately under those terrain and weather conditions. The graphical estimate for 7-day LD_{50} distance is about 5-7 m on a steep response curve to deltamethrin between the exposure levels received at 0 and 10 m (Figure 1.10). Likewise, the LD_{20} distance may be estimated at about 45 m but the irregular mortality profile renders such estimates rather dubious. It is possible that the low mortality at 50 m and increased mortality at 75 m were due to the shelter effect of the hedge at 45 m (Davis *et al* in press). However, spray deposition downwind of helicopter-sprayed areas can show similar profiles to that in Figure 1.10 even in hedgeless areas, with "hot spots" as a result of resonance in spray patternation (A.J Gilbert, pers. comm.).

The results from the tractor spraying show a similar steep decline in larval mortality between 0-10 m with a 7-day LD_{50} distance again of 5-7 m. The mortality at the plot edge itself was higher than in the helicopter plot because the targets were within direct range of the spray boom. The mortality curve up to 30 m was comparable with that obtained from cypermethrin on peas at Haverhill (Davis *et al.* 1993b); detailed comparisons cannot be made because fewer observations were made at shorter distances at Holme Lacey.

It is difficult to know exactly how drift deposition would have occurred downhill and under these light winds. The increasing mortality levels at 40 m and 50 m for the more western of the two transects concur with the results for aquatic fauna. These three transects were spaced only 5 m apart but it seems likely that the ends of these transects received spray drift from both the helicopter and tractor spraying. If so this appears to have had an impact on the water targets even though they were only exposed after the helicopter had finished spraying. The time interval was, however, only a matter of a few minutes. Alternatively, there may have been an eddy effect from the hedge or trees at the crop boundary, though it is not obvious why the most eastern transect should have been unaffected. In either case, the large change in mortality noted above between 0-10 m for both plots suggests that relatively small increases in deposits could cause large changes in response.

Direct comparisons of spray drift effects from helicopter and tractor spraying must be reviewed in the light of Dr Gilbert's results (Table 1.2) which showed a roughly 3-fold difference in application rates. These deviations from the intended dose rates are thought to have resulted from errors in calculating the total amount of water and/or concentrate needed for these relatively small plots which were only determined in the field that afternoon. (Commercially, such calculations would be made well in advance for whole fields or for whole spray tanks.) Subsequent enquiries suggested strongly that too much Decis had been measured out for the tractor spray tank, while too much water had been measured into the bowser for the helicopter and not all the diluted spray was used.

1.3.4 Conclusion

A buffer zone for aerial spraying with deltamethrin *under these conditions* would need to be about 90 m for 10% mortality in the standard targets of *P. brassicae* larvae. Aquatic invertebrates would not be affected in water 25 cm deep beyond a distance of 30 m. However, as the application rate was only 36% of the specified rate, these estimates might need to be considerably increased.

The application rate for the tractor was probably within the variation found in normal agricultural practice, but the large difference from the helicopter rate prevents close comparisons of drift effects. The U-shaped mortality curves in several cases also prevents good estimates of buffer zones to safeguard non-target species.

Wind conditions (steady breeze, force 2) would be theoretically optimal for spraying during the day when unstable meteorological conditions would normally prevail. However, at this late evening hour, neutral or stable meteorological conditions might have developed (as at Chatteris in 1991) in which drift particles had little tendency for vertical dispersal, thus exacerbating the impact of spray drift. Commercial spraying, from the air or ground, would not be advisable under these conditions.

1.4 TRIAZOPHOS

1.4.1 Methods

Spraying and sampling

A potato field in Curf Fen, Chatteris, was used for this trial with Hostathion under an off-label approval. Three parallel lines of (single) potted cabbage plants and two lines of water traps were set out from the western, downwind, edge of the potato field through a wheat crop up to 150 m (Figure 1.14). This maximum target distance was decided after the bioassay results from the previous deltamethrin trial but before the low helicopter application rate was known. Each plant, with about 12 *P. brassicae* larvae 3.5 days old, was suspended just above the level of the potatoes or wheat (80 cm).

Conditions were warm and sunny with a moderate south-east wind. The plane made eight passes covering the western third of the field at about 15 m spacing, with the centre of the first swath 20 m from the edge (Table 1.3).

Bioassays

Caterpillars

After the spraying, the cabbage plants were examined within six hours to check the larvae for knock-down effects and then for the following six days. The total numbers of dead plus live larvae recorded on the day of spraying (day 0) were taken to be the number exposed and are given under day -1.

On day 4, the larvae on three control plants (then in the 3rd instar) were each divided into two equal batches. Three batches were kept on their original (control) plants while the other three were transferred to plants that had been exposed to drift at 50, 100 or 150 m and from which all the original larvae had died. These six groups were monitored for a further six days.

Aquatic invertebrates

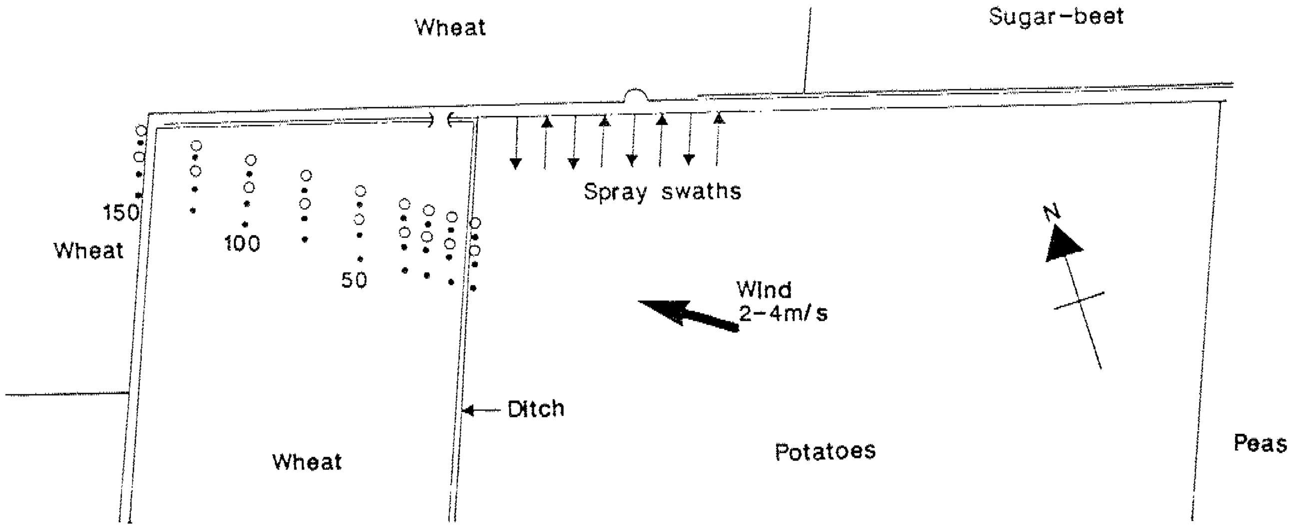
Water samples from the targets were returned to the laboratory where subsamples were placed in 250 ml, washed glass beakers. Animals were exposed to the undiluted water from each tray and also to samples that were diluted to simulate contamination of water bodies that were 25 cm, 50 cm and 100 cm deep. Experimental animals included nymphs of a mayfly *Baetis* sp. in addition to *Gammarus* and *Asellus*. Two replicate controls of each species were also established and all were maintained in incubators at 15°C over a period of four days during which mortality was assessed.

Table 1.3 Spraying details for four trials at Chatteris (2, 3, 4, 6) and one at Abbots Ripton (5) in chronological order.

Aircraft; and boom length (m)	Piper Pawnee 235
Nozzles; and operating pressure (psi/bar)	36 Lurmark D6-45, hollow cone; 45-50/3.1-3.4
Speed (kph); and height above crop (m)	130; 4

Trial	2	3	4	5	6
Date/Time	29.7.92/1010	26.8.92/1250	2.6.93/1105	15.6.93/0915	7.7.93/1130
Pesticide	Triazophos	Pirimicarb	Fenitrothion (1)	Phosalone	Fenitrothion (2)
Product	Hostathion	Aphox	Fenitrothion 50	Zolone	Dicofen
Crop	Potatoes	Sugar beet	Wheat	Oilseed rape	Wheat
Application rate					
fl oz: in gal water ac^{-1}	10:2.5	4:2.5	20:2.5	20:2.5	20:2.5
g ai ha^{-1}	295	140	700	700	700
No. of sprayed swaths	8	6	9	8	8
Wind speed ($m\ s^{-1}$) mean ± range	3.0±1	4.0±1.5	1±0.8	1.5±1.0	3.5±1.0
Dry bulb/wet bulb (°C)	20.0/16.9	15.7/14.4	16.8/14.6	15.3/13.2	19.5/17.7

Figure 1.14. Area sprayed with triazophos at Normoor, Chatteris, and positions of targets ● *P. brassicae* ○ water trays.



1.4.2 Results

Caterpillars

The caterpillars exposed to drift showed very rapid response and high mortality at all downwind distances up to 50 m, and only a little less rapid at further distances up to 150 m (Figure 1.15). More than 88% mortality was recorded at all distances up to 150 m after six days.

Control larvae showed no mortality between day 1 and day 10. However, all those that were transferred to plants that had received drift at 50 m and 100 m died during the subsequent six days, and 63% of those fed on a plant from 150 m. (Note the reduced scale for these results in Figure 1.15, starting from a new base line on day 4.)

Aquatic invertebrates

The combined results for the two lines of targets are shown in Figures 1.16-1.18. No mortality occurred in the controls. When exposed to the undiluted target water, *Asellus* was much less susceptible to the effects of triazophos drift than *Gammarus*. The latter suffered 100% mortality to a distance of 125 m while *Asellus* were all killed to a distance of only 20 m beyond which mortality declined quite rapidly to only 10% at 100 m and zero at 150 m. *Baetis* nymphs were also much less susceptible than *Gammarus*, all being dead after four days at 0 m, 10 m and 20 m with a steady decline to only 15% at 150 m.

Except for *Gammarus* there was no effect of spray drift at any distance when the target water was diluted to the equivalent of a depth of 100 cm. Even at this dilution the mortality among the freshwater shrimps was 30% in water from the edge of the sprayed zone, falling to zero at 30 m. Both *Asellus* and the mayfly nymphs were affected to a distance of 75 m in samples diluted to simulate a water depth of 25 cm, although the results for *Asellus* were very erratic, possibly because of the difficulty of determining whether these animals, which often remained paralysed for long periods, or partially so, were dead or merely immobilised.

1.4.3 Discussion

The nominal application rate of 295 g ai ha^{-1} (Table 1.3) was somewhat less than the dose recommended for triazophos (c. 350 g ai ha^{-1}) to control cabbage caterpillars or pea moth by ground spraying (Scopes & Stables 1989) and considerably less than that given on the off-label recommendations for aerial spraying against Colorado beetle (630 g ai^{-1}), ie higher rates are applied in other situations. Nevertheless, the 150 m maximum distance was clearly not enough to give a no-effect result for *Pieris* though it was appropriate for the aquatic invertebrates tested.

The caterpillars were thought to have suffered some dehydration stress two days before the experiment when a proportion of newly hatched larvae died. The field exposure during warm sunny conditions was also considered to impose some stress which might have contributed to the initial high mortality. However, larval mortality on day 0 was clearly related to distance and that at

100 m was little more than control mortality. The controls were kept in a vehicle and therefore not exposed to sun in the same way. In all subsequent trials the controls were exposed to the full field conditions, and the results for the second fenitrothion trial (described below) suggest that the caterpillars are not unduly stressed by such weather conditions.

The continuing mortality among exposed larvae after day 1, and the subsequent mortality of control larvae fed on exposed plants, clearly suggested a residual stomach action of the triazophos. The efficacy period for pest control with triazophos is considered to be 3-4 weeks (Ivens 1993).

The three species of aquatic invertebrates that were tested showed substantial differences in their susceptibility to triazophos; *Gammarus* was generally the most susceptible, although measurable effects persisted to a greater distance in *Asellus* in a simulated depth of 50 cm. If it is accepted that 10% is well within the range of natural mortality then a buffer zone of around 70 m appears, on the basis of these results, to be adequate to protect invertebrates living in water bodies 25 cm deep or more. However, considerably greater distances may be necessary to protect fauna living in shallow, still water, or slowly flowing habitats.

Figure 1.15. Cumulative mortality among *P. brassicae* larvae exposed to triazophos drift at different distances downwind. Mortality at day 0 was 6 hours after spraying. Controls subdivided on day 4.

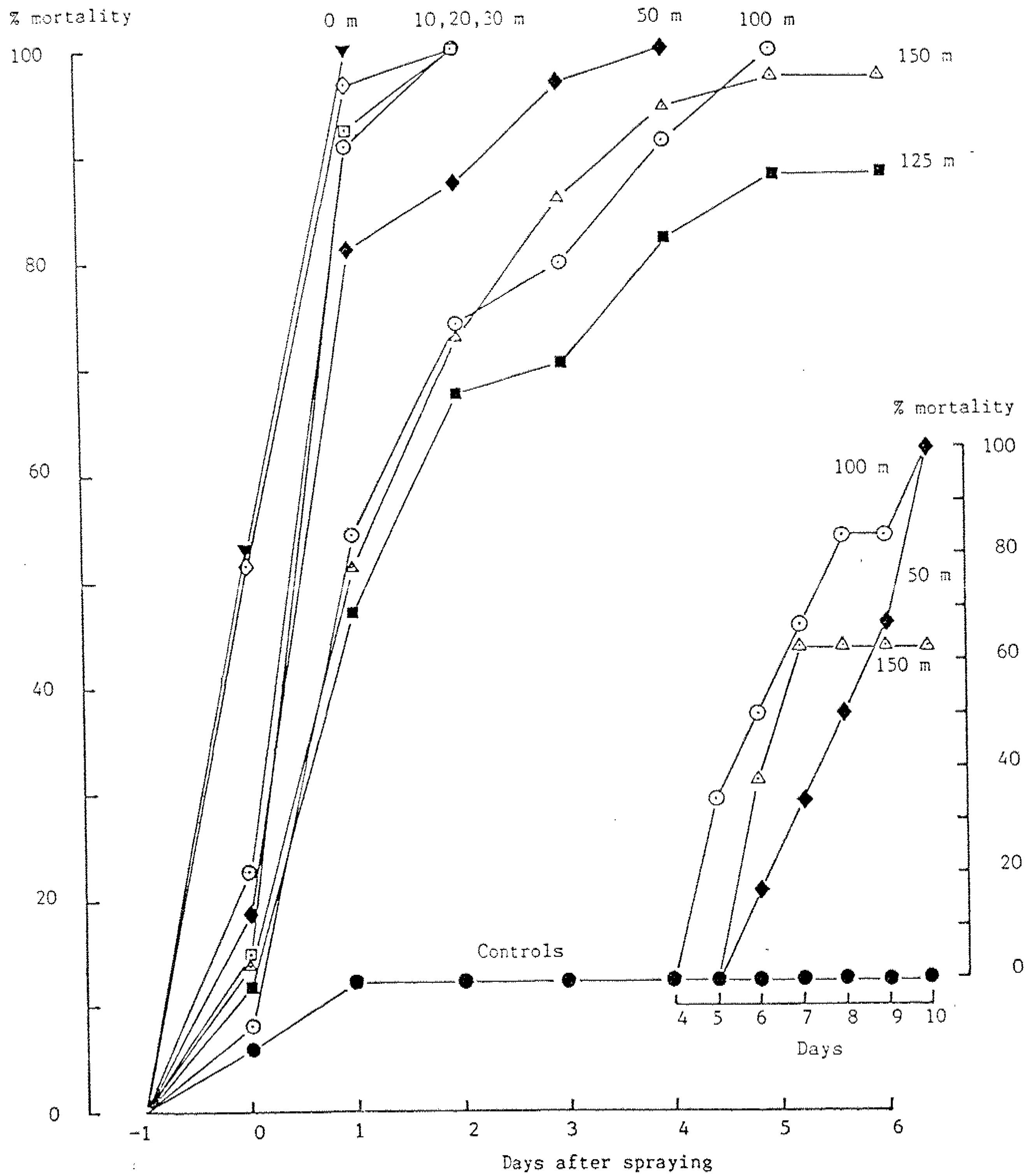


Figure 1.16. Mortality among *Asellus aquaticus* after 4 days following aerial spraying with triazophos. Target water 2 cm deep (undiluted) and diluted to simulate greater depths.

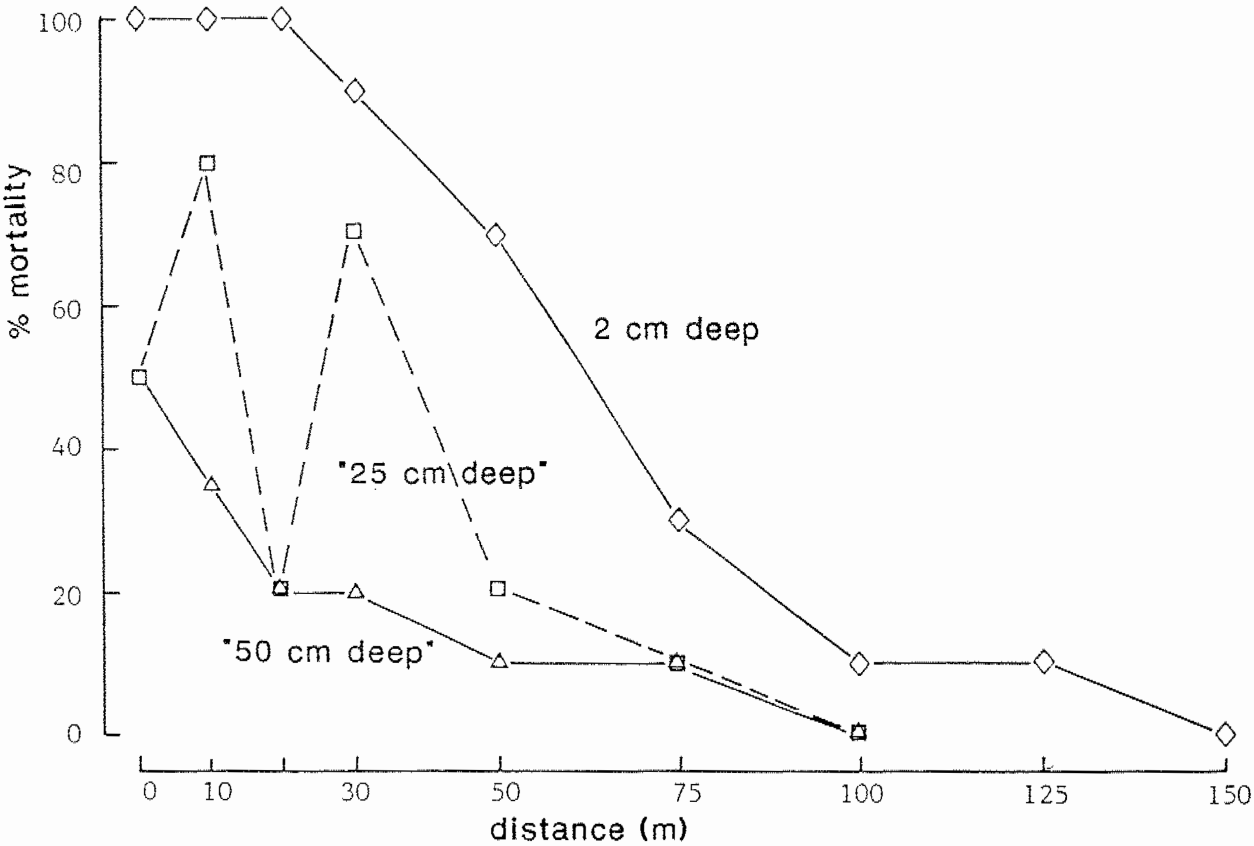


Figure 1.17. Mortality among *Gammarus pulex* after 4 days following aerial spraying with triazophos. Target water 2 cm deep (undiluted) and diluted to simulate greater depths.

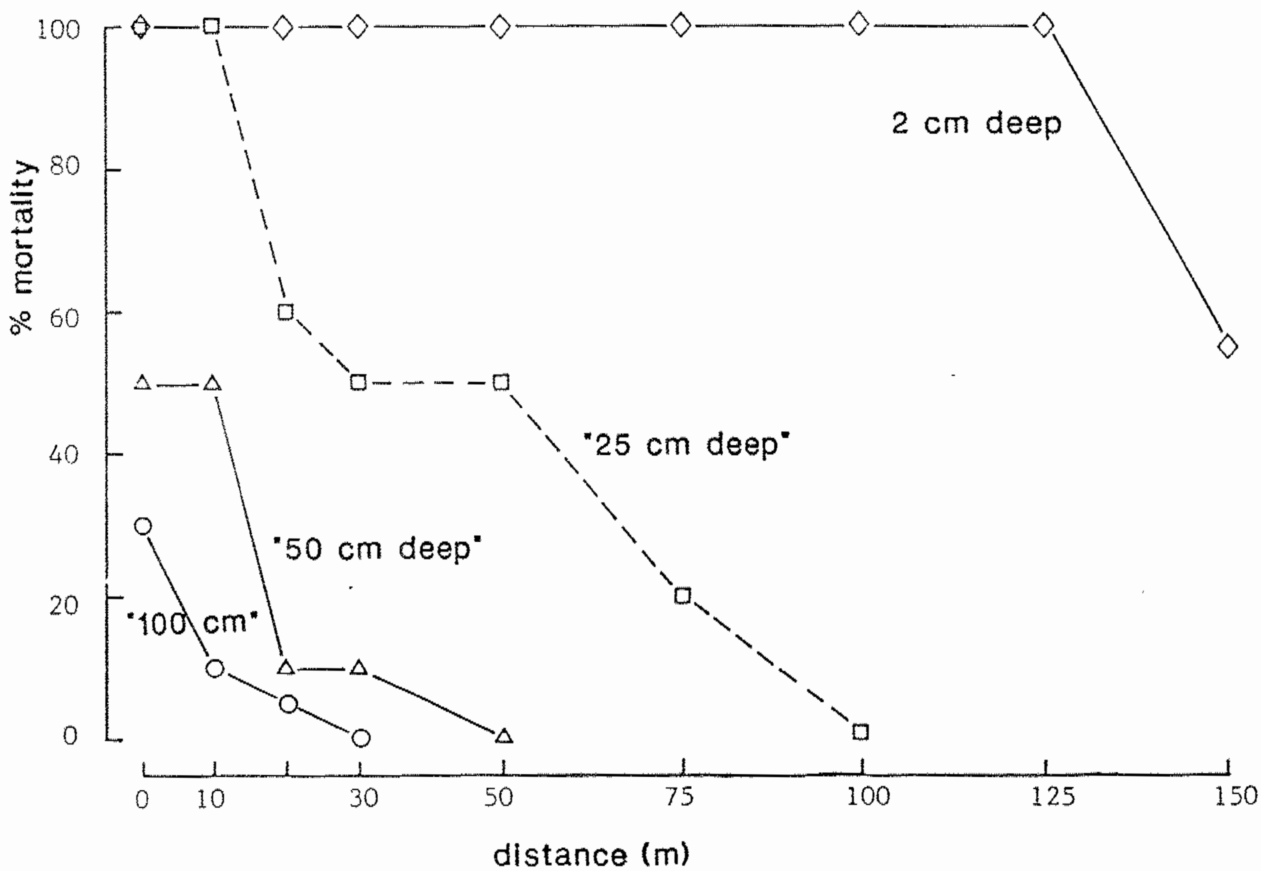


Figure 1.18. Mortality among *Baetis* nymphs after 4 days following aerial spraying with triazophos. Target water 2 cm deep (undiluted) and diluted to simulate greater depths.