Bull. Environ. Contam. Toxicol. (1993) 51:523–531

Environmental Contamination and Toxicology

Pesticide Risk Assessment and Non-Target Invertebrates: Integrating Population Depletion, Population Recovery, and Experimental Design

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Given the extent and seriousness of soil pollution problems, ecological risk assessment procedures are required which can accurately predict harm but which minimize demands on time and resources. Where the environmental concentration of the chemical is more or less constant then simple models may be developed that relate environmental exposure to laboratory toxicological criteria (Kooijman, 1987). Where the chemical's levels fluctuate temporally however, as is the case with pesticide applications to agricultural crops, the development of such models may be far more intractable (Van Straalen et al., 1992). It has been suggested that risk analysis may need to be based not only on the immediate damage done but also on the potential for ecological recovery (Jepson, 1989; Van Straalen et al., 1992).

In the case of non-target invertebrates, that are exposed to pesticides in arable crops, the development of such analyses have been slow. Although numerous studies have demonstrated the adverse effects of pesticides (e.g. Vickerman & Sunderland, 1977; Jepson, 1989 [review]; Basedow, 1990), the ecological significance (and hence the development of effective risk predictions) of such effects is as yet unclear. At least one of the reasons for this uncertainty is that the recovery of the species that were adversely affected in these trials was not quantified (Jepson & Thacker, 1990).

In this paper we utilize data collected over a three year period to investigate the recovery of two non-target invertebrate families following exposure to pesticide in a conventional field trial. The data from the first two years were used to develop models of the recovery process while data from the third year was subsequently used to validate these models.

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Utilizing all three years data a method by which the initial population depletion could be integrated with population recovery was then developed. The results show that for the development of effective risk analyses not only are measurements of recovery essential, but also a clear understanding of how recovery may be affected by the experimental design that is used.

MATERIALS AND METHODS

The data for the analyses were derived from three field experiments carried out between June and August in 1987, 1988, and 1989 in winter-wheat crops that were sprayed with dimethoate. The crop/spray details for the experiments in 1987 and 1988 have been presented elsewhere (Jepson & Thacker, 1990). The treatment regime and cropping details in 1989 were similar with a single hydraulic spray application at anthesis. Schematics of the experimental layouts that were used are given in Figures 1a - c.

The non-target epigeal invertebrate fauna were sampled using pitfall traps, which were emptied weekly. In this paper, data are presented for two invertebrate families, the Carabidae and the Linyphiidae.

For each sampling occasion and position the mean $\log_{10}$ (n+1) numbers of the Carabidae and Linyphiidae, per trap per day, were first calculated. The mean numbers that were trapped in the treatment plots were then plotted as a percentage of the mean numbers that were trapped in the control plots. In 1987 and 1988 these values were based upon a comparison of treatment and control numbers at equivalent sampling positions (Figs 1a & b). In 1989 the comparison was made between each treatment sampling position and the number trapped in the center of the control plot (Fig 1c). Although the sampling positions that were used in 1989 were therefore no longer independent of each other, this change was made because a preliminary analysis of the previous two years data had indicated that recovery of the non-target invertebrate fauna was mediated primarily by reinvasion from surrounding untreated areas (Jepson & Thacker, 1990). This then meant that a separate control for every sampling position in the treatment area was no longer necessary.

Pre-spray variation in the numbers in the treatment plots was found to be within +/- 20% of the numbers in the control plots in all three years. Recovery time was therefore defined and calculated as the day, after treatment, when carabid or linyphiid numbers at a given position, were within 20% of the value for the control.

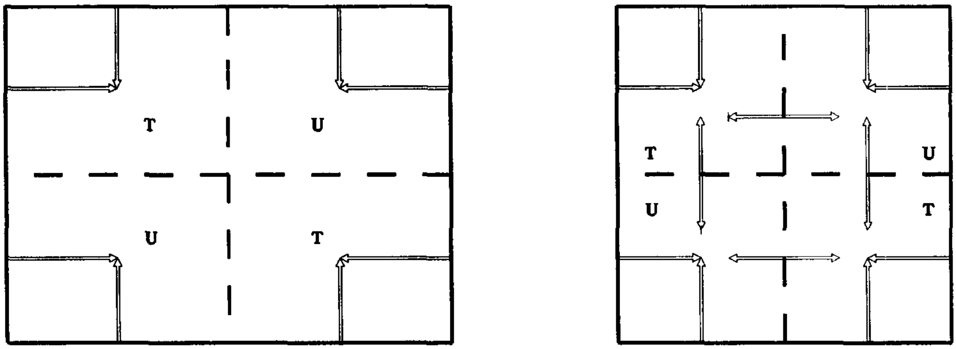

Figure 1a - 1b. Experimental design in 1987 and 1988. The plot sizes were 170m * 350m (6 ha) and 245m * 245m (6 ha), respectively.

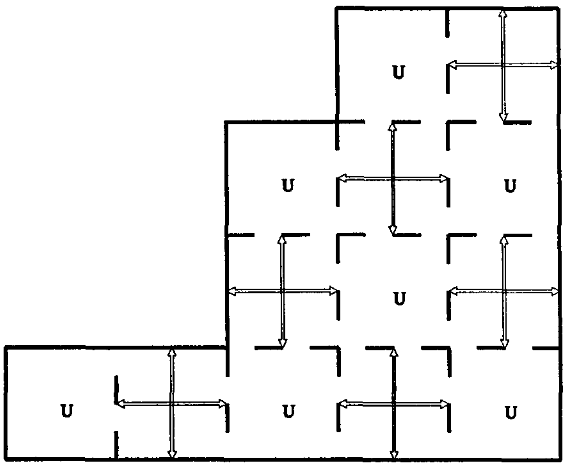

Figure 1c. Experimental design in 1989. The plot sizes were 173m * 173m (3 ha).

Figure 1a - c. Diagrammatic representations of experimental designs. In all three years whole fields were used. U = untreated plots, T = treated plots; arrows represent the positions of sampling transects. In 1989 the design used transects in the treatment plots only (traps at 10m, 30m, 50m, 70m and 90m from the plot edge) with center plot sampling in the control plot.

The values for recovery time were then regressed against distance from the control plot, distance from the field boundary, or distance from the nearest untreated area (i.e. control plot or field boundary). The aim of this analyses was to identify the most likely source from which recovery (by reinvasion) might be taking place. The data for both 1987 and 1988 were used in the initial analyses and the data that were collected in 1989 were then used to crudely assess the fit of the linear models to the data.

Finally, using all three years data, and for each sampling position, the duration and extent of the population depletion (for reductions > 20% compared to the control) was quantified to give an expression of the overall effect. This value, which was called the '% depressed days' was derived by measuring, on graph paper, the duration and level of the depletion described above. The values of '% depressed days' were, for each family, then regressed, using a multiplicative regression model, against the distance of that sampling point from the most likely source of reinvasion (Jepson & Thacker, 1990). The x-axis in these models (distance) was then converted to area (ha), based upon the assumption that each distance measurement could be considered equivalent to a central sampling point in a square untreated area. These models, which were based on all three years' data, therefore describe, mathematically, the likely overall effect of the pesticide upon the Carabidae and Linyphiidae within plots of differing sizes.

RESULTS AND DISCUSSION

The fit of the regression models that were used to analyze the data collected in the first two years are given in Table 1.

Table 1. Regression models describing the most likely source of reinvasion mediated recovery for the Carabidae and Linyphiidae at each sampling position. The recovery time (days) was regressed against the distance of the sampling position from the control plot, field boundary, or both.

Family	Recovery vs dist.	Model (Y=a+bX)	r	SIG.
Carabidae	to control plot	Y= 7.83+0.115X	0.64	<0.05
Carabidae	to field boundary	Y=22.42-0.109X	0.67	<0.05
Carabidae	to either	Y=19.44-0.077X	0.32	NS
Linyphiidae	to control plot	Y=12.26+0.024X	0.27	NS
Linyphiidae	to field boundary	Y=14.38-0.002X	0.02	NS
Linyphiidae	to either	Y=12.18+0.079X	0.66	<0.05

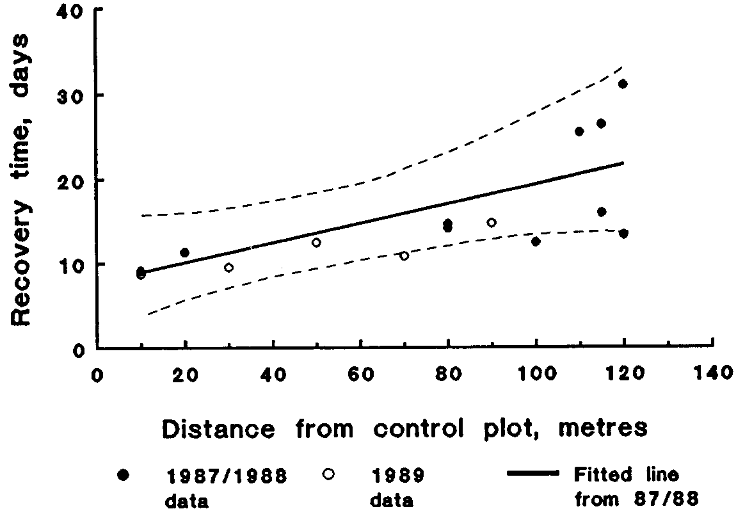

Figure 2. Regression line giving the best fit for the 1987 and 1988 carabid data (+/- 95% confidence limits). Data points are either from 1987/1988 or 1989 (which were not used to fit the model).

Table 1 shows that in the case of the Carabidae a positive, significant fit for the model was obtained when the distance of each sampling position from the nearest control plot was considered. This result suggests that recovery is mediated via movement of individuals from nearby control plots. The table also shows that a negative, significant fit for the regression model was obtained with regards to the distance of each sampling position from the field boundary. This latter result indicates that the field margin is a poor source for reinvasion mediated recovery. This was not unexpected since most ground beetle species will have fully colonised the field from boundary overwintering sites by mid-summer (Sotherton & Coombes, 1986). In contrast to the result with the Carabidae, the linear regression model of linyphiid recovery gave the best fit when proximity to the nearest untreated area was considered. This result suggests that recovery for this family may be mediated by movement of individuals from all surrounding untreated areas.

The intercept values of the most significant models were 7.3 and 12.1 for the Carabidae and Linyphiidae, respectively. These values represent the minimum time over which arthropods dispersing into the plot either succumb to pesticide residues or depart again. The slopes of the models, which give an index of recovery rate, were 0.115 (Carabidae) and 0.079 (Linyphiidae).

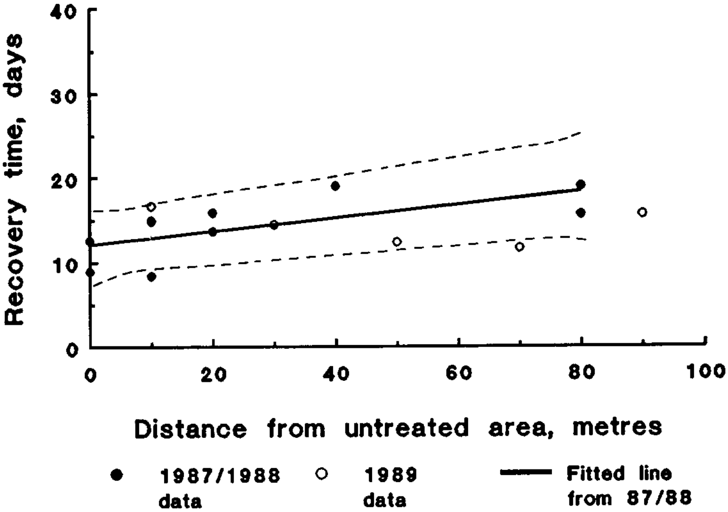

Figure 3. Regression line giving the best fit for the 1987 and 1988 linyphiid data (+/- 95% confidence limits). Data points are either from 1987/1988 or 1989 (which were not used to fit the model).

Figures 2 and 3 present the crude validation of the linear models that were used to quantify the recovery process. In both figures the data collected in 1989 was found to fall within the 95% confidence limits for the regression equations.

The fit of the models that were used to analyze the '% depressed days' for all three years data are given in Table 2. These functions are then plotted in Figure 4 where the x-axis has been converted to the equivalent plot area and the y-axis is '% depressed days'. Following conversion to equivalent plot area the greatest x-axis value for the Linyphiidae was 2.56 ha. However to simplify the comparison between the families, the equation for the Linyphiidae was extrapolated and plotted over the range of x-axis values for the Carabidae (Figure 4).

Table 2. Regression models describing the overall effect of dimethoate (integrating initial depletion and recovery) on Carabidae and Linyphiidae, as a function of plot size.

Family	Multiplicative model ($Y=a*X^b$)	r	SIG.
Carabidae	$Y = 8.83 * X^{0.692}$	0.63	< 0.02
Linyphiidae	$Y = 89.32 * X^{0.188}$	0.53	< 0.05

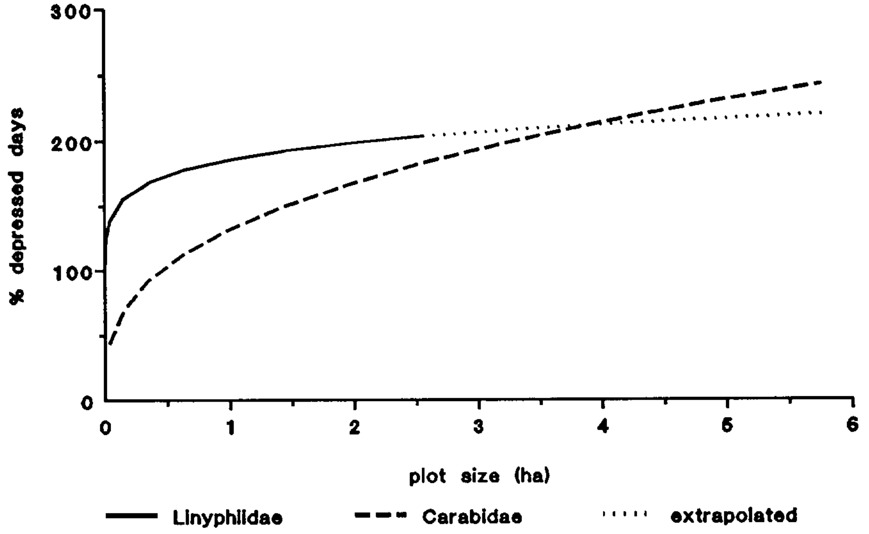

Figure 4. Regression models describing the relationship between the overall effect of dimethoate on Carabidae and Linyphiidae and the plot size used in a conventional within-field side-effects evaluation trial.

Figure 4 indicates that for small plot sizes the Linyphiidae may undergo the greatest overall depletion. Conversely, where large plot sizes are used the Carabidae may be affected to the greatest extent. This reversal in hazard ranking between the families, that is observed as the plot size increases, occurs because the Linyphiidae are initially depleted to a greater extent than the Carabidae, but subsequently have a higher comparative recovery rate (Jepson & Thacker, 1990).

The ranking of families that would be derived from a consideration of the initial population depletion alone is analogous to a laboratory risk ranking. Since this ranking is reversed as the plot size is increased, these results question the utility of laboratory tests alone within risk assessment procedure (e.g. Hassan, 1989). A non-target family that is reduced by only 20% but is unable to recover is likely to be far more at risk from exposure to a pesticide than a family that is reduced by 99% for a short period (i.e. because of a high recovery potential). It should also be noted that, statistically, it is unlikely that any side-effects on the former would be detected within a single-season field experiment. These findings emphasize the importance of recovery rate as an important element of risk assessment, because they demonstrate that rankings of hazard may vary depending upon whether or not this parameter is considered and, depending upon the experimental design employed.

Although the data were derived from experiments that included control plots, which would not exist in commercial agricultural situations, they have practical value because they represent the scale on which current assessments of pesticide side-effects are carried out. For example, guidelines produced by the Ministry of Agriculture, Fisheries and Food in the UK, for the testing of pesticides for registration purposes, currently recommend that a minimum plot size of 1 ha be used (Jepson, 1993). The data presented here suggest that if a 1 ha plot is used to evaluate the effects of dimethoate on these two non-target families then the depletion in numbers of Linyphiidae would be greater than that of the Carabidae. However, the data also indicate that on a larger (and more realistic) scale that this trend would be reversed.

The data and discussion in this paper is concerned with adverse effects at the family level. The two families concerned however are represented in arable crops by a large number of species. Although many of these species share similar properties, i.e. they are epigeal and dispersive, their differing phenologies are likely to affect the apparent recovery at the family level, at sites where different species are represented. We consider these models to be robust however, in that they were derived from data collected over three years at different sites. The analysis should in the future though be directed towards individual species, to examine the level of variation in recovery rate within families.

If effective risk predictions concerning the adverse effects of pesticides are to be developed then clearly the potential for ecological recovery should be quantified. The recovery potential of a given taxon will be based on both its dispersal capacity and the size and location of reservoir populations. While studies on the former factor have recently been carried out (e.g. Duffield & Baker, 1990; Jepson & Thacker, 1990; Thacker & Jepson, 1990, Thomas et al., 1990), studies which explore invertebrate spatial dynamics on a farm scale are still required. Until this work is carried out it is likely that effective risk analyses will remain intractable and continue to be hampered by a lack of ecological realism.

Acknowledgements. JRMT was funded by a Southampton University 'Linked' Studentship and by a charitable grant from the Perry Foundation.

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Received November 21, 1992; accepted March 20, 1993.