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The effect of time of soil cultivation on the incidence of *Pterostichus melanarius* (Illig.) (Coleoptera: Carabidae) in arable land in Ireland

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The life cycle and seasonal adult activity patterns of *Pterostichus melanarius* (Illig.) in Ireland are described. Pitfall trap catches are analysed using a multiple linear regression model to test the hypothesis that time of soil cultivation influences the breeding success and population production of this species. Whilst total seasonal catches were not strongly influenced by soil cultivation history, catches made during the main emergence phase of the new generation were lower in spring cultivated fields compared with uncultivated or autumn cultivated fields. The analysis suggests that spring soil cultivation reduces larval/pupal survival but that rapid inter-field dispersal by adult *P. melanarius* following emergence from pupation masks the effect of soil cultivation on individual fields.

1. Introduction

Carabid populations in arable land are subject to a range of husbandry practices during the course of the crop year, many of which are potentially harmful. In particular, the adverse effects of many types of agrochemical application on carabids has been widely documented (e.g. Basedow *et al*. 1985, Matcham & Hawkes 1985, Cole *et al*. 1986, Purvis *et al*. 1986, Jepson & Thacker 1990). Such applications frequently result in more-or-less immediate reductions in incidence as assessed by pitfall trap catches. Longer-term studies suggest that such effects are, for many species, only temporary with population recovery occuring by the following season (Purvis & Bannon 1992). In comparison to the detrimental effects of pesticides, relatively little is known of the adverse influence of other cropping practices and, in particular, of how damaging are practices such as soil cultivation compared to pesticide use. Studies have shown generally lower incidence of especially larval overwintering carabid species in spring-cultivated compared to autumn-cultivated crops (Hance & Gregoire-Wibo 1987, Hance *et al*. 1990) suggesting at least larval and pupal sensitivity to inappropriately timed soil disturbance. A number of studies have documented differences in general carabid abundance and community structure in different types of crop (see accounts by Thiele 1977 and Luff 1987) and, in particular, several recent studies have compared carabid incidence in conventionally tilled and non-tilled production systems (e.g. House 1989, Stinner & House 1990, Weiss *et al*. 1990, Càrcamo & Spence 1994). Desender *et al*. (1985) showed exceptionally high population densities of *Pterostichus melanarius* (Illig.) in uncultivated pasture. Such differential incidence is often interpreted in terms of variables such as habitat cover, general food availability, specific preferences for particular microclimatic conditions or differential pesticide use rather than soil cultivation history. Surprisingly little quantitative information is available about the effect of direct physical injury to carabids resulting from routine soil cultivations. The objective of this study is to seek quantitative evidence of differences in the incidence of *P. melanarius* in arable fields of differently timed cultivation history using pitfall data. *P. melanarius* is a common carabid in arable fields throughout Europe which breeds in the autumn to overwinter mainly in the soil as a relatively large soft-bodied larval instar (Larsson 1939, Desender *et al*. 1985) which might be expected to be particularly vulnerable to spring soil tillage operations when these coincide with the main period of larval/pupal incidence.

2. Methods

The study took the form of a survey of the incidence of *P. melanarius* on seven different fields on a silty-clay-loam soil type at the University College Dublin farm, Celbridge, Co. Kildare, Ireland. Each of these fields followed a different rotation of arable cropping as outlined in Table 1. These rotations are typical of Irish agriculture involving a mixture of autumn and spring-sown cereals, late spring/early summer-sown root crops and maize and short-term uncultivated grass leys.

2.1. Sampling Method

Adult *P. melanarius* were sampled routinely on each field from May, 1992 to September, 1994, inclusive, over three successive cropping seasons. Ten pitfall traps spaced in a line at 5 m intervals in the centre of each field were used synchronously, being operated for seven day trapping periods usually at 2-week intervals. Traps constisted of glass jars (5 cm diam.) filled with 2–3 cm of water to which a little detergent was added. In the laboratory, catches were sorted, preserved in 70% ethanol and identified using Lindroth (1974). The ratio of males to females was determined and up to a maximum of 50 females from each field on each sampling date were dissected and classified into one of four categories according to their ovary development:

stage I – newly emerged females with small fat body and ovaries not discernible, ovipositor often unpigmented.
stage II – fat body large, ovaries discernible but only pale immature eggs present, ovipositor always pigmented.
stage III – ovaries with mature pigmented eggs present.
stage IV – all eggs laid and fat body spent.

2.2. Analysis

Fields in each season were defined as being one of the following four types according to the time of soil cultivation:

1. Uncultivated — i.e. grass leys from their 2nd year onwards
2. Autumn Ploughed/Cultivated — in October–November
3. Early Spring Cultivated — in February–March
4. Late Spring Cultivated — in April–May

For the purpose of field type definition, the crop year was considered to begin on October 1. Both time of soil cultivation in the 'Current' crop year, and in the 'Previous' crop year, were considered to be potentially important so that each field in each year constituted a particular combination of 'Previous' and 'Current' crop type- or '**Crop Rotation**'**.** The data available, therefore, comprise trap counts from seven different fields representing a range of different crop rotations over

Table 1. Cropping history of the fields surveyed.

Field (ha)	Prestudy year (1990/91)	Year 1 (1991/92)	Year 2 (1992/93)	Year 3 (1993/94)
Canal (8 ha.)	1st. ley grass	2nd. ley grass	winter wheat	fodder beet
Eleven Acres (6 ha.)	sugar beet	spring barley	winter barley	1st. ley grass
Hagard (9 ha.)	potatoes	fodder beet	spring wheat	1st. ley grass
Silverstream (9 ha)	3rd. ley grass	4th. ley grass	5th. ley grass	6th. ley grass
Skeagh lawn (9 ha.)	2nd. ley grass	winter wheat	sugar beet	spring barley
Hill I (4 ha.)	fodder beet	winter wheat	maize	1st. ley grass
Hill II (4ha.)	2nd. ley grass	3rd. ley grass	maize	1st. ley grass

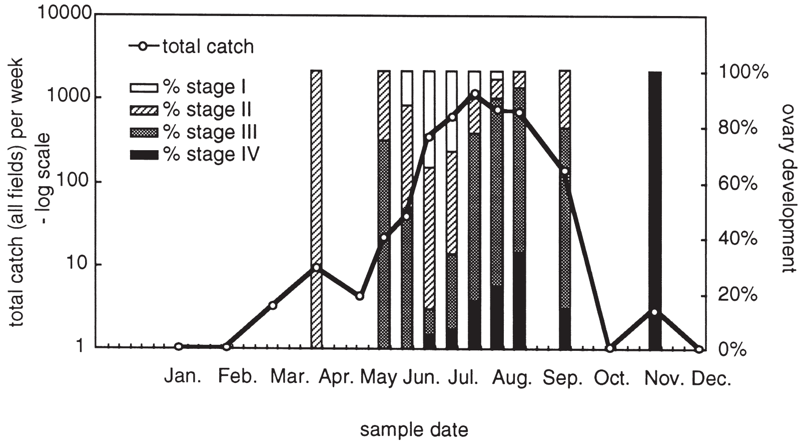

Fig. 1. Total weekly catch of *P. melanarius* between January and December, 1993 and proportion of females in each ovary development stage (see text for stage definitions).

a three year period. Other than for the choice of roughly equal numbers of autumn and spring cultivated arable fields and uncultivated grass crops in the first year of the survey, it was not possible to control the particular rotations followed on individual fields in an experimental manner. Rather, the original seven fields were followed through their different and unique histories as imposed by the routine management of the farm. This uncontrolled data structure meant that some particular crop rotation combinations were not available and others were replicated to varying degrees. The actual combinations and numbers of replications available in the data set is shown in Table 2. All of these constraints make the application of standard Analysis of Variance impossible and enforce the adoption of a multiple linear regression approach to data analysis. The factors considered to be of likely importance to carabid incidence and which were included as independent factors in the fitted regression model were: 1. Year, 2. Field, 3. 'Rotation, where 'rotation' is the combination of 'Previous' and 'Current' crop cultivation history. Trap catch data fitted to this model were first transformed to natural logs ($\ln(n + 1)$) in order to stabilise the variance of typically skewed animal counts data. The model was fitted using GENSTAT (Lane 1989) and least squares means (LSM's) for each crop rotation were calculated to estimate crop rotation effects in average year and field conditions. Covariances between crop rotations outputed by the GENSTAT programe were then used to calculate two-tailed t-statistics for computation of the probability of significant difference between any pair of estimated means in single rows or columns of Table 2; i.e. between all pairs of current or previous crop type with common previous or current crop history, respectively. In these comparisons, some crop types can be compared on the basis of two available estimates of means which must be combined in the calculation of t-statistics. For example, LSM's for Late Spring Cultivated and Uncultivated current crops are available with either Autumn Cultivated or Uncultivated preceeding crop type (see Table 2). Other mean comparisons are available only from single mean estimates e.g. Autumn Cultivated and Early Spring Cultivated current crop types can only be compared on the basis of preceeding Late Spring Cultivated history.

3. Results

A total of 7 877 adult *P. melanarius* were caught during the study period and 3 577 females were dissected.

Relatively small numbers of successfully overwintered adults with immature stage II ovaries were caught early in each year during March and April (Fig. 1). In May, the activity-density of these overwintering adults increased as an increasing pro-

Table 2. Number of replications of all available crop rotations in the survey (see text for explanation of rotation types).

Previous crop cultivation	Current crop cultivation: Autumn cultivated	Early spring cultivated	Late spring cultivated	Uncultivated
Autumn cultivated	–	–	4	1
Early spring cultivated	2	–	–	–
Late spring cultivated	1	3	3	–
Uncultivated	2	–	1	4

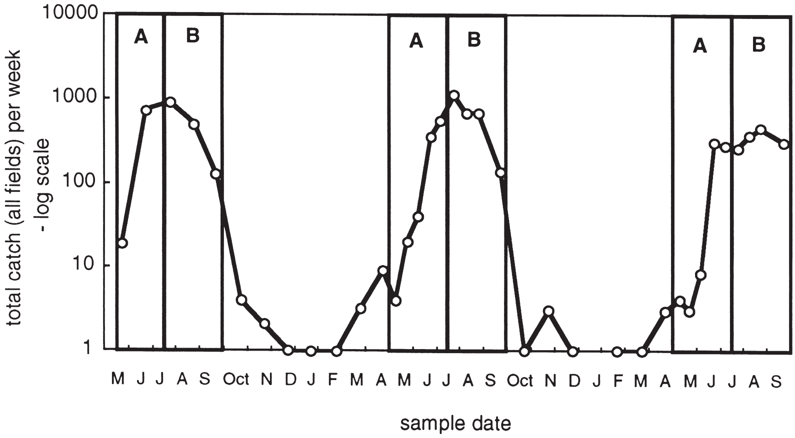

Fig. 2. Total pooled trap catch of *P. melanarius* from all fields throughout the study period: boxes marked A and B define the main phases of emergence of the new generation from pupation and egg-laying, respectively.

portion matured and began egg laying. Catches increased very rapidly from mid-May to peak in July as the new generation, indicated by the occurrence of a of stage I females, appeared from pupation during June and July. From this peak in catches in July until September, a majority of mature egg-laying stage II females were caught with an increasing proportion of post-reproductive females appearing in traps towards autumn. Catches from October onwards were very small. On the basis of this phenology, the main period of activity by the new generation of adult *P. melanarius* can be divided into two phases; phase A, from May to mid July, corresponding to the period of emergence from pupation and phase B from mid July to September when newly emerged females reached maturity and the majority of new generation egg laying occurred. Conveniently, these phases were clearly demarked by a mid-July seasonal peak in trap catches in each year of the study (Fig. 2). Outside these phases, catches were small and erratic being composed of a relatively small numbers of overwintering adults.

On this basis, the described regression model was fitted to three subsets of the data corresponding to total field catches made between May and September each year and separately to catches made during phases A (May-early July) and B (late July–September), respectively. Additionally, the total number of newly emerged stage I females in each weekly field catch was estimated from the proportion observed in the subsample (maximum = 50) of dissected females, and the regression model fitted to the estimated total seasonal catch of stage I females from each field.

Table 3 summarises the fitted regression models for each data set. *F*-statistic probabilities for the full model and the percentage variance accounted for provide a measure of the relative ability of the model to describe each data set. The model provides a marginally better description of total catches and catches of stage I females than of catches made during phases A and B. *F*-statistic probabilities for the contribution of each independent factor indicate the relative contribution of each factor to the model for each data set. These values should be treated with caution since interactions between factors may very well exist, but these cannot be assessed because of the unbalenced data structure. In general, both field

Table 3. Summary statistics for the multiple linear regression models fitted to each trap catch data set (see text for details).

Data set	Full model		*P*-value for each model factor		
	P-value	% variance accounted for	year	field	rotation
total catch	0.078	73.6%	0.887	0.051	0.148
phase A catch	0.137	63.4%	0.727	0.086	0.178
phase B catch	0.135	63.7%	0.874	0.095	0.156
stage I female catch	0.098	69.9%	0.219	0.098	0.170

and rotation appear to be relatively important components of the respective models whilst in the absence of knowledge of factor interactions, year appears to be a less important factor. All factors were retained in the models for the subsequent calculation of predicted least squares means (LSM's) for each crop rotation. These means are presented backtransformed to the original arithmetic scale in Table 4.

Estimated total seasonal catches for each rotation show very little indication of differences between different rotations, although relatively high catch predictions are made for current autumn cultivated fields in comparison with current late spring cultivated fields (Table 4a). An exception to this trend is the relatively low catch estimated from autumn cultivated fields which are preceeded by a late spring cultivated crop type. Otherwise, predicted total seasonal catches are not obviously different between different crop rotations. Predicted LSM's for catches made during the emergence phase of the new generation are of a similar rank order to total season catches but generally show bigger differences between crop types. Estimates of catches made from current late spring cultivated and second year or older grass ley fields during new generation emergence are particularly low in comparison to current autumn cultivated fields and fields uncultivated for only their first year (i.e. grass leys in their first uncultivated year after establishment), (Table 4b). In marked contrast, predicted LSM's for catches made during the main period of new generation reproduction (phase B), revealed a quite different rank order of crop rotations (Table 4c). In particular, predicted catches from late spring crops following grass leys and older grass leys now produced the largest catches of any field types. Finally, predicted LSM's for estimated total season catches of stage I females closely match the rank order of catches of all individuals made during phase A with much smaller numbers apparently emerging from both current and previous late spring-sown fields and from older grass following previously uncultivated grass. Calculation of probability levels for differences in estimated catches of stage I females between different previous and different current crop types (Table 5) shows, in particular, the high likelyhood of lower catches being made from fields following a late spring cultivation.

4. Discussion

The annual cycle of activity of *P. melanarius* monitored in the current study broadly matches that previously described for the species elsewhere in Western Europe (Basedow *et al.* 1976, Jones 1979, Desender *et al.* 1985). In particular, the majority of the population overwinters in the soil as larval instars and appears from pupation from early May onwards. This emergence leads to a rapid increase in the

Table 4. Backtransformed least square means estimates for trap catches from each crop rotation.

	a) Total season catch, Current crop cultivation				b) Emergence phase A catch, Current crop cultivation			
Previous crop cultivation	Autumn	Early spring	Late spring	Uncult.	Autumn	Early spring	Late spring	Uncult.
Autumn	–	–	148.9	324.7	–	–	28.0	304.8
Early spring	494.2	–	–	–	406.9	–	–	–
Late spring	101.9	244.4	82.1	–	31.1	135.9	3.7	–
Uncultivated	709.5	–	328.3	271.3	406.5	–	3.2	4.8

	c) Reproductive phase B catch, Current crop cultivation				d) Estimated stage I female catch, Current crop cultivation			
Previous crop cultivation	Autumn	Early spring	Late spring	Uncult.	Autumn	Early spring	Late spring	Uncult.
Autumn	–	–	90.3	109.0	–	–	11.3	109.2
Early spring	213.9	–	–	–	76.3	–	–	–
Late spring	59.1	119.3	55.6	–	0.5	26.9	1.1	–
Uncultivated	346.6	–	766.6	511.4	121.7	–	3.6	1.7

number of beetles trapped which reaches a peak in mid-July. From this point onwards, the majority of females reach maturity and dissections showed that the majority of egg laying occurs between peak catches made in July, and September. During this main reproductive phase, trap catches decline as females with mature ovaries seem to be less active than they were as newly emerged individuals. This may be a reflection of greater foraging by immature females seeking the necessary food reserves to produce eggs (Ericson 1978). Alternatively, this pattern of trap catches may be explained by particularly high levels of mobility during a relatively short period immediately following pupation, which may be viewed as an adaptation for rapid dispersal from successful breeding sites in order to redistribute the species and ensure continued survival in a very heterogeneous landscape (Den Boer 1981,1985).

Analysis of total seasonal catch data largely failed to demonstrate any clear relationship between soil cultivation history and beetle incidence. Numbers of all individuals caught during the initial emergence period of the new generation and, more particularly, the numbers of newly emerged immature stage I females trapped, were substantially greater on autumn-cultivated or first-year uncultivated field types, than on spring cultivated ones. Indeed, virtually no newly emerged stage I beetles were trapped throughout the *entire season* on fields cultivated in April or May for late-spring-sown crops such as maize, fodder beet, sugar beet and potatoes. This is probably not so surprising since large late-instar larvae and pupae are likely to be prone to physical injury at this time. Almost certainly the failure to detect any influence of field type on total seasonal catches was because of redistribution from field types which were more productive during pupation. These fields seem mainly to be those growing autumn-sown cereals or those in their first year as uncultivated grass leys which were established by autumn cultivation in the previous season.

Other studies have documented a delay of approximately one month in the peak incidence of *P. melanarius* on sugar beet fields compared with either autumn or early spring-sown cereals (e.g. Purvis & Curry, 1984, Hance *et al.* 1990). Decreased or delayed carabid incidence in sugar beet crops compared to cereals is often attributed to the effect of greater pesticide use on sugar beet. In the current study, late spring cultivated crops comprised a mixture of maize, fodder and sugar beet and potatoes (Table 1) of which sugar and fodder beet routinely receive pesticide inputs including the carbamate granular insecticide, carbofuran. However, maize and potatoes generally receive less pesticide than spring or winter cereals to which at least one herbicide, two fungicides and a winter and/or summer aphicide are routinely applied. Differences in pesticide inputs are, therefore, unlikely to expain the observed pattern of trap catches. Differences in overwinter ground cover are similarly unlikely to explain differences between field types since many spring-sown fields in the study were not ploughed until the early spring and, during the autumn period, developed a ground cover of volunteer cereals and weeds which persisted over the winter.

In contrast to spring soil cultivations, autumn cultivation for winter cereals seems to have little or no effect on early larval instars as comparison between autumn-sown cereals and uncultivated first year grass leys would suggest. Interestingly, older grass leys uncultivated for two or more seasons seem to be relatively unproductive habitats for *P. melanarius* compared with autumn-sown crops or new grass leys. The reason for this is unclear and obviously is not because of damaging soil cultivations.

Following very low catches on spring cultivated fields and older grass leys during the emergence phase of the life cycle, particularly high catches were obtained on these field types during the subsequent, mainly egg-laying stage. This strongly suggests that a substantial redistribution of the species between

Table 5. Significance probabilities for differences in stage I female catches between soil cultivation times (X = unavailable comparison).

	a) Current crop cultivation times			b) Previous crop cultivation times		
	Autumn	Early spring	Late spring	Autumn	Early spring	Late spring
Early spring	0.112	–	–	X	–	–
Late spring	0.258	0.055	–	0.141	0.075	–
Uncultivated	0.093	X	0.493	0.183	0.739	0.063

fields was occurring during the peak of activity in July. Very high levels of incidence during the egg-laying stage in late spring-cultivated fields are not, however, translated into high catches during the emergence phase of the next generation in subsequent autumn-sown crops, as might be expected. This may well be a result of extensive soil disturbance and damage associated with the delayed harvesting of root crops and forage maize in wet conditions prior to normal soil tillage for winter-sown cereals, which, in this rotation in Ireland, usually occurs after late October but may be as late as December. This does, in effect, explain why there seems to be a previous crop effect as well as a current crop effect associated with late spring soil cultivation despite the evidence for widespread re-dispersal of the species between fields. It must be pointed out, that high incidence in older leys during the main egg-laying phase is also not translated into high numbers trapped during the emergence of the next generation and factors other than soil disturbance must be involved in this instance.

In conclusion, the survey provides some evidence that the breeding success of a species present as a late larval or pupal instar at the time of spring soil cultivations is reduced by such cultivations. Results of a subsequent study involving replicated field plots comparing the effect of autumn and early spring cultivation (Purvis & Fadl 1996) suggest that spring soil cultivations may reduce the numbers of *P. melanarius* emerging from pupation by as much as 80% compared with cultivation for winter-sown crops. Effects of this magnitude are similar to the kind of population reductions which can be induced by single pesticide applications (Purvis & Bannon 1992). Carabid populations living in arable landscapes probably have to survive such high levels of mortality on a frequent local basis. *P. melanarius* appears able to do so each year, largely as a consequence of its powers of dispersal within a patchwork mosaic of field types where breeding success is highly variable.

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