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ECOLOGICAL REQUIREMENTS FOR HIBERNATING *PROPYLEA QUATUORDECIMPUNCTATA* (L.) AND *COCCINELLA SEPTEMPUNCTATA* [*COL. : COCCINELLIDAE*]

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During 3 successive winters, we studied the dormancy sites of *Propylea quatuordecimpunctata* (L.) and *Coccinella septempunctata* L., 2 species of ladybirds which hibernate in leaf litter. Samples of litter were taken from several kinds of forest to study the influence of 3 variables (exposure ; altitude ; sampling place : edge or inner wood) on the abundance of ladybirds.

We found the ecological requirements of the 2 species of coccinellids to be quite different : *C. septempunctata* prefers forest edges orientated towards the South and the West. *P. quatuordecimpunctata* prefers the inner wood and does not show a preference for station exposure. For each species, the number of ladybirds collected in the samples is positively correlated with station altitude. In addition, some observations were carried out to examine the main mortality factors just before and during dormancy. In maize fields near dormancy sites, the harvest is very harmful for *C. septempunctata*. During the winter, *P. quatuordecimpunctata* and *C. septempunctata* suffer from *Beauveria ssp.* and some ladybirds have parasitoïds.

KEY-WORDS : *Propylea quatuordecimpunctata, Coccinella septempunctata,* hibernation, *Beauveria ssp.,* parasitoïds.

The aphidophagous *Coccinellidae* of agricultural biocenosis hibernate in sites whose characteristics vary in relation to the different species. For example, *Semiadalia undecimnotata* (Schneider) hibernates at the top of hills or mountains (**Iperti,** 1966a ; **Hodek,** 1973), *Adalia bipunctata* (L.) prefers crevices in buildings or in tree bark (**Hodek,** 1973 ; **Brakefield,** 1984 ; **Hemptinne,** 1985) while *Propylea quatuordecimpunctata* (L.) and *Coccinella septempunctata* L. are known to spend the winter in forest litter (**Bielawski,** 1961 ; **Savoïskaya,** 1960 ; 1965 ; **Sem'yanov,** 1965 ; **Hodek,** 1973 ; **Larochelle & Larivière,** 1980 ; **Basedow,** 1982).

A good knowledge of dormancy sites and ladybird ecology would enable building up aphid control strategies and land management which is compatible with biological control. *Hippodamia convergens* (Guerin) clearly illustrates these points. Indeed, biological control experiments with this ladybird were inconclusive because of an incomplete understanding of migratory behaviour (**Carnes,** 1912a, b). Moreover for biological control, a network of dormancy sites and cultures which can be used as breeding places and shelter is preferable

to a monotonous landscape (**Banks,** 1955). **Iperti** (1966b) has shown that the quality of dormancy sites greatly influences the survival of ladybirds: the mortality of *S. undecimnotata* varying from a few to 70 % according to the station and its altitude.

This paper covers observations about hibernation of *P. quatuordecimpunctata* and *C. septempunctata* in the Belgian Province of Hainaut. We mainly studied the influence of 3 station characteristics (altitude ; exposure ; sampling place : edge or inner wood) on the abundance of coccinellid beetles in the litter. We also collected some data about adult mortality factors (*Beauveria ssp.*, parasitoïds and maize harvest).

MATERIAL AND METHODS

The study took place during 3 successive winters (from 1982-83 to 1984-85) in the Province of Hainaut (Belgium) (fig. 1). This agricultural region which is also extensively wooded, has been described elsewhere (**Hemptinne,** 1985). During the first season, observations were made to prepare the sampling design for the next 2 years. At the end of the first winter, forests appeared to be the prevailing dormancy sites for *C. septempunctata* and *P. quatuordecimpunctata*. Samples were taken from 20 woods in 1983-84 and from 22 in 1984-85. Their main characteristics are described in the table 1. Furthermore, some qualitative observations were carried out on old slag-heaps and in woods outside the study area (fig. 1).

TABLE 1
Main characteristics of the wood

Nr. of the wood	1983		1984	
	General orient. of the edge	Altitude of the edge (m)	General orient. of the edge	Altitude of the edge (m)
1	S	62	S	62
2	N	82	N	82
3	E	60	E	60
4	N	60	N	57
5	S	80	S	80
6	S	65	S	65
7	E	105	E	105
8	N	55	N	55
9	S	115	S	115
10	W	75	W	75
11	E	120	E	120
12	S	115	S	120
13	E	125	N	127
14	N	115	N	110
15	S	125	S	125
16	W	95	W	70
17	N	90	N	90
18	S	70	W	82
19	N	125	E	60
20	N	100	S	65
21			W	50
22			N	110

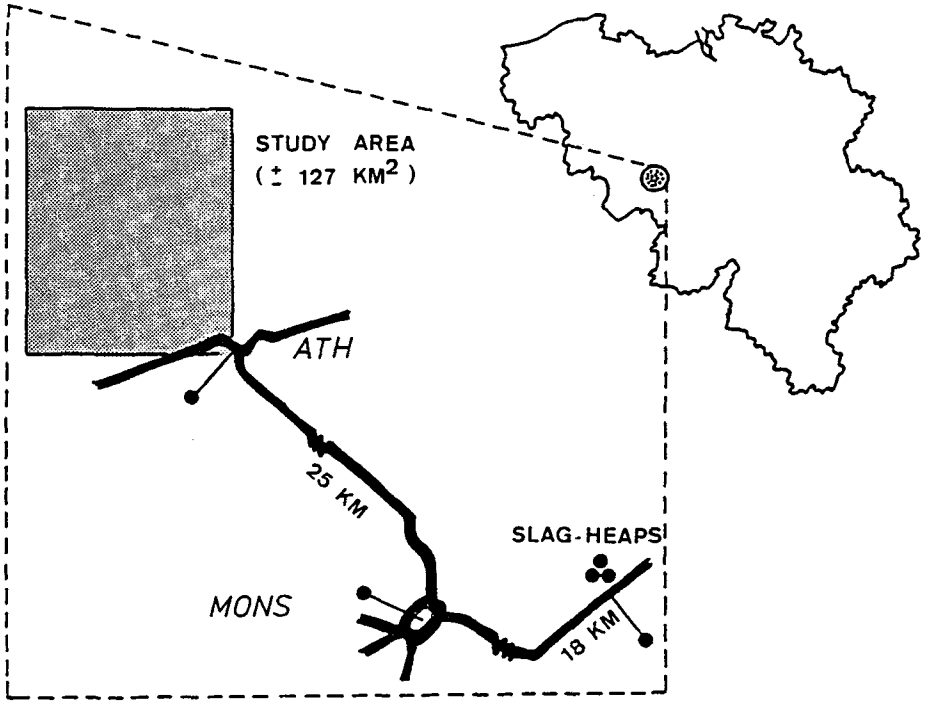

Fig. 1. Geographical situation in Belgium.

In each station, 3 litter samples of 1 m^2 were completely removed at 2 different locations, firstly at the forest edge and secondly, inside the wood on an alignment 20 meters from the edge. The litter was brought to the laboratory in hermetically sealed plastic bags, living beetles were sorted from dead specimens. The number of living ladybirds was transformed according to $y' = \sqrt{y + 0.5}$, where y is the initial number of ladybirds observed, and processed by analysis of variance (**Dagnelie,** 1975). In 1983-84, the living ladybirds were kept in the laboratory (25 °C ± 1 °C ; 16 HL) to detect the presence of parasitoïds.

In addition, we observed the mortality of the ladybirds due to agricultural practices in maize fields during the autumn migration towards dormancy sites. *P. quatuordecimpunctata* and *C. septempunctata* were monitored on 3 dates from 22 August 1985 to the harvest in late September in 2 maize fields contiguous to hibernating sites. The ladybirds were counted on 10 plants in sampling sites along a random trail (fig. 2). By this method, we made a rough estimate of the ladybirds number killed by the maize harvesters.

RESULTS

COMPARISON BETWEEN STATIONS

The frequency distribution of *P. quatuordecimpunctata* and *C. septempunctata* in the samples shows that these ladybirds only from small or medium size aggregations, not exceeding 11 beetles per m^2 in the case of *C. septempunctata* and 21 for

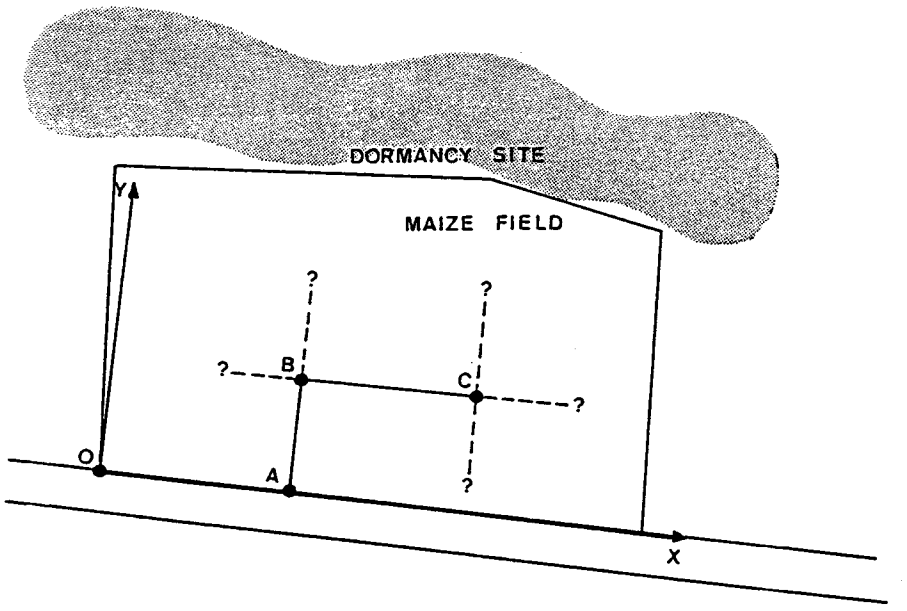

Fig. 2. Diagram of the random trail design.
O : origin ;
A : beginning of the random trail ;
B, C : sampling sations ;
OA, AB, BC : directions selected and distances determined by random numbers.

P. quatuordecimpunctata. Their index of dispersion ($\hat{V} = \hat{\sigma}^2 \cdot \hat{m}^{-1}$, where $\hat{}$ indicates estimated values), 3.61 for *C. septempunctata* and 4.84 for *P. quatuordecimpunctata* indicate a tendency to contagious distribution (**Dagnelie,** 1978) (fig. 3).

An analysis of variance has been performed with the transformed data to compare the influence of the 3 variables (table 2). Analysis of variance reveals no significant differences in the mean number of ladybirds collected between the 2 winter seasons. On the other hand, major differences exist ($P < 0.001$) between the mean number of ladybirds observed in the different woods. As the stations differ mainly by their exposure and altitude, it is interesting to study further the influence of these characteristics on the distribution of the 2 coccinellids species. If the 3 variables are considered as fixed (fixed model of analysis of variance), there are significant differences in the mean number of ladybirds of the edges and of the inner woods. However, this model clearly shows opposite tendencies in the 2 species : *C. septempunctata* prefers the edges as hibernating site (0.98 ± 0.05 ladybirds/m^2 at the edges versus 0.78 ± 0.05 inside the wood ; $P < 0.01$) while the inner wood is more attractive for *P. quatuordecimpunctata* (1.11 ± 0.11 ladybirds/m^2 at the edge versus 1.41 ± 0.11 inside the wood ; $P < 0.01$).

STATION EXPOSURE

As we can see in the table 3, the station orientation is not important for *P. quatuordecimpunctata.* On the other hand, the extended Newman-Keuls test (**Kramer,** 1956) shows that *C. septempunctata* clearly prefers sites orientated towards the South and the West.

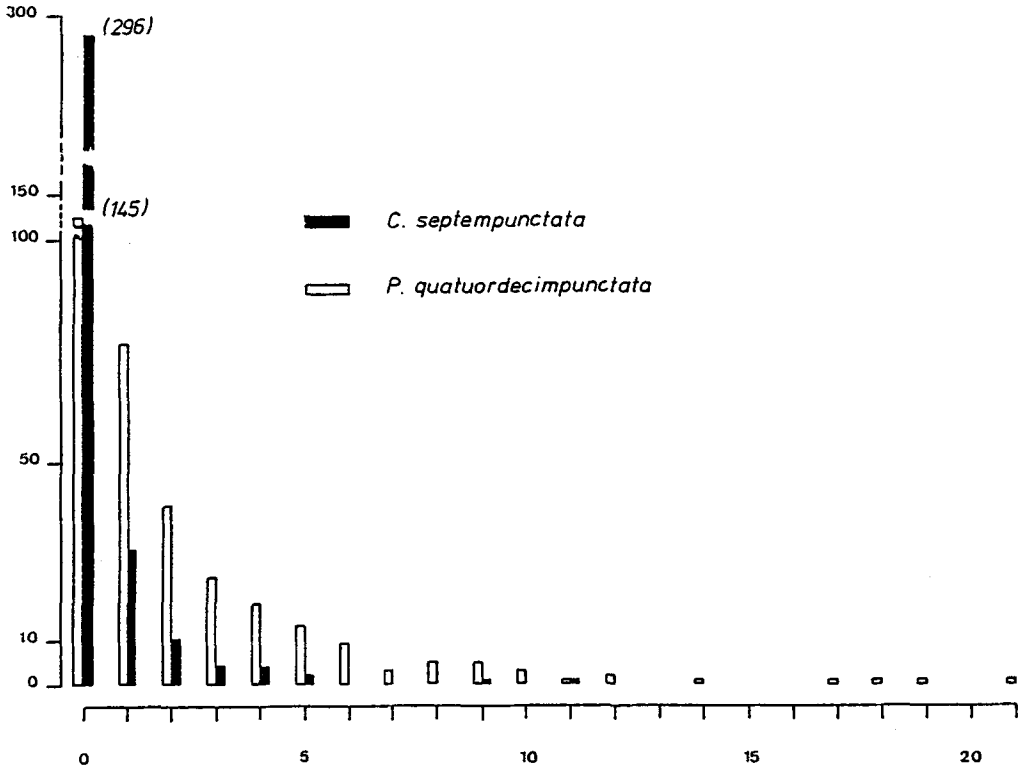

Fig. 3. Frequency distribution of *P. quatuordecimpunctata* and *C. septempunctata* in the one meter square litter samples.
Horizontal axis : number of ladybirds in 1 m^2 of forest litter.
Vertical axis : frequencies.

TABLE 2

Three-way analysis of variance of the ladybird population in the different stations

		C. 7 punctata			*P. 14 punctata*		
Sources of variation	d.f.	S.S.D.	M.S.	F	S.S.D.	M.S.	F
Winters	1	0.0040	0.0040	0.012	0.6075	0.6075	0.470
Alignments	1	1.5369	1.5369	9.800^{++}	5.4355	5.4355	11.440^{++}
Interaction winters-alignments	1	0.0971	0.0971	0.620	1.0242	1.0242	2.150
Stations/winters	40	13.3225	0.3331	3.190^{+++}	51.8590	1.2965	3.870^{+++}
Interaction alignments-stations/winters	40	6.2708	0.1568	1.840^{+++}	19.0085	0.4752	1.420
Residual	168	14.3147	0.0852		56.3200	0.3352	
Total	251	35.5460			134.2547		

++ : highly significant deviation ($\alpha = 0.01$).
+++ : very highly significant deviation ($\alpha = 0.001$).

TABLE 3
Influence of station orientation on the mean density of ladybirds
(A : results of analysis of variance ; transformed data
B : results of extended Newman-Keuls tests expressed in original data)

A.

Sources of variation	d.f.	*C. 7 punctata* S.S.D.	M.S.	F.	*P. 14 punctata* S.S.D.	M.S.	F.
Orientation	3	3.6244	1.2081	9.44^{+++}	2.7006	0.9002	2.65
Residual	248	31.7157	0.1279		131.5677	0.5305	
Total	251	35.3401			134.2683		

B.

Station Orientation	N	E	S	W
Nb. of samples	84	48	84	36
Mean density/m^2				
P. 14 punctata	0.81(a)	0.93(a)	1.40(a)	1.27(a)
C. 7 punctata	0.04(a)	0.09(a)	0.53(b)	0.25(a)

+ + + : very highly significant deviation ($\alpha = 0.001$).
The same letter in brackets following the figures indicates that they do not differ significantly.

STATION ALTITUDE

In order to examine the importance of station altitude, we studied the regression between the altitude of the sites and the mean number of ladybirds in the samples. However, 2 remarks are to be made : firstly, we used the modified data ; secondly, we only took into account the densely populated sampling places : for *P. quatuordecimpunctata* this meant the samples came from inside of the woods, and for *C. septempunctata,* from the woods orientated towards the South and the West. These were selected as a result of the previous station comparisons.

There is a highly significant regression of the mean number of ladybirds on altitude ($b = 0.014$ for *C. septempunctata ;* $b = 0.014$ for *P. quatuordecimpunctata ;* $P < 0.001$) (fig. 4). The regression coefficients are, however, low. Additional observations in more mountainous regions, mainly in the case of *C. septempunctata,* will improve the understanding of the relation between station altitude and ladybird abundance in the litter. *C. septempunctata's* preference for elevated hibernation sites appears in the qualitative survey outside the study area (fig. 1). It was found on the top of old slag-heaps at the upper limit of vegetation, hibernating in birch litter, in grass tussocks and under stones, while *P. quatuordecimpunctata* stays strictly inside the arbustive vegetation growing at the slag-heap base. Nevertheless, the hibernating behaviour of *C. septempunctata* shows great flexibility to the environment conditions. In region without conspicuous hills as in the Northern lowlands of Mons, its dormancy sites are situated at forest edges, clearings or wind breaks. We also found some ladybirds hibernating between the ear spathes of maize plants left by the combine harvesters in field headlands in the surroundings of Ath.

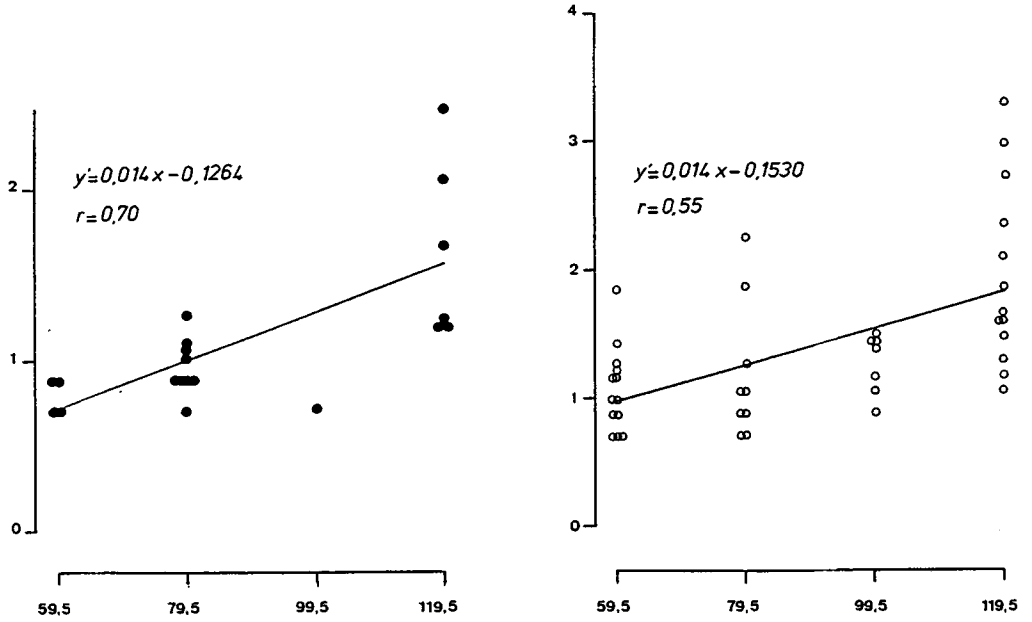

Fig. 4. Linear regression between altitude and the mean number of ladybirds per square meter in the litter (modified data).
Open circles : *P. quatuordecimpunctata.*
Solid circles : *C. septempunctata.*
Horizontal axis : altitude (meters).
Vertical axis : mean number of ladybirds per square meter.

MORTALITY FACTORS

Three main mortality factors were found to influence *P. quatuordecimpunctata* and *C. septempunctata* in dormancy : the maize field harvest at the moment of the autumn migratory flights ; the fungus *Beauveria ssp.* and parasitoïds.

In autumn, maize fields in the vicinity of dormancy sites are attractive because aphids of the ear spathes constitue one of the most important feeding sources for coccinellid beetles. As maize is a green crop, they become traps when plants are crushed for ensiling, the beetles staying between the spathes can not escape or fall on the ground. Just before the maize harvester was brought in, a mean density of 2.50 and 14.86 *C. septempunctata* per 10 plants was observed in the 2 fields. A simple calculation, on the basis of this estimation and with 80,000 plants/ha, gives a loss from about 20,000 to 120,000 in these fields when, on the other hand, only a few *P. quatuordecimpunctata* were counted (table 4). The *C. septempunctata* aggregations in maize were so conspicuous that a qualitative survey was set up through most of the study area (18 maize fields). These additional observations suggested that aggregations only occur in those fields contiguous to dormancy sites. More accurate research is necessary to confirm this.

Table 5 shows the impact of *Beauveria ssp.* and parasitoïds on the survival of the 2 ladybird species. The χ^2 test for 2 independent samples shows that mycosis seems to be a more important mortality factor for *P. quatuordecimpunctata* than for *C. septempunctata* ($\chi^2_{obs.} = 3.85$; $P < 0.05$). Perhaps this is in relation to its dormancy site pattern as the

TABLE 4
Ladybirds monitoring in two maize fields

	Date	Nb. of stations	*P. 14 punctata*				*C. 7 punctata*			
			Min.	$\bar{x}$	Max.	S.D.	Min.	$\bar{x}$	Max.	S.D.
Field A (Renowelz)	22.08.85	10	0	1.00	2	0.21	0	1.10	3	0.30
	03.09.85	5	0	0.60	2	0.40	1	3.00	5	0.84
	24.09.85	7	0	0.57	2	0.37	3	14.86	61	7.94
Field B (Warloche)	22.08.85	5	2	3.40	6	0.75	0	0.80	1	0.20
	03.09.85	5	0	1.00	2	0.45	0	1.00	2	0.45
	24.09.85	6	0	0.17	1	0.17	1	2.50	4	0.50

— For the 2 species and for each date, the results are given as the minimum, the mean, the maximum and the standart deviation of the number of ladybirds in the stations.

— One station = 10 maize plants.

TABLE 5
Mortality due to Beauveria ssp. *and parasitoïds*

	n	*Beauveria ssp.*	Parasitoïds
P. 14 punctata	221	52 (23.53%)	9 (4.07%)
C. 7 punctata	47	5 (10.64%)	1 (2.13%)

environmental conditions seem more favorable for the development of fungi inside the woods rather than at the edges. Live ladybirds kept in the laboratory yielded one *Dinocampus (Perilitus) coccinellae* (Schrank) from a batch of 47 *C. septempunctata* and 9 *Centistes subsulcatus* Thomson (*Braconidae,* sub. fam. *Euphorinae,* tribe Centistini) from 221 specimens of *P. quatuordecimpunctata.* Although the number of *C. septempunctata* is low, this suggests that parasitoïds may be more harmful for *P. quatuordecimpunctata* ($\chi^2_{obs.} = 3.92$; $P < 0.05$).

DISCUSSION

P. quatuordecimpunctata and *C. septempunctata* both spend the winter season in forest litter although their ecological requirements are quite different. The *P. quatuordecimpunctata* dormancy sites are generally situated inside forests on the top of hillocks without preference as regards to exposure. Although the station altitude has an effect upon the choice of sites, *P. quatuordecimpunctata* is more evenly distributed throughout the landscape than *C. septempunctata.* Indeed, the latter generally hibernates at forest edges orientated towards the South and the West. Furthermore, *C. septempunctata* aggregates on more elevated hills than does *P. quatuordecimpunctata.* Although **Iperti** (pers. communication) thinks that, at least in South-Eastern, France,

P. quatuordecimpunctata is not migratory, its pre-dormancy behaviour is unknown, while *C. septempunctata* seems to travel over long distances to reach specific dormancy sites (**Basedow,** 1982).

All these observations are supported by the data collected from slag-heaps. Furthermore, *C. septempunctata* overwinters in grass tussocks on the dune top at the Belgian seaside (**Pasteels,** pers. communication). However, in contrast to species such as *S. undecimnotata, C. septempunctata* is not solely dependent on elevated dormancy sites. Indeed, in lowlands, it hibernates at forest edges, clearings, wind breaks. According to **Hodek's** review (1973), the dormancy behaviour of *C. septempunctata* is extremely heterogeneous even within the same ecological region. However, the following tendencies are apparent from our study. *C. septempunctata* prefers raised stations if they are available in the landscape. Whatever the relief, *C. septempunctata* overwinters very close to the ground in small aggregations and its dormancy sites are generally orientated towards the South or the West. The impact of *Beauveria ssp.* on ladybirds during the winter might be reduced by this dormancy pattern (**Iperti,** 1966b). In contrast, little has been written about dormancy sites of *P. quatuordecimpunctata.* **El Hariri** (1966), **Hodek** (1973) and **Larochelle & Larivière** (1980) briefly reported that these ladybirds hibernate in forest litter. In Poland, *P. quatuordecimpunctata* is more abundant in Pinus litter than in Quercus litter (**Bielawski,** 1961).

Though *A. bipunctata* (**Hemptinne,** 1985) and *C. septempunctata* hibernating quarters are very variable, it appears that, at least in the study area, forests or woody biotopes are important dormancy sites for *P. quatuordecimpunctata, C. septempunctata* and also *A. bipunctata,* the 3 most important ladybirds in controlling cereal aphids (**Hemptinne & Naisse,** 1988). Among these 3 species, *C. septempunctata* is maltreated by the maize harvesters during migration flights towards dormancy sites. In other countries, the detrimental effects of agricultural practices on *C. septempunctata* have already been recorded. **Honěk** (1978) estimates that 38 % of the total ladybird population on farm land was destroyed by machine cropping of forage legumes in Czechoslovakia. Likewise, *C. septempunctata* suffers from dried vegetation being burnt at the end of the winter, a widely used practice in Eastern Europe (**Hodek,** 1973). Evidently, population dynamics study is needed to measure the impact of green maize harvest on the population of *C. septempunctata.* However, this detrimental effect coupled with winter severity could be sufficient to reduce ladybird efficiency in controlling aphids.

As it seems that the ladybirds temporarily visit in autumn only those fields close to dormancy sites, the planning of the spatial relationships of maize fields and dormancy sites at the regional level would avoid the maize harvesting being harmful for *C. septempunctata* populations.

The integration of these recommendations in the management of the agricultural ecosystem could be useful for integrated pest control.

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RÉSUMÉ

Exigences écologiques pour l'hivernation de *Propylea quatuordecimpunctata* et de *Coccinella septempunctata* L. [*Col. : Coccinellidae*]

Durant 3 hivers successifs, on a étudié les sites d'hivernation de *Propylea quatuordecimpunctata* (L.) et de *Coccinella septempunctata* L., espèces hivernant toutes deux dans la litière forestière. Des échantillons de litière ont été récoltés pour étudier l'influence de 3 variables (exposition ; altitude ; lisière ou intérieur des peuplements) sur les effectifs de coccinelles.

Les exigences écologiques des 2 espèces sont différentes. *C. septempunctata* préfère les lisières orientées du Sud à l'Ouest, tandis que *P. quatuordecimpunctata* se rencontre à l'intérieur des peuplements. Pour les 2 espèces, on a mis en évidence une corrélation positive entre les effectifs observés et l'altitude des sites d'hivernation.

L'impact de quelques facteurs de mortalité intervenant avant et pendant l'hivernation a été évalué. La récolte des champs de maïs adjacents aux sites d'hivernation provoque de lourds dégâts aux populations de *C. septempunctata*. Durant l'hiver, les 2 espèces souffrent de *Beauveria ssp.* et abritent des parasitoïdes.

MOTS CLÉS : *Propylea quatuordecimpunctata* , *Coccinella septempunctata* , hivernation , *Beauveria ssp.* , parasitoïdes.

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