ENDURE

European Network for Durable Exploitation of crop protection strategies

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Glossary

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Definitions

Conservation biological control: biological control of pests through the conservation or enhancement of their natural enemies.

Habitat can be defined as the area inhabited by a population, i.e., in particular, where individuals reproduce. The suitability of a habitat and in particular whether it behaves as a source or a sink depends on the relative value of the birth rate versus the mortality rate.

Summary

We performed a literature review of studies investigating the impact of landscape composition on arthropod pests' abundance and biological control via natural enemies. We analyzed 28 studies about pests, among which 19 reporting about pest abundance (52 independent cases) and 9 about their conservation biological control (20 cases). We compared results to those of 27 studies about non pest herbivores (99 cases) among which 20 about abundance (73 cases) and 7 about biocontrol by their natural enemies (26 cases).
We collected information about landscape composition in these studies as well as pests characteristics. Using generalized linear models, we searched for landscape or pests variables that may influence the pest response to landscape characteristics.
We finally had few significant effects from this literature review but globally, the picture that emerges is consistent with our expectations: (1) biological control is enhanced by increasing amounts of non cultivated habitat in the landscape and (2) the amount of pests in a landscape tends to respond positively to an increasing amount of habitat and/or more negatively to an increasing amount of non habitat. As very few studies reported both about pest abundance and biocontrol, it is difficult to assess if there is a causal relationship between the two.

Teams involved:
INRA, RRES, CIRAD, CNR, AGROS, SSSUP, UdL, Szie

Geographical areas covered:
Worldwide literature review

1. INTRODUCTION

So far landscape ecology has contributed mostly to the development of methods and concepts for the conservation of rare and vulnerable species in arable landscape, whereas development of integrated pest management strategies (IPM) has rarely been considered at scales larger than the field and its surrounding margins (cf deliverable 2.2). The European Network of Excellence ENDURE seeks to promote the design and implementation of innovative environmentally friendly crop protection strategies in part based on better understanding of pests/weeds population biology in relation to surrounding landscape. In research activity Ra2.3, we decided to perform a literature review of studies investigating the impact of landscape composition on pest abundance and pest biological control via natural enemies. The goal of this literature review was to identify situations where landscape management impacts pest abundances and thus inform ENDURE system case studies on potential management options at that scale. Although all cropping systems are not considered within ENDURE, we decided not to exclude any study on that basis as published studies are rare.

Before performing the review, we made a number of hypotheses concerning landscape impacts on pest abundance and biocontrol.
1-We hypothesized that a pest’s abundance on a crop would be positively correlated with the amount of that crop in the landscape. This hypothesis came (i) from conservation biology referring to the negative impact of habitat fragmentation on abundance of rare species: it is widely recognized that habitat loss and fragmentation are major drivers of population extinctions, and (ii) from studies investigating the effect of within plot crop diversity on pest dynamics: it has been shown that species diversity reduces pest damage in forestry (Jactel and Brockerhoff 2007) and agriculture (Altieri 1999). Similarly, within species genetic diversity is expected to decrease disease damage in some crops (e.g. Pilet et al. 2006 in potato but many more exist).
2-We hypothesized that conservation biocontrol (CBC) of pests would increase with an increasing proportion of non cultivated area over the landscape. This hypothesis came from the numerous published results about the supporting effect of non crop habitat on pest enemies.
3- Finally, as it is expected that species with high dispersal ability interact with the landscape structure at a larger spatial scale (Keitt, Urban & Milne 1997), but at the same time, as it is recognized that less mobile species are more susceptible to landscape fragmentation, we expected pests with intermediate dispersal abilities to be more frequently affected by landscape characteristics than species with very low or very high dispersal abilities.

However, some characteristics of pests and cropping systems plead against these hypotheses.
The first one is that, contrary to rare species, pests are fought against in crops where they could be the most abundant. It is thus possible that most of their potential habitat is in fact hostile and that, unless they have acquired resistance to pesticides, their abundance would be lower for a higher surface of crops in the landscape and/or would mainly depend on the presence of small amounts of untreated habitat (e.g. garden trees for fruit pests). The second is that some pests do not perform their whole life-cycle on the crop but recolonise it each year from another host. This is for example the case of numerous aphid species (e.g. two cereal aphid species: *Rhopalosiphum padi*, overwinter on shrub *P. padus* Östman et al 2001

L4, *Sitobion avenae* overwinter on grass species Thies et al. 2005 T4). Their abundance thus also depends on that of alternative host plants and it may have a different relation to the surface of cultivated and non-cultivated area. Thirdly, some pests migrate over very long distances (e.g. *Autographa gamma*, Klug et al. 2003 A4) and their abundance may depend on the abundance of host plants in another region than that under study. Finally, these hypotheses are more likely to be true for specialist pests that for generalists, and in particular are unlikely to apply for arable weeds as the more arable crops one finds in a given landscape, the less diversity and abundance one finds for arable weeds. A specific activity on weeds is thus carried out within Ra2.3.

Concerning the biological control of pests, relating the rate of predation/parasitism of a pest with the diversity and abundance of pest enemies is often problematic (Tscharntke et al. 2007). In fact some authors think that the most efficient biocontrol is probably due to the activity of generalist predators whose efficiency on the target pest will also depend on the abundance of alternative preys (Symondson et al. 2002). Only a few main predator species were observed in most of the studies that we found in the literature.

In this study, we sough to determine whether insect pest abundance and their conservation biological control display globally consistent response to the habitat structure at landscape level. However the approach of applied research may bias the outcomes of studies, so we decided to include data on non-pest herbivore species and to compare basic trends.

2. METHODS

2.1. Bibliographic search

We searched for scientific articles in the Web of Science until mid march 2009, using the keywords: landscape, agri* and one scientific name of arthropod taxa. The choice of taxa was based upon reference to a meta-analysis that aimed at determining whether arthropod biodiversity responds to agricultural intensification (Attwood et al 2008). The list was modified according to the aim of our study (see Appendix 1).

To extend our database for pest species (that were not numerous), we also checked all publications indexed in the Web of Science of authors appearing in the last three IOBC bulletins of Landscape management for functional biodiversity. It is unlikely that we detected all relevant studies but attempts to modify keywords did not help in finding additional references. Neither did we receive additional articles after contacting our colleagues from the RA2.3 Sub-Activity.

We thus performed the analyses using the articles thus found.

Studies reporting about the effect of cultivated or non cultivated areas were more easily found for non pest herbivore species than for pest species. Although we only considered species with behavior that make them resemble pests (in particular, we discarded numerous articles on pollinators), searching the web of science allowed us to reach the same number of studies as for pests, without further enquiry.

We included studies for the review if they met two conditions: (1) the abundance of herbivorous insects or their parasitism or predation rate was reported, (2) the effect of the proportion of cultivated area or habitat at landscape scale was analyzed. For this last point, distances of at least 100m from the target fields had to be considered in the paper.

2.2. Analysis of articles

Different taxa within a single study were treated as independent cases, but in case of multiple time periods, we used results from only one period, choosing the one with the lowest P-value. In some articles the analysis was carried out at different scales, landscape composition being considered at different distances from the focal field. As it is likely that landscape effects, if present, cannot be detected at all scales but only at some scales that are relevant given the organism biology (Moilanen 2002), we used the results of the scale where the correlation between the studied variable and landscape composition was the strongest. If both the effect of the cultivated area and some non-cultivated area were reported in a single study, we considered them as independent cases if their proportions added to a value much smaller than 1. Indeed, if they added to 1, correlations of pest abundance to these two variables are not independent and only the results concerning the proportion of cultivated area were considered.

Using the above procedure, we located 46 studies and 171 independent cases (reduced to 144, see below) published between the years 1993-2008 (Appendix 1 Table 5). 28 studies reported about pest abundance (19 studies, 52 cases) and their conservation biological control (9 studies, 20 cases), while 27 studies and 99 cases were about non pest herbivores abundance (20 studies, 73 cases) and their natural enemies (7 studies, 26 cases).

In most of the papers there were 1 or 2 cases per study (Figure 1). However, four studies reported results for a large number of species, corresponding to more than ten cases (10, 12, 15, 18 cases). To avoid excessive pseudoreplication, we decided to limit the number of cases per study to 7. The seven cases were selected randomly. Our final data set thus contained 144 cases, evenly shared between pests and non pests but largely in favour of articles dealing with abundance as compared to articles dealing with conservation biological control (Table 1).

	Pest	Non Pest Herbivores	Total
Abundance	52	50	102
Biological control	20	22	42
Total	72	72	144

Table 1: Summary of selected cases.

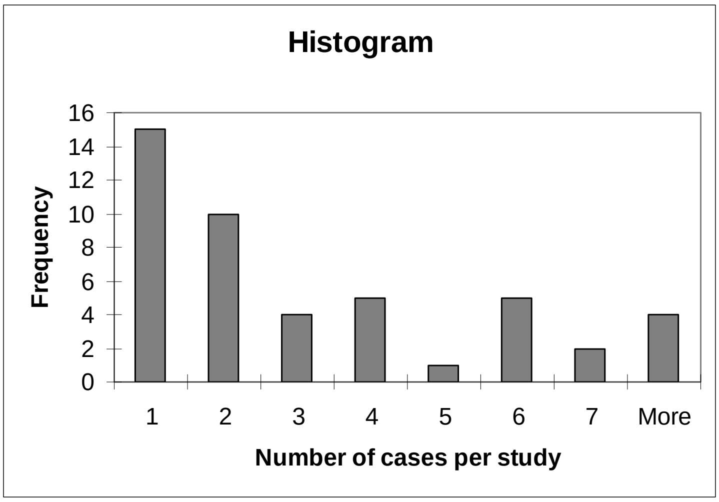

Figure 1: Distribution of number of cases per study before randomly removing cases for studies reporting more than 7 cases.

2.3. Data collection

To build up a precise dataset for the statistical analyses, detailed information was collected about the experimental design, scale, statistics, characteristics of the species and then they were classified into simplified categories as follows (Table2).

- *Landscape data*: we distinguished between the effect of cultivated areas, habitats and host plant areas. We made a distinction among these three categories because the level of information provided by articles was somewhat variable, some considering cultivated areas as a whole, others detailing the different cultivated crops. Furthermore, crop and habitat were often confounded (or at least partially redundant) for pest species but generally not for non pest species.
    - o *Cultivated area*. This variable was quantified for all cases. We attributed a value of 1 when the proportion of the cultivated area was reported and 0 when the proportion of non cultivated area was reported. We considered the proportion of arable or horticultural fields as “cultivated area” and the proportions of forest, grassland, ecological corridors as “non cultivated area”.
    - o *Habitat*. This variable was only considered for the cases reporting abundance data and only in articles where the level of landscape characterization made it possible to attribute the habitat and even the host plant area proportion. Let us for example consider the study where the abundance and the parasitism rate of the rape pollen beetle (*Melighethes aeneus*, Thies et al. 2008 E3) were correlated to the proportion of surrounding oilseed rape field areas. For the abundance data, we considered that the study dealt with “cultivated area”, “habitat” and “host plant area”. For the parasitism rate, we considered that it dealt only with “cultivated area” as no data was reported for habitats and host plant areas of parasites. In the case of *Metriocnemus knabi* (Diptera, Krawchuk and Taylor 2003 C1), which is a non pest species the proportion of peat land was measured, so the attribute of the variable “cultivated area” was 0, but the attribute of the “habitat” was 1.

- *Landscape effects*. We used the vote-counting method to identify trends in landscape effects as studies reported very heterogeneous statistics based on different variable measures (e.g. pest densities measured per day or season, per trap, leaf or unit area). Our dependent variable could thus take three values, (+), (-) or (0) depending on the effect of landscape metrics on the insects.
  For most analyses, we reported a value "+" when an increasing rate of measured area resulted in a significant increase of the abundance of the insects or a less effective conservation biological control (i.e. we placed ourselves from the point of view of the herbivore). Conversely, we reported a value "-" when an increasing rate of measured area resulted in a decreasing abundance of the insects or increasing conservational biological control. Finally, we reported value "0" when there was no significant effect.
- *Species characteristics*. Species were characterized in three different ways. First they were classified by their taxonomy at the order level. Second, they were classified as sedentary or mobile, using information provided by authors of the articles and of colleagues from RA2.3. Finally they were characterized with respect to their feeding behavior as specialists (monophagous), oligophagous (i.e. feeds on different plant species from a same family) or generalists (polyphagous).
- *Focal plant species*. Focal plant species on which insects were studied were characterized as being horticultural, arable, forest, grassland or others.

Independent variable	Variable	description	Values
Landscape	CULT	% cultivated or non-cultivated area	1, 0
	HAB	% habitat or non-habitat	1, 0
	HOST	% host	1, 0
Measured variable on insects	ABUND	Abundance or biological control	1, 0
Focal plant species	PLANT	Arable, Horticultural, Grassland, Forest, Other	Ar Hor Gras For Other
Species	PEST	Pest or non pest	1, 0
Specialization	SPE	Polyphag, oligophag, monophag	1, 2, 3
Mobility	MOB	Small scale, intermediate scale, migrating	1, 2, 3
Niche category	NICHE	external on leaves leafminer shelter makers swiches from leaf feeding to boring borers	Ext Min Shel Swi Bor

Table 2: Criteria used for characterization of studied cases. See text above for more details.

2.4. Statistical analyses

2.4.1. What variables explain a significant landscape effect?

Looking only at significant results, we tested whether the number of “+” or “-“ results depended on landscape or species characteristics. A similar amount of “+” and “-“ significant effects may either mean that landscape effects vary inconsistently depending on species, but may also result from a publication bias in favour of the 5% chance significant results. A same amount of “+” and “-“ may thus be a sign of the absence of a landscape effect. Tests were performed using Chi2 tests.

We created a synthetic variable Lands that took value “1” if there was a significant landscape effect, positive or negative, and “0” otherwise. We then used logistic regression on binomial data to check variables that would affect the probability of finding a significant result using proc Genmod in SAS (SAS 9.01, SAS Institute). Variables used were either 1)*CULT*, *ABUND* and *PEST* or 2) *HAB* and *PEST*.

2.4.2. What is the direction of the landscape effect, if any, and what variables explain it?

To investigate the characteristics of studies (and thus the landscape and species variables) that report more positive landscape effects than others, we first ordered results of studies from “-“ to “0” and “+” (coded 0,1,2) and analyzed their distribution using a logistic regression on multinomial data using proc Genmod in SAS (SAS 9.01, SAS Institute). As numerous models were tested, they will be presented along the results for clarity.

3. RESULTS

3.1. Data structure

3.1.1. Country

The 46 studies were carried out in 12 different countries, mostly in Germany (9), Canada (8) and in the USA (7). Most of the studies about pests were made in Germany (5), USA (4), France (3) and the Netherlands (3), while the major part of the studies about non pest species was performed in Canada (6), Germany (4), and USA (3). There were no data reported from Africa, Asia, Australia and Oceania. Central-Europe and the Mediterranean area were not well represented either (Appendix 2, Figures 1 and 2).

3.1.2. Year of publication

Figure 3 presents the number of collected publications per year for pests and non pest species (Appendix 1, table 5). It is obvious from this graph that the number of publications from the scientific community on the impact of landscape characteristics on the abundance or the biocontrol of insects has increased recently. However, searching only for 'pest control' in the Web of Science also showed an increased number of publications from 2904 for the period from 1996 to 2002 to 4458 for the period from 2003 to 2008, i.e. a 1.5 fold increase. In comparison, publications about pests in our database increased from 10 to 23, i.e. an almost two-fold increase with a peak in 2008. This indicates that recent studies focus more on the effect of landscape on insect pests.

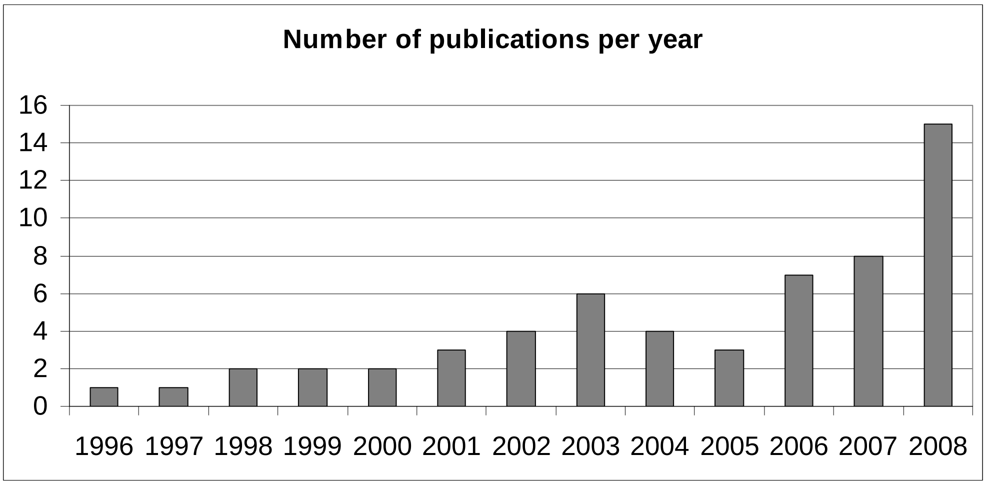

Figure 3: Number of considered publications per year.

3.1.3. Methods used in the articles

In general landscapes effects were investigated in either of two ways. In most of the studies (117 cases) the percentage of crop and non-crop habitat area was measured around independent insect sampling sites, and this percentage value was correlated to the insect data. In other studies (27 cases), larger areas were determined as being complex or simple landscapes (generally corresponding to more or less cultivated areas) and their insect data were compared by sampling at several sites. Even though this classification is simple, a large variety of statistical methods were used, generally based on more or less sophisticated generalized linear models. Some studies were based on descriptive multivariate analyses.

We had to disregard a number of studies about landscape effects on pests. The first reason was that such effects were reported at a too small scale, considering mainly field margins. Other reasons include the description of landscape through its connectivity or its diversity. Although of interest, we did not consider such articles here to keep the database as homogeneous as possible. In other articles, the effect of the landscape structure on biodiversity was questioned, but there were no data on the species abundances or the effectiveness of the CBC. These articles were thus not considered either. Finally, there were a few articles using GIS-based maps coupled with geostatistics that we also neglected for homogeneity.

3.1.4. Taxa

Pests and non pests of 8 orders were reported (Coleoptera, Diptera, Hemiptera, Homoptera, Hymenoptera, Lepidoptera, Orthoptera, Thysanoptera), mostly of Lepidoptera, Coleoptera and Hemiptera species (Table 3). 117 cases provided data at the species level.

	Pest			Non pest			Total
Order	Biocontrol	Abundance	Total	Biocontrol	Abundance	Total	
Coleoptera	4	12	16	2	15	17	33
Diptera					5	5	5
Hemiptera	8	12	20	4	2	6	26
Homoptera		5	5		1	1	6
Hymenoptera				5	3	8	8
Lepidoptera	8	18	26	11	21	32	58
Orthoptera					3	3	3
Thysanoptera		5	5				5
Total	20	52	72	22	50	72	144

Table 3: distribution of analyzed cases as a function of insect order.

3.1.5. Focal plant species

As expected, focal plant species are mainly crops for pests and generally not for non pests. Crops are not represented according to their importance in agriculture in the study. On the one hand there are some crop types for which there is a lot of data available, while on the other hand there are crops which are missing. Orchards, greenhouses and potato are not well studied compared to their economic importance. We collected no data on other crops like soybean, cotton, rice or tropical fruits (Table 4).

	Pest		Non pest		Total
Focal plant category	biocontrol	abundance	biocontrol	abundance	
Horticulture	6	16			22
Arable	14	20			34
Forest		4	15	17	36
Grassland		1	3	17	21
Other		11	4	16	31

Table 4: Studies classified according to the focal crop type.

3.2. What variables explain a significant landscape effect?

For pest species, biological control tended to respond positively to the proportion of non cultivated area (khi2 (1), P=0.094 testing H0 same amount of positive and negative cases). All other tests were not significant (or data too few) meaning that published significant results might either show no trend or be false positives/negatives.

Using logistic regression on the synthetic variable *Lands* on each explanatory variable separately did not provide evidence that (1) studies investigating the impact of either cultivated or non-cultivated area, (2) studies investigating insect abundance or conservation biocontrol, (3), studies investigating mobile or sedentary species have different probabilities of reporting significant landscape effects. The only significant effect was that the ratio of non-significant to significant results was higher for non pests than for pests studies, considering either insect abundance or biological control (P=0.004 in model *CULT+ABUND+PEST* and P=0.0142 in model *HAB +PEST*) (Figure 4).

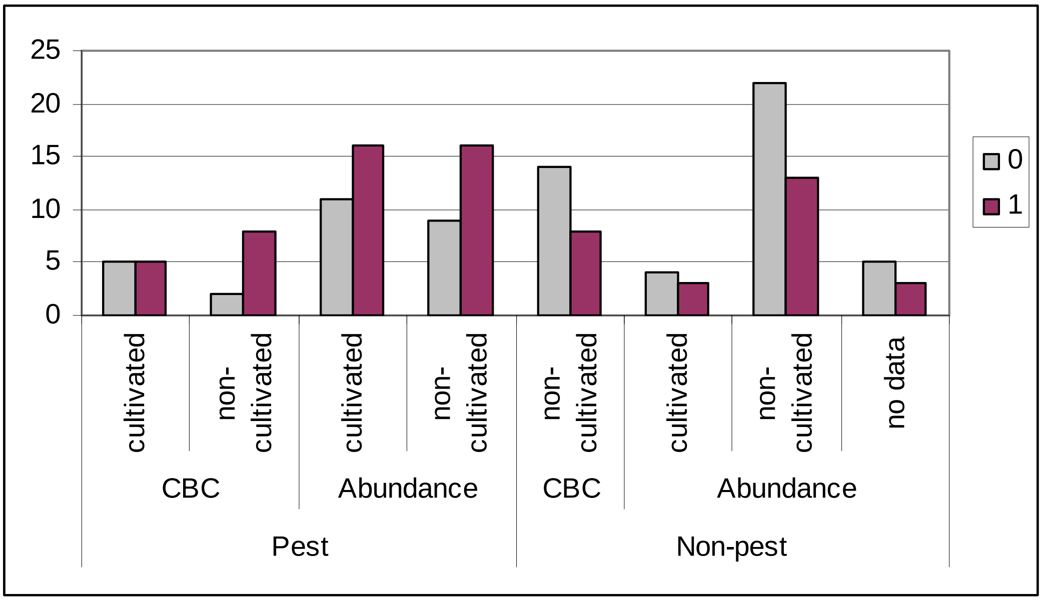

Figure 4: Distribution of significant (1) and non significant (0) cases.

3.3. What is the direction of the landscape effect if any and what variables explain it?

Detailed results per study and independent variable are provided in appendix 2.

3.3.1. Global analysis

Multinomial models allowed testing which studies were more likely to report more negative impacts of landscape variables on insect population (i.e. smaller pest abundance or larger biological control).

In a first global model, we tested the together the following variables: being about cultivated or non cultivated area (*CULT*), being about pests or non pests (*PEST*) and being about abundance or conservation biocontrol (*ABUND*). We found that studies about pests and non pests did not behave similarly, with studies about pests being more likely to report negative impacts of landscape (khi2(1)=3.95, P=0.047). Studies about non cultivated areas were also marginally more likely to report a negative impact on insects (khi2(1)=2.76, P=0.096). Finally we did not find any impact of a study being about abundance or biological control (khi2(1)=0.13, P=0.72) (Figures 5 and 6).

3.3.2. Cultivated area

Because there was a tendency for studies about pests and non pests to behave differently, we analyzed the effect of being about cultivated or non cultivated area (*CULT*) for pest and non pests separately, although this reduced the power of analyses.

Studies reporting on the impact of cultivated or of non cultivated area had similar probabilities of reporting more or less positive impacts on either pest or non pests abundance (khi2(1)=1.27, P=0.26 and khi2(1)=0.46, P=0.49 respectively). For biological control, there was enough data for studies reporting about pests only. In that case, we found that studies about the effect of non cultivated area tended to report more negative results than studies about cultivated areas, which indicates that article report more frequently a positive effect of an increasing amount of non cultivated area on pest biological control (khi2(1)=4.87, P=0.027) (figure 5 and 6).

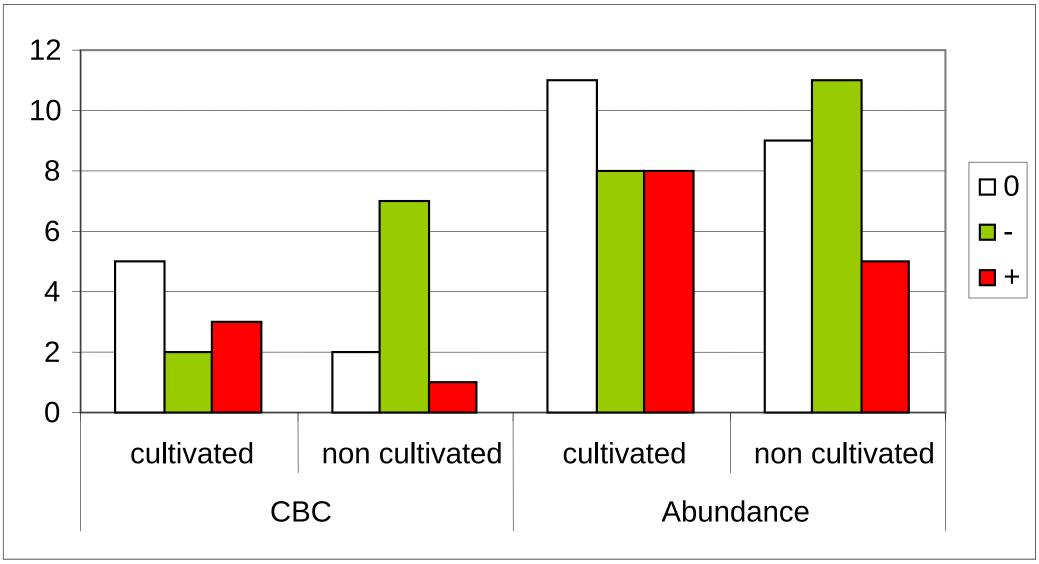

Figure 5: Number of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas in the landscape on pests. Data are presented separately for conservation biological control (CBC) and population abundance.

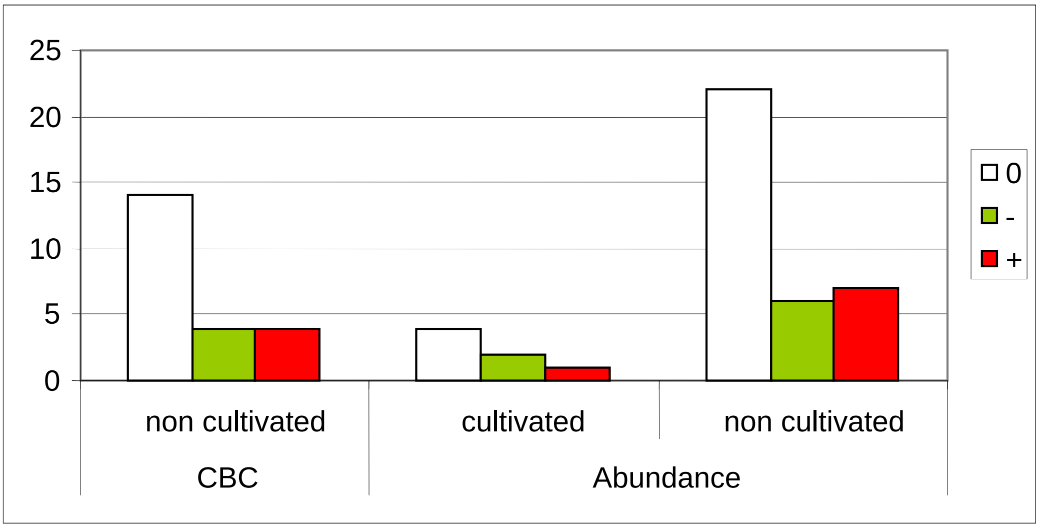

Figure 6: Number of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas in the landscape on non pests. Data are presented separately for conservation biological control (CBC) and population abundance.

3.3.3. Habitat area

Habitat area could only be defined in the case of studies reporting about insect abundance as we had no information about habitats of natural enemies.

When all abundance studies were considered together, there was a very significant tendency for studies reporting about non habitat to have more negative results than studies about habitat, which can be interpreted as a positive relationship between habitat density surrounding focal study sites and insect abundance (khi2(1)=6.87, P=0.009). When studies about pests and non pests were considered separately, this effect only remained marginally significant for the pest studies and not for the non-pest studies (khi2(1)=3.43, P=0.064 and khi2(1)=2.17, P=0.14) (Figure 7).

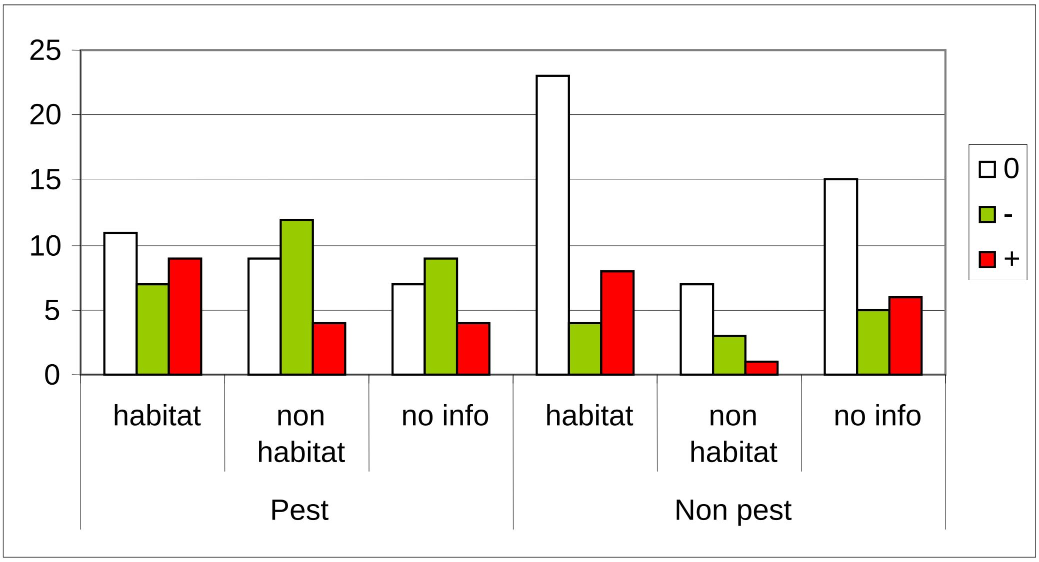

Figure 7: Number of positive, negative and non significant results concerning the impact of habitat and non habitat areas in the landscape on abundance of pests and non pests.

3.3.4. Plant species and insect factors

When enough data were available, we also tested in the same way if focal plant species (*PLANT*) or insects species characteristics (*SPE, MOB, NICHE*) may affect the influence of landscape on pest abundance or conservation biological control but none of the tested variables appeared significant.

4. Discussion

4.1. Aims and choices

In this report, we aimed at testing if the density of a single crop species over a landscape would increase the abundance of pests on that species and positively or negatively affect its biological control. Although we made a large census of the scientific literature trying to find studies addressing that question, we finally found only 11 of them : about cereal aphids (Ostman 2002, D1, Fabre et al 2005, E2), about oilseed rape (Thies et al. 2003 E3, Zaller et al. 2008 E6),about leek (Belder et al. 2002 E7), about pomefruit orchards (Ricci et al 2009 T5), about vineyards (van Helden et al 2008 E10), about potato (Boiteau 2008 P2) , about maize (Veres et al 2006, T2,) greenhouses (Veres et al. 2008, S2) and about grasslands (Grilli & Bruno 2007 R2). It is to note however that most of them were published in the last few years and it is hoped that more of them will be available soon.
As most authors, we thus considered a much rougher classification of landscape, considering cultivated area as a whole. When enough information was available, we also tried to detail somewhat if the cultivated area was habitat or not for the pest. This rougher classification should obviously be less of a problem for generalist pest species than for specialists, although we did not see any effect of this factor in the analyses.

As in all reviews, we were also careful about a possible publication bias towards significant results, as this is very often reported and experienced by most researchers as the file-drawer problem (Rosenberg 2005). We were also worried that scientists working on pests would generally be interested in controlling the pest and thus investigate situation in which they would expect that the observed variable in the landscape could help controlling the pest. For this purpose, we compared results with those observed on non pests by a different scientific community which may on the contrary wish to conserve the study species, or at least to simply test ecological theories. We had no large differences in the types of effects reported for pests and non pests and this bias was not obvious from our data. Conversely we found a larger proportion of significant results on pest species, meaning either that non significant results are more easily published on non pest species or that landscape composition has a larger impact on pests than non pests. As non pest studies generally considered more species par article than pest studies, it is indeed possible that authors were more prone to present non significant results.

4.2. Main trends

We finally had few significant effects from this literature review but globally, the picture that emerges is consistent with our expectations: (1) biological control is enhanced by increasing amounts of non cultivated habitat in the landscape and (2) the amount of pests in a landscape tends to respond positively to an increasing amount of habitat and/or more negatively to an increasing amount of non habitat. As very few studies reported both about pest abundance and biocontrol, it is difficult to assess if there is a causal relationship between the two.

In particular, parasitism or predation rates may also be increased in cases of high host/prey (i.e. here pests) availability (Freier et al 2007, T6) as a sufficiently large population of host/preys is necessary to sustain a higher trophic level, and pests abundance and predation or parasitism rates may be positively correlated. It is worth noting that the positive effect of natural elements over the landscape on the abundance or the diversity of natural pest enemies has often been reported. Although much less data is available about the resulting predation or parasitism rates on pests (Bianchi et al. 2006), our results tend to show a similar trend. In any case, the impact of parasitism and predation on the population dynamics of the pest is difficult to assess as enemies may arrive too late on a pest for its control at agronomical acceptable levels. Control efficiency may for example be largest at the beginning of the growing season, when pest populations are little abundant.

Another difficulty in working with rough categories such as “cultivated” and “non cultivated” is that recent studies showed that crop may also support natural enemies. For example early-maturing plants such as barley, or early-sown wheat act as reservoirs of aphid parasitoids in the spring, and these parasitoids migrate into nearby late-sown wheat (Brewer et al. 2008, A1). Generalist predators have also been shown to benefit from the high prey resource in extensive managed crop fields (Rand & Louda 2006, Rand and Tscharnke 2007 C4).

The direct effect of landscape composition on pest abundance was more difficult to assess. As results tend to be more significant when habitat rather than cultivated area is considered, it may be a classical effect that the abundance of a species over a landscape is generally influenced by the amount of its habitat over that landscape (e.g. Wiegand et al. 2005). This effect would still hold for pests but the direction of the effect may depend on pesticides treatments that are generally used against them (Ricci et al. 2009 T5). It is worth noting, for example, that for the 19 cases (11 studies) that considered specifically the amount of pests host plants in the landscapes 11 report significant results but seven report a positive impact of host amount of pest abundance and five report a negative impact.

Conclusion

Although they should be considered with caution as not many studies have been published yet, our results thus generally confirm that crop protection against pests should be considered at a landscape level (Deguine et al. 2008) and would be enhanced by inclusion or maintenance of natural habitats over the landscape. No general conclusion can be drawn about the direct effect of landscape composition on pest abundance. Significant results are reported, in particular when distribution of the pests host plant over the landscape is considered, but reported effects were either positive or negative. This inconsistency pleads for a better description of landscape composition, considering pests host plants over the landscape if possible, and not only cultivated versus non cultivated area and including a more thorough description of the habitat. Studies were carried out in agricultural systems that largely differ in intensity, although this is not always considered. Comparisons of their results should be carried out cautiously as pesticide applications have a direct impact on the dynamics of the species under study. It is in fact the general cropping system and its time dynamics that may have to be considered as some crops may in fact be hosts to pest enemies or on the contrary some non cultivated areas may be transitory reservoirs of pests that allow them to move from one crop to another. Landscape impacts on pest dynamics may thus largely depend on characteristics of the agro-ecosystem, the associated cropping system and land use intensity. More studies are needed that consider these three aspects for a better understanding of pest management at a landscape level.

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Tscharntke, T., R. Bommarco, Y. Clough, T. O. Crist, D. Kleijn, T. A. Rand, J. M. Tylianakis, S. van Nouhuys, and S. Vidal. 2007. Conservation biological control and enemy diversity on a landscape scale. Biological control 43:294-309.

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Appendix 1

Characteristics of the data set

Table 1: terms used for the literature search

Taxonomic term
Acari
arthropod
Blattodea
Byrrhidae
Chilopoda
Coleoptera
Colydiidae
Cucujidae
Dermaptera
Diplopoda
Diptera
Elateridae
Hemiptera
Histeridae
Homoptera
Hymenoptera
Isopoda
Isoptera
Lepidoptera
Mantodea
Neuroptera
Opiliones
Orthoptera
Phasmida
Pseudoscorpiones
Scarabaeidae
Scolytidae
Scorpionidae
Staphylinidae
Symphyla
Tenebrionidae
Thysanoptera
Thysanura

Table 2: Distribution of studies among focal vegetation type

Focal vegetation type	**Number of studies**
forest	36
grassland	14
oilseed rape	12
meadow	9
spinach	8
Cirsium arvense in winter wheat	7
maize	7
tomato	7
winter wheat	7
spring barley	6
Urtica dioica	6
vineyard	6
brussels sprout	5
Sarracenia purpurea	3
alfalfa	2
arable field, boundary	2
leek	2
sweet pepper greenhouse	2
cereal	1
orchard	1
potato	1

Table 3: Names of taxa for the abundance studies and level of mobility and specialisation

Name of the taxa (pests and herbivores)	Mobility	Specialisation
Plathypena scabra	3	1
Aphis fabae	2	1
Autographa gamma	4	1
Bruchus atomarius	3	2
Buccaluatrix albertiella	3	2
Caloptilia agrifoliella	3	2
Cassida caniculata	2	3
Cassida rubigosa	3	1
Ceutorhyncus napi, Ceutorhyncus pallidactylus	3	2
Choristoneura fumiferana	3	2
Crambus agitatellus	3	2
Cydia nigricana	3	2
Cydia pomonella	3	2
Dasineura brassicae	2	2
Delphacodes kuscheli	3	2
Dioryctria sylvestrella	3	2
Dryseriocrania auricyanea	3	2
Empoasca vitis	2	1
Epitrix hirtipennis	3	2
Eupoecilia ambiguella	3	3
Eusomus ovulum	3	2
Fletcherimyia fletcheri	2	3
Frankliniella occidentalis	2	1
Gonioctena fornicata	3	1
Helicoverpa armigera	4	1
Helicoverpa zea	4	1
Hypera postica	2	2
Labidostomis longimana	3	2
Leptinotarsa decemlineata	3	2
Lithacodia muscosula	3	2
Lobesia botrana	3	3
Lymantria dispar	3	3
Melanagromyza aenoventris	2	2
Meligethes aeneus	3	2
Melitaea athalia	3	1
Metriocnemus knabi	1	3
Microlophium carnosum	2	3
Myzus persicae	2	1
Ostrinia nubilalis	3	3
Oxystoma ochropus	3	2
Pararge aegeria	4	1
Phyllotreta vittula	3	1
Pieris rapae	3	2
Plagiotrochus amenti	3	1

Pseudocleonus cinereus	3	2
Rhophalosiphum padi	2	2
Scaphoideus titanus	2	3
Sitobion avenae, Metopolphium dirhodum, Rhopalosiphum padi	2	1
Sitona humeralis	3	1
Synophrus politus	3	1
Thrips tabaci	2	1
Tychius quinquepunctatus	2	2
Vanessa cardui	4	1
Wyeomyia smithii	1	3

Table 4: Names of taxa for the biological control studies and level of mobility and specialisation

Name of the taxa (biological control)	**Mobility**	**Specialisation**
Actia interrupta	0	0
Aphelineus albipodus	1	1
Aphidius microlophii	1	3
Arachnidomyia aldrichi	1	2
Carcelia malacosomae	1	2
Cecidomyiid midge	2	2
Diadegma spp.	3	3
Exochus nigripalpis tectulum	0	0
Glyptapanteles militaris	1	2
hiperparasitoids: Alloxysta, Asaphes, Dendrocerus, Coruna, Phaenoglyphis, Diaeretiella	2	0
Leschenaultia exul	2	2
Lysphlebus testaceipes	2	2
Meteorus spp.	2	2
parasitoids: Aphidius, Praon, Ephedrus, Aphelinus, Toxares	2	0
Patelloa pachpyga	1	2
Phradis interstialis	1	3
Pteromalus sequester, Eupelmus vesicularis, Triapis, thoracicus, Pigeria piger	1	2
Tersilochus heteroceus	1	3
Tranosema rostrale, Phytodiatus fumeriferanae	0	0
Trichogramma spp	1	2

Table 5: List of studies used for the deliverable and their identifier used in appendix 2. Please note that sometimes more that one paper may have a single identifier as they report results that we considered as being from a single study.

identifier	Reference
A1	Brewer, M. J., T. Noma, N. C. Elliott, A. N. Kravchenko and A. L. Hild (2008). "A landscape view of cereal aphid parasitoid dynamics reveals sensitivity to farm- and region-scale vegetation structure." European Journal of Entomology 105(3): 503-511.
A3	Grilli, M. P. (2008). "An area-wide model approach for the management of a disease vector planthopper in an extensive agricultural system." Ecological Modelling 213(3-4): 308-318.
A4	Klug, T., A. G., H.-M. Poehling, R. Meyhofer (2003). "Area-dependent effects of landscape structure on the colonisation of spinach cultures by the silver Y moth (Autographa gamma L., Lepidoptera: Noctudidae) in Western Germany." IOBC 26(4): 77.
A5	Klug, T., A. G., H.-M. Poehling, R. Meyhofer (2008). "Are landscape structures important for the colonization of spinach fields by insects?" IOBC 34: 69-72.
C1	Krawchuk, M. A. and P. D. Taylor (2003). "Changing importance of habitat structure across multiple spatial scales for three species of insects." Oikos 103(1): 153-161.
C3	Summerville, K. S. and T. O. Crist (2004). "Contrasting effects of habitat quantity and quality on moth communities in fragmented landscapes." Ecography 27(1): 3-12.
C4	Rand, T. A. and T. Tscharntke (2007). "Contrasting effects of natural habitat loss on generalist and specialist aphid natural enemies." Oikos 116(8): 1353-1362.
D1	Ostman, O. (2002). "Distribution of bird cherry-oat aphids (Rhopalosiphum padi (L)) in relation to landscape and farming practices." Agriculture Ecosystems & Environment 93(1-3): 67-71.
D2	Taki, H., B. F. Viana, P. G. Kevan, F. O. Silva and M. Buck (2008). "Does forest loss affect the communities of trap-nesting wasps (Hymenoptera : Aculeata) in forests? Landscape vs. local habitat conditions." Journal of Insect Conservation 12(1): 15-21.
D3	Summerville, K. S. (2004). "Do smaller forest fragments contain a greater abundance of Lepidopteran crop and forage consumers?" Environmental Entomology 33(2): 234-241.
E10	Decante, D. and M. van Helden (2006). "Population ecology of Empoasca vitis (Gothe) and Scaphoideus titanus (Ball) in Bordeaux vineyards: Influence of migration and landscape." Crop Protection 25(7): 696-704.
E10	van Helden, M., Fargeas E., Fronzes M., Maurice O., Thibaud M., Gil F., Pain G. (2006). "The infuence of local and landscape characteristics on insect pest population levels in viticulture." IOBC 29(6): 145-148.
E10	van Helden, M., Pain G;, Simonneau M-A. (2008). "Experimenting with landscape management to control pest populations in viticulture." IOBC 34: 117-120.
E2	Fabre, F., M. Plantegenest, L. Mieuzet, C. A. Dedryver, J. L. Leterrier and E. Jacquot (2005). "Effects of climate and land use on the occurrence of viruliferous aphids and the epidemiology of barley yellow dwarf disease."

Agriculture Ecosystems & Environment 106(1): 49-55.
E3 Thies, C., I. Steffan-Dewenter and T. Tscharntke (2001). Effects of landscape context on herbivory and parasitism at different spatial scales. Workshop on Context-Dependence in Plant-Herbivore Interactions, Ekenas, Sweden, Blackwell Munksgaard.
E3 Thies, C. and T. Tscharntke (1999). "Landscape structure and biological control in agroecosystems." Science 285(5429): 893-895.
E3 Tscharntke, T., I. Steffan-Dewenter, A. Kruess and C. Thies (2002). "Contribution of small habitat fragments to conservation of insect communities of grassland-cropland landscapes." Ecological Applications 12(2): 354-363.
E3 Thies, C., I. Steffan-Dewenter and T. Tscharntke (2008). "Interannual landscape changes influence plant-herbivore-parasitoid interactions." Agriculture Ecosystems & Environment 125(1-4): 266-268.
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E8 Holland, J. and L. Fahrig (2000). "Effect of woody borders on insect density and diversity in crop fields: a landscape-scale analysis." Agriculture Ecosystems & Environment 78(2): 115-122.
E9 Bianchi, F., P. W. Goedhart and J. M. Baveco (2008). "Enhanced pest control in cabbage crops near forest in The Netherlands." Landscape Ecology 23(5): 595-602.
F1 Rothman, L. D. and J. Roland (1998). "Forest fragmentation and colony performance of forest tent caterpillar." Ecography 21(4): 383-391.
G1 Chust, G., L. Garbin and J. Pujade-Villar (2007). "Gall wasps and their parasitoids in cork oak fragmented forests." Ecological Entomology 32(1): 82-91.
G2 Nesslage, G. M., B. A. Maurer and S. H. Gage (2007). "Gypsy moth response to landscape structure differs from neutral model predictions: implications for invasion monitoring." Biological Invasions 9(5): 585-595.
H1 Jactel, H., M. Goulard, P. Menassieu and G. Goujon (2002). "Habitat diversity in forest plantations reduces infestations of the pine stem borer Dioryctria sylvestrella." Journal of Applied Ecology 39(4): 618-628.
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I2 Roland, J. and P. D. Taylor (1997). "Insect parasitoid species respond to forest

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L3 Bianchi, F., W. van Wingerden, et al. (2005). "Landscape factors affecting the control of Mamestra brassicae by natural enemies in Brussels sprout." Agriculture Ecosystems & Environment 107(2-3): 145-150.

L4 Ostman, O., B. Ekbom and J. Bengtsson (2001). "Landscape heterogeneity and farming practice influence biological control." Basic and Applied Ecology 2(4): 365-371.

L5 Clough, Y., A. Kruess and T. Tscharntke (2007). "Local and landscape factors in differently managed arable fields affect the insect herbivore community of a non-crop plant species." Journal of Applied Ecology 44(1): 22-28.

L5 Kruess, A. (2003). "Effects of landscape structure and habitat type on a plant-herbivore-parasitoid community." Ecography 26(3): 283-290.

M2 Schmidt, B. C. and J. Roland (2006). "Moth diversity in a fragmented habitat: Importance of functional groups and landscape scale in the boreal forest." Annals of the Entomological Society of America 99(6): 1110-1120.

M3 Heisswolf, A., H. J. Poethke and E. Obermaier (2006). "Multitrophic influences on egg distribution in a specialized leaf beetle at multiple spatial scales." Basic and Applied Ecology 7(6): 565-576.

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R2 Grilli, M. P. and M. Bruno (2007). "Regional abundance of a planthopper pest: the effect of host patch area and configuration." Entomologia Experimentalis Et Applicata 122(2): 133-143.

S1 Kruess, A. and T. Tscharntke (2000). "Species richness and parasitism in a fragmented landscape: experiments and field studies with insects on Vicia sepium." Oecologia 122(1): 129-137.

S2 Veres A., T. F., Orosz Sz., Kristof D., Fetyko K. (2008). "Spatial analysis of greenhouse density in relation to western flower thrips (Frankliniella Occidentalis), onion thrips (Thrips tabaci) and minute pirate bug (Orius spp;) population in greenhouses." IOBC 34: 129-132.

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landscapes." Basic and Applied Ecology 5(4): 347-355.
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T1 Menalled, F. D., P. C. Marino, S. H. Gage and D. A. Landis (1999). "Does agricultural landscape structure affect parasitism and parasitoid diversity?" Ecological Applications 9(2): 634-641.
T2 Veres A., T. F., Szalkai G. (2006). "The damage pattern of Helicoverpa armigera and Ostrinia nubilalis in relation to landscape attributes - comparing two databases of Hungary at country level." IOBC 29(6): 153-156.
T3 Rickman, J. K. and E. F. Connor (2003). "The effect of urbanization on the quality of remnant habitats for leaf-mining lepidoptera on Quercus agrifolia." Ecography 26(6): 777-787.
T4 Roschewitz, I., M. Hucker, T. Tscharntke and C. Thies (2003). The influence of landscape context and farming practices on parasitism of cereal aphids. Symposium on Agri-Environment Schemes as Real World Landscape Experiments held at the World Congress on Crossing Frontiers of the International-Association-for-Landscape Ecology, Darwin, AUSTRIA.
T4 Thies, C., I. Roschewitz and T. Tscharntke (2005). "The landscape context of cereal aphid-parasitoid interactions." Proceedings of the Royal Society B-Biological Sciences 272(1559): 203-210.
T4 Vollhardt, I. M. G., T. Tscharntke, F. L. Wackers, F. Bianchi and C. Thies (2008). "Diversity of cereal aphid parasitoids in simple and complex landscapes." Agriculture Ecosystems & Environment 126(3-4): 289-292.
T5 Ricci, B., P. Franck, J.-F. Toubon, J.-C. Bouvier, B. Sauphanor and C. Lavigne (2009). "The influence of landscape on insect pest dynamics: a case study in southeastern France." Landscape Ecology 24(3):337-349.
T6 Freier, B., H. Triltsch, M. Mowes and E. Moll (2007). "The potential of predators in natural control of aphids in wheat: Results of a ten-year field study in two German landscapes." Biocontrol 52(6): 775-788.
T7 Sjodin, N. E., J. Bengtsson and B. Ekbom (2008). "The influence of grazing intensity and landscape composition on the diversity and abundance of flower-visiting insects." Journal of Applied Ecology 45(3): 763-772.

Appendix 2

Distribution of positive, non significant and negative results among categories

This appendix is a compilation of tables and figures that detail results of the 144 studied cases. Results are generally provided concerning the impact of % cultivated or % non cultivated habitat and, if applicable, also concerning the impact of % habitat or %non habitat.

Table 1: Distribution of positive, negative significant results concerning the impact of cultivated and non cultivated areas on the landscape on non pests.

Effect measured	Landscape measure	Study	Name of the herbivorous species	habitate category measured	**-**	**+**
BC	% of Non-cultivated	C4	Microlophium carnosum	% of perennial habitat	x	
		I2	Malacosoma disstria	% forest		x
		S4	Choristoneura fumiferana	coniferous patches in deciduous matrix	x	x
Abundance	% of Cultivated	A3	Delphacodes kuscheli	total area of winter pastures		x
		I1	grasshopper	% arable	x	
		T3	Dryseriocrania auricyanea	% arable	x	
	% of Non-cultivated	G2	Lymantria dispar	% forest		x
		H1	Dioryctria sylvestrella	pine %		x
		I1	grasshoppers	% grassland		x
		L2	Melitaea athalia	% non crop		x
			Pieris rapae	% non crop	x	
		L5	Cassida rubigosa	% non crop		x
			Vanessa cardui	% non crop	x	
		M2	arboreal moths	proportion of non forest / forest		x
			non arboreal moths	proportion of non forest / forest	x	
		R1	Eusomus ovulum	% grassland	x	
			generalist leaf-beetles	% grassland	x	
			Pseudocleonus cinereus	% grassland		x
			Sitona humeralis	% grassland	x	
	.	C4	Microlophium carnosum	% nettle, number of nettle patches in the model		x
		O1	Pararge aegeria	% suitable habitate		x
		S4	Choristoneura fumiferana	coniferous patches in deciduous matrix		x

Table 2. Distribution of positive, negative significant results concerning the impact of cultivated and non cultivated areas on the landscape on pests.

Effect measured	Landscape measure	Study	Name of the pest species	Habitate measured	-	+
BC	% of Cultivated	L3	Mammestra brassicae	% horticult	x	
		L4	Rhophalosiphum padi	% arable		x
				% perennial crop		x
		T4	Sitobion avenae, Metopolphium dirhodum, Rhopalosiphum padi	% arable	x	
	% of Non-cultivated	E3	Meligethes aeneus	% non crop		x
		E9	Plutella xylostella	% forest		x
		L3	Mammestra brassicae	% forest		x
				% grassland		x
		P1	Aphis fabae	% non crop		x
		T1	Pseudaletia unipuncta	% non crop		x
Abundance	% of Cultivated	A4	Autographa gamma	potato		x
		E10	Empoasca vitis	% vineyard	x	
			Lobesia botrana	% vineyard		x
		E2	Rhophalosiphum padi	area of wheat, barley, oats / area of maize, as a factor		x
		E6	Ceutorhyncus napi, Ceutorhyncus pallidactylus	% oilseed rape	x	
			Meligethes aeneus	% oilseed rape	x	
		E7	Thrips tabaci	% horticult		x
		L4	Rhophalosiphum padi	% arable	x	
				% perennial crop	x	
		P2	Leptinotarsa decemlineata	% potato of preveous year		x
		S2	Frankliniella occidentalis	% greenhouse		x
		T4	Sitobion avenae, Metopolphium dirhodum, Rhopalosiphum padi	% arable	x	
		T5	Cydia pomonella	% orchard	x	
		T6	Sitobion avenae, Metopolphium dirhodum, Rhopalosiphum padi	% crop		x
	% of Non-cultivated	A5	Aphis fabae	% forest	x	
				% vegetation strip		x
		D3	Plathypena scabra	% forest	x	
			Crambus agitatellus	% forest	x	
			Lithacodia muscosula	% forest	x	
			Ostrinia nubilalis	% forest	x	
		E3	Meligethes aeneus	% non crop	x	
		E6	Dasineura brassicae	% forest		x
			Meligethes aeneus	% forest		x
		E7	Thrips tabaci	% forest	x	
		P1	Aphis fabae	% non crop	x	
			Empoasca	% non crop		x
			Myzus persicae	% non crop	x	
		R2	Delphacodes kuscheli	% winter pasture		x
		T2	Helicoverpa armigera	% non crop	x	
			Ostrinia nubilalis	% non crop	x	

Figure 1. Numbers of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on pests. Data are presented per country.

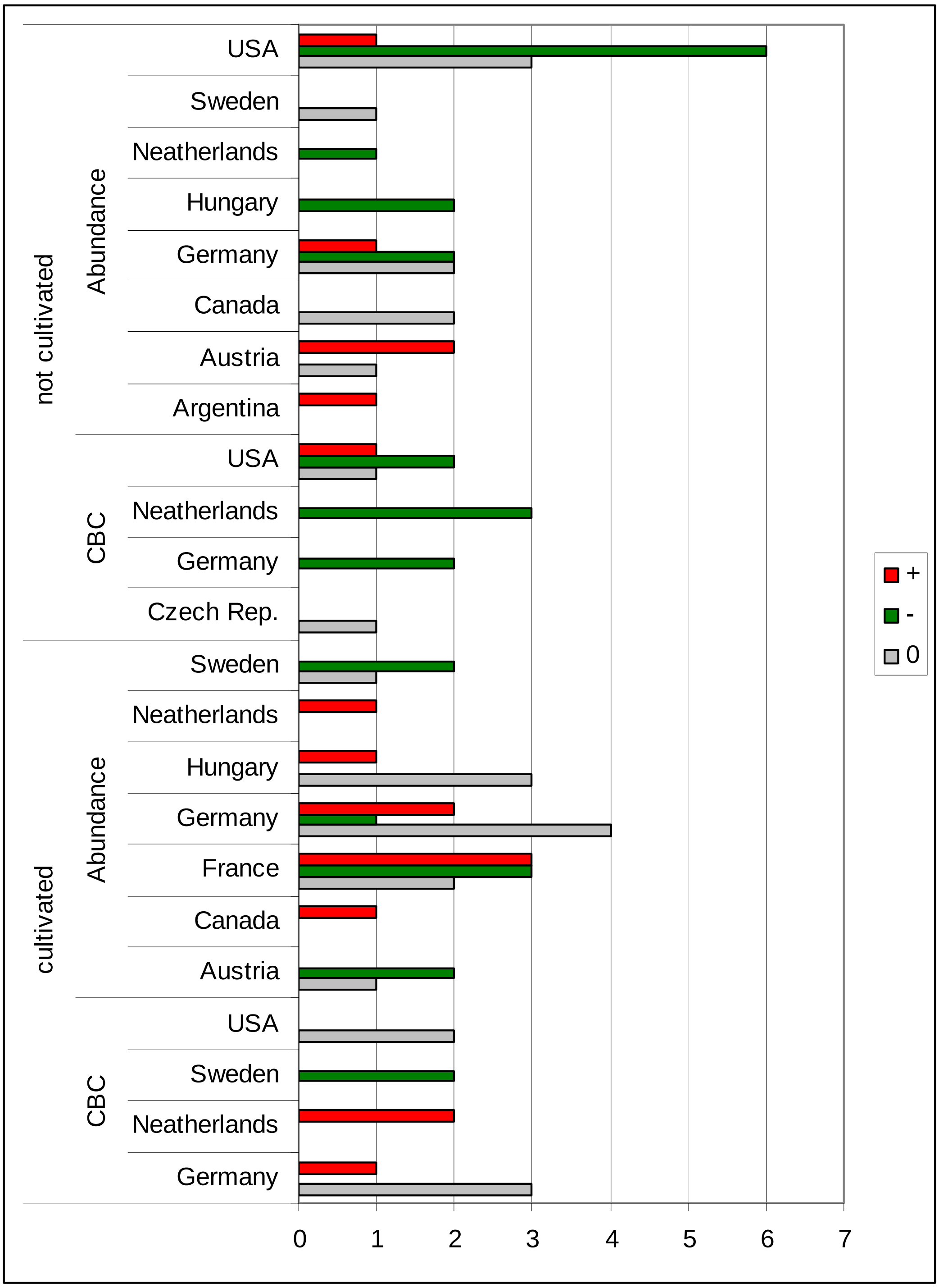

Figure 2. Numbers of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on non pests. Data are presented per country.

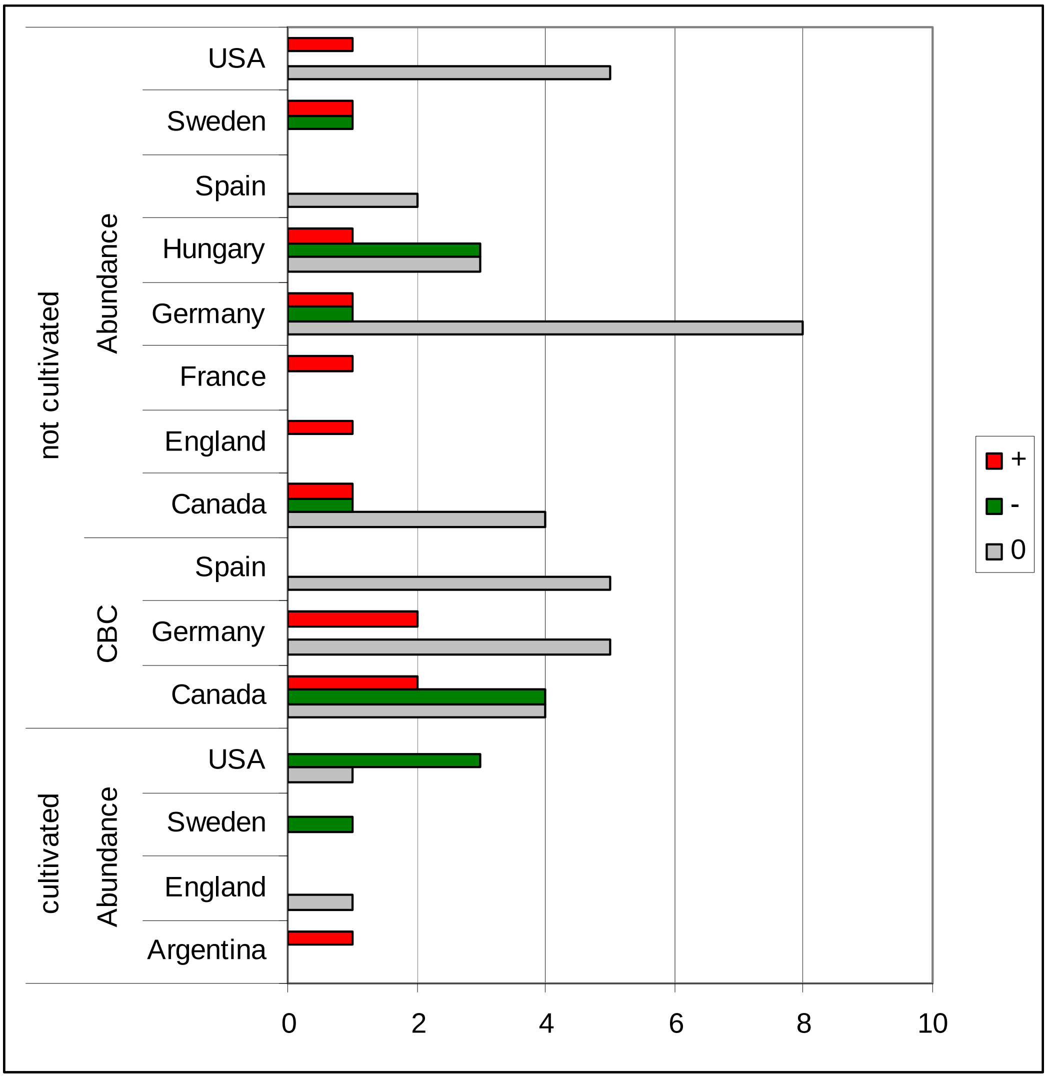

Figure 3. Numbers of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape. Data are presented per focal crop type.

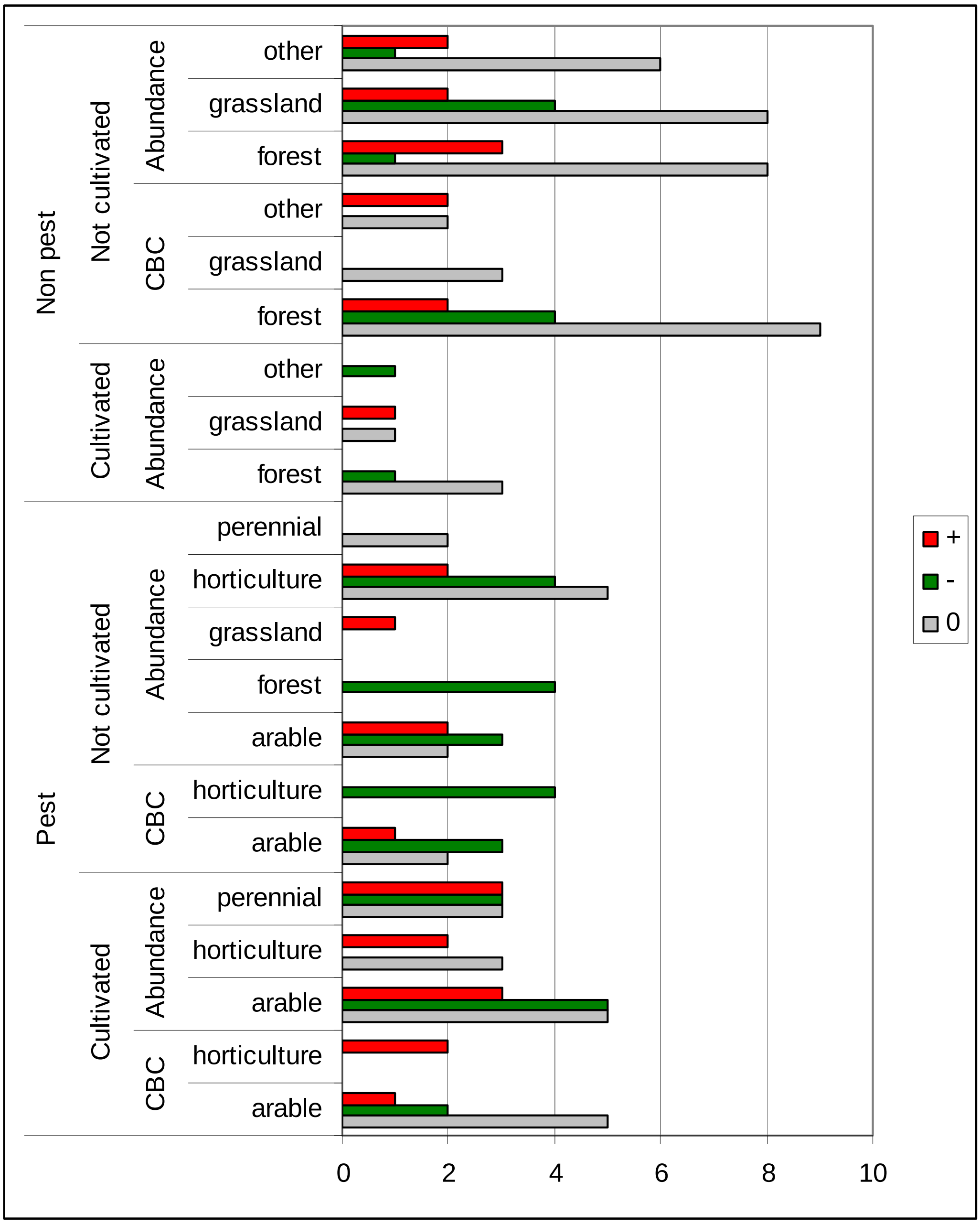

Figure 4. Numbers of positive, negative and non significant results concerning the impact of habitat and non habitat areas on the landscape. Data are presented per focal crop type.

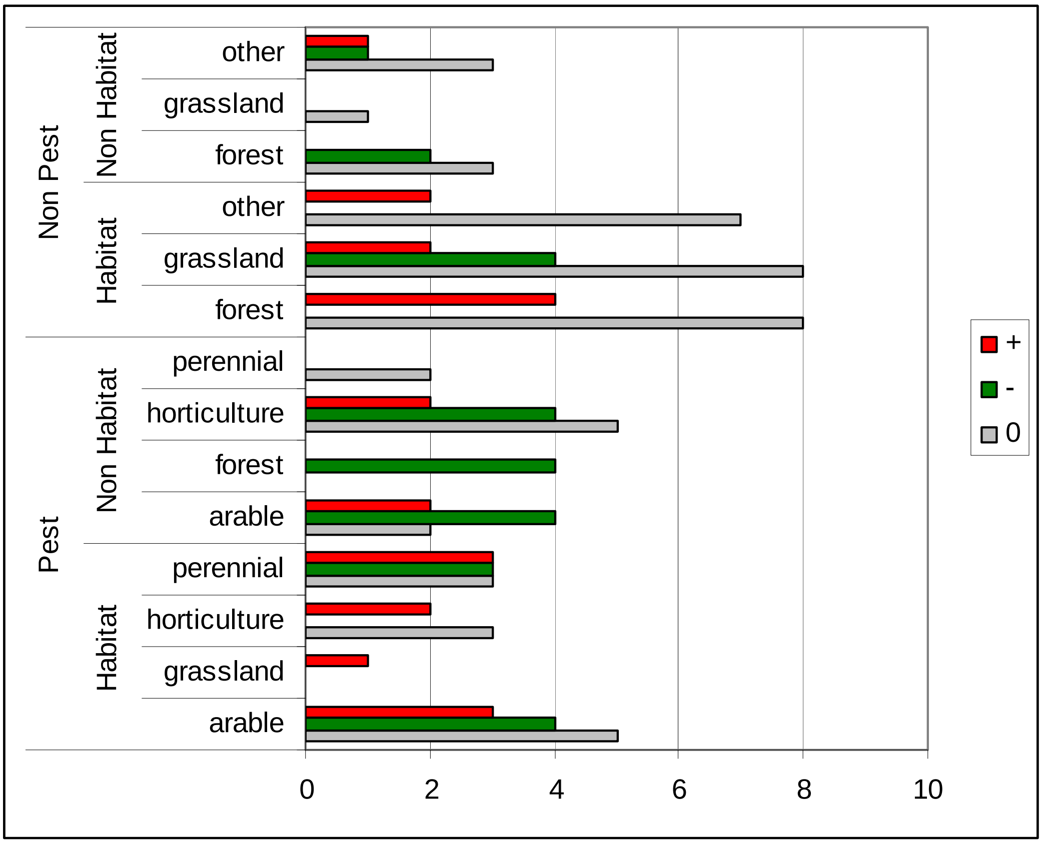

Figure 5. Distribution of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on pests. Data are presented separately per taxonomic order.

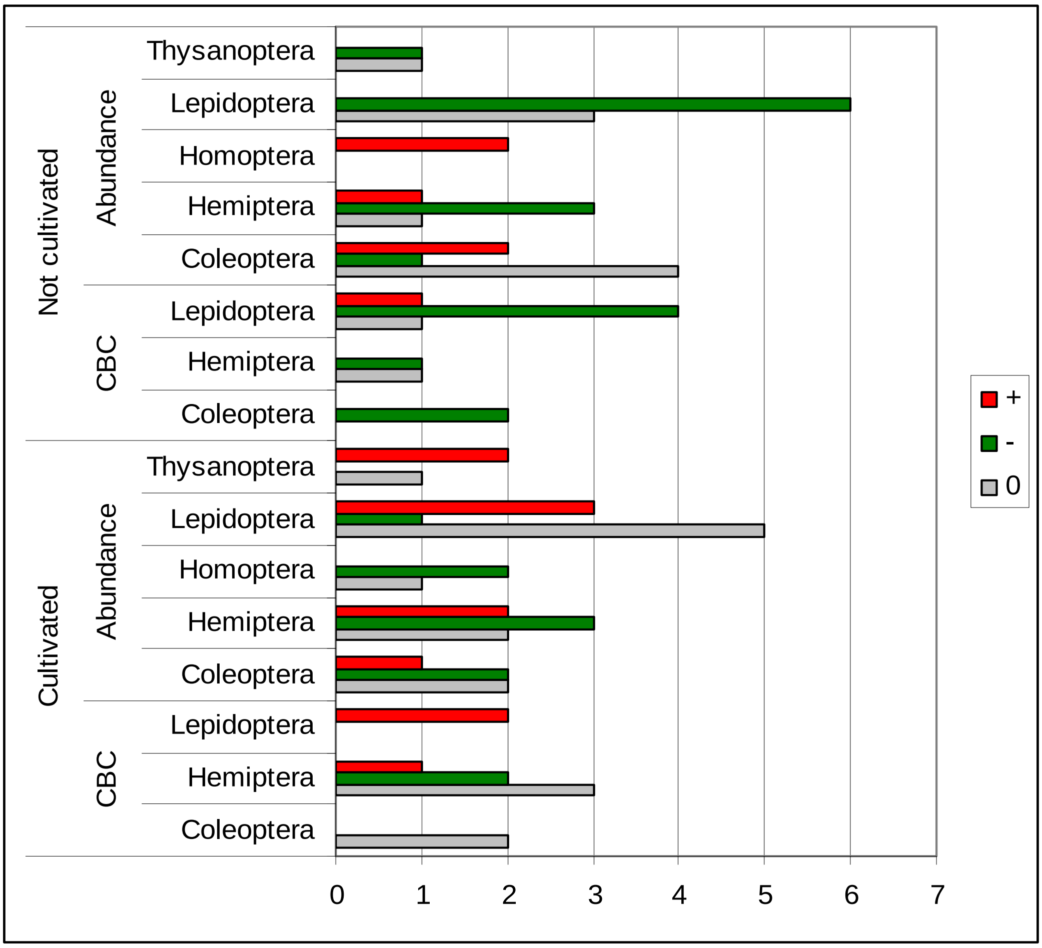

Figure 6. Distribution of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on non pests. Data are presented separately taxonomic order.

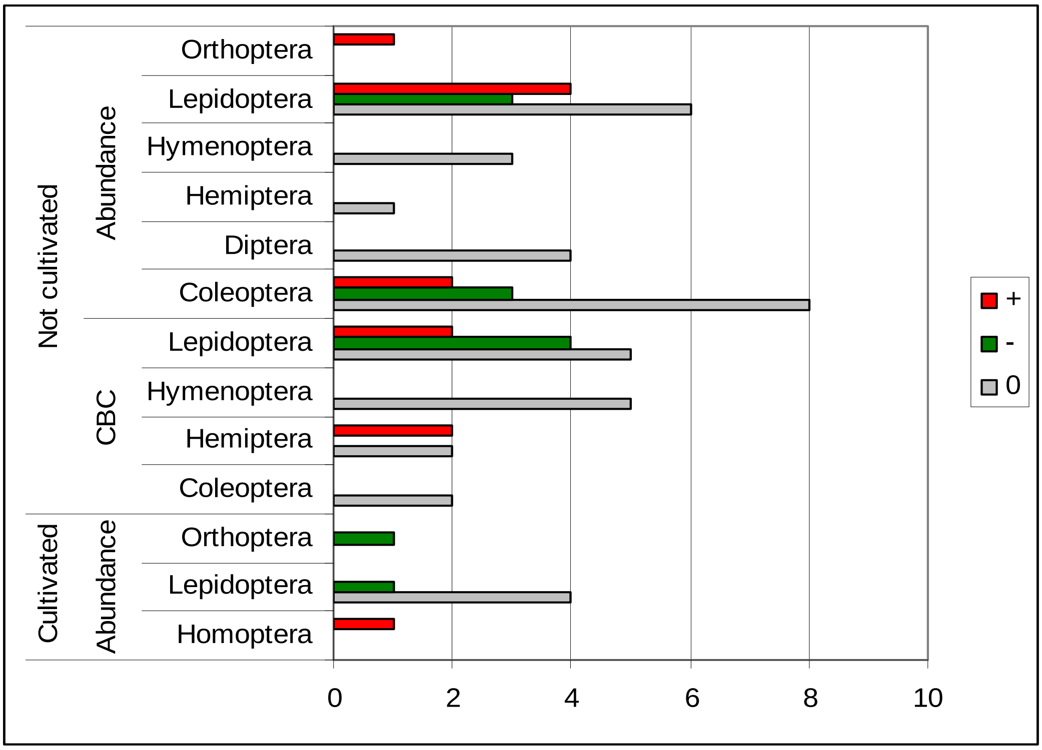

Figure 7. Distribution of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on pests. Data are presented separately per insect mobility class.

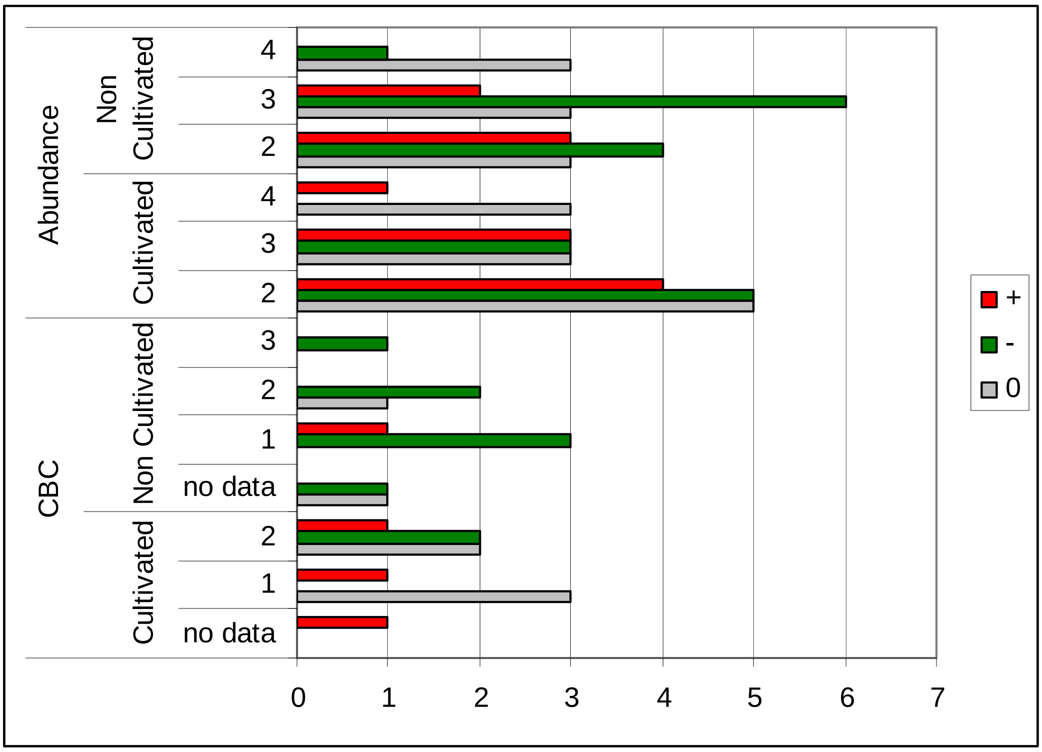

Figure 8. Distribution of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on non pests. Data are presented separately per mobility class.

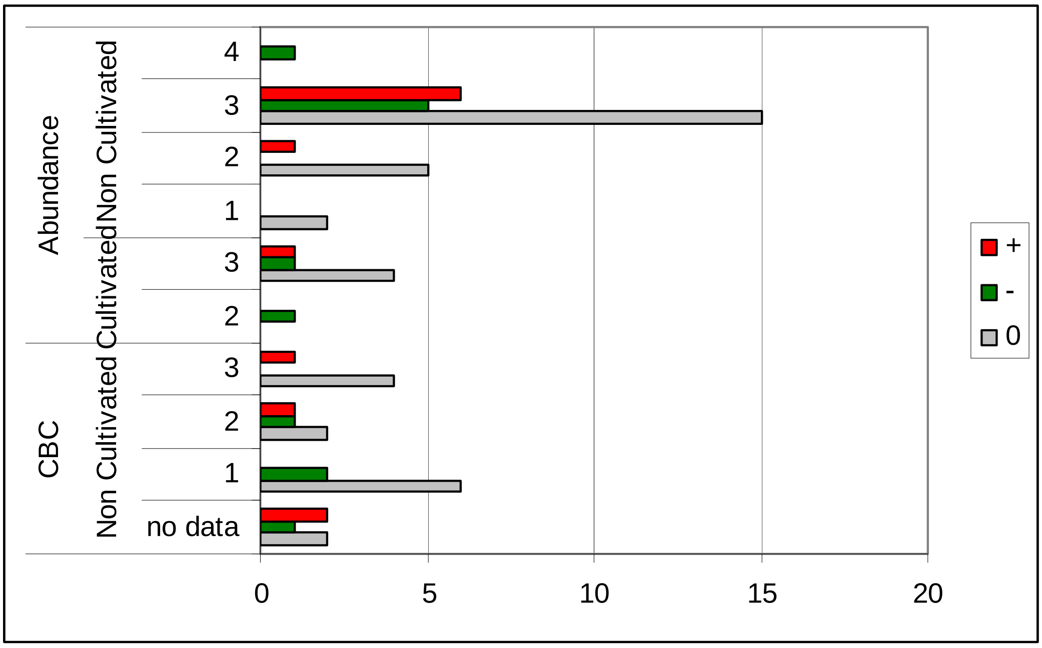

Figure 9. Distribution of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on pests. Data are presented separately per specialization level.

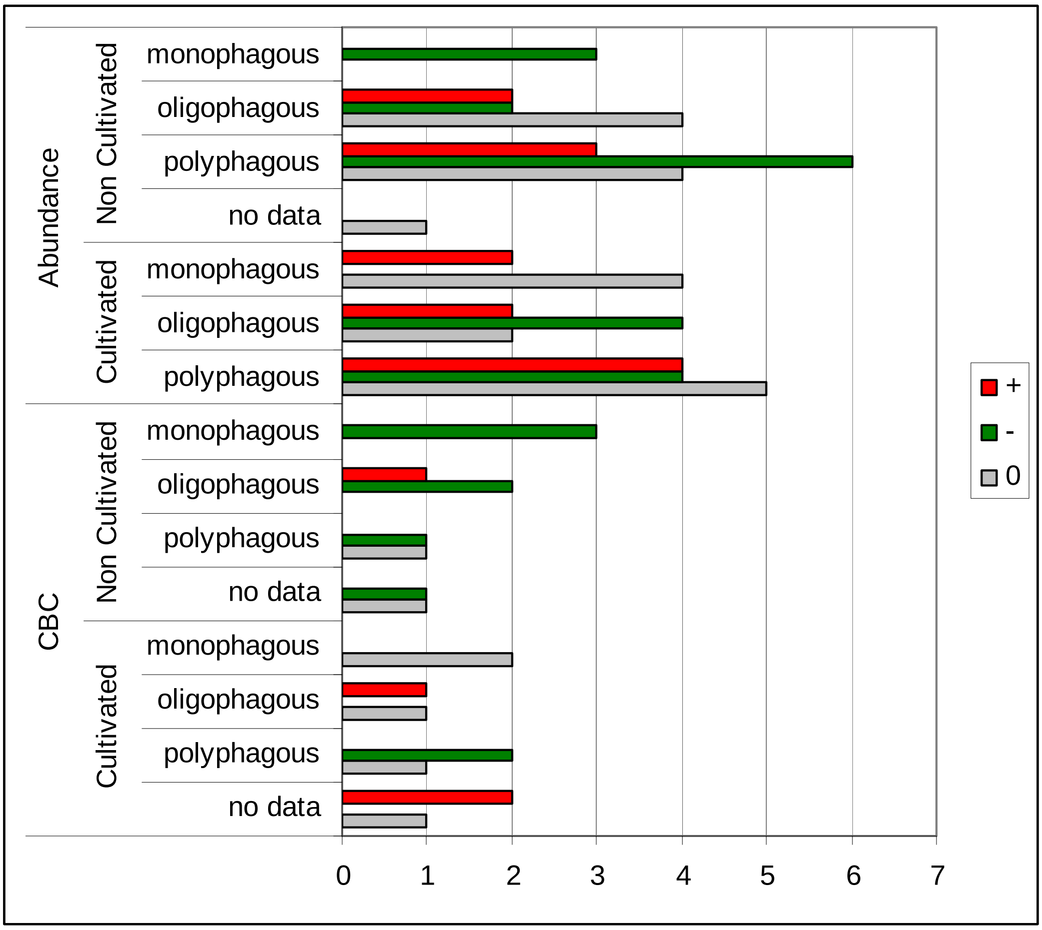

Figure 10. Distribution of positive, negative and non significant results concerning the impact of cultivated and non cultivated areas on the landscape on non pests. Data are presented separately per specialization level.