RAPID ASSESSMENT OF SPECIES DIVERSITY CHANGES AFTER PESTICIDE APPLICATION IN AGRICULTURAL LANDSCAPES

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Abstract. The aim of our study was to assess the changes in ground-dwelling arthropod communities structure in wheat, potatoes and lucerne crops, with and without pesticides application. We estimated the impact of chemical control on species richness and propose several indicators for biodiversity assessment. The significant differences between agrosystem structure in control and pesticide-treated crops indicated that aboveground arthropod diversity can be used as an indicator of biological diversity reduction assessment. The best estimator indices for human induced impacts are taxa richness, the ratio between species richness and the number of individuals in control and pesticide treated samples, the changes in the ratio between primary–secondary consumers, and the proportion of spiders (Aranea). The use of diversity indices in impact assessment was misleading or inconclusive in some cases. Only the Shannon-Wiener index appears to perform relatively well, but sample sizes must be first equalized through rarefaction.
Keywords: *bioindicator, pesticide, agrosystem, species richness*

Introduction

The intensification and expansion of modern agriculture is amongst the greatest current threats to biodiversity worldwide [8]. The impact of agriculture comes not only from the increasing areas of former natural ecosystems transformed into croplands, but also from the increased use of pesticides associated with modern agriculture [11].

The level of internal regulation of function in agrosystems is largely dependent on the amount of plant and animal species diversity present [1]. Two distinct components of biodiversity can be recognized in agrosystems [21]. The first is ‘planned biodiversity’, which includes the crops and livestock purposely included. The second component is the ‘associated biodiversity’, which includes all soil flora and fauna that colonize the agrosystem. Planned biodiversity perform major direct functions, while associated biodiversity functions are mediated through planned biodiversity. Modifications in associated biodiversity eventually affect the functions performed by planned biodiversity. Changes in species composition within associated biodiversity should be quantified and monitored for improved management practices. To address the problem of the unprecedented loss of biodiversity due to human activities, the Conference of the Parties to the Convention on Biological Diversity adopted a Strategic Plan (decision VI/26), planning to achieve by 2010, a significant reduction of the current rate of biodiversity loss. To monitor the progress in reducing human impacts a series of bioindicators were proposed. The European Environment Agency has initiated a program to identify a coherent indicator set covering the main environmental issues [5]. There are several proposed indicators for agrosystems, but their usefulness still needs testing.

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The impact of pesticides on ground invertebrates in different types of ecosystems has been thoroughly documented (e.g. [14]). Most studies showed that the application of pesticides affected not only the target taxa, but also induced a massive mortality of non-target taxa and caused an overall decrease in species richness.

Pesticide application is a disturbance and it is important to assess its strength. According to the intermediate disturbance hypothesis [13] the highest species richness is found at intermediate levels of disturbance. Previous studies have investigated the impact of pesticides and industrial emissions on the aboveground arthropods [16], [17], [18], [19], [20]. Would it be possible to maintain or even increase species richness in agriculture landscape and still apply moderate amounts of pesticides?

In this paper we monitored the changes in ground-dwelling arthropod communities in agrosystems before and after pesticide application in order: (1) to characterize the shifts in species richness, and (2) to find the best descriptors useful for monitoring purposes.

Materials and methods

We collected aboveground arthropods using pitfall traps from 12 agrosystems in the southern plain of Romania, cultivated with wheat (seven sites), corn and potatoes (two sites each) and lucerne (one site). Each crop type was exposed to the usual pesticides used in pest control.

Pitfall traps consisted of a plastic or glass container with a diameter of 100 mm and a volume of 500 ml positioned at ground level. We used a grid of five traps positioned at the corners and in the middle of a 10 m wide square. Traps were emptied on a daily basis and the arthropods captured were stored in 70% alcohol. Identification of the trapped arthropods was done, whenever possible, to species level.

As control sites, we used either untreated crops, sampled simultaneously with the pesticide treated ones, or the same crop, before treatment. In the latter, the survey lasted for two weeks: one week before application of pesticides and one week after.

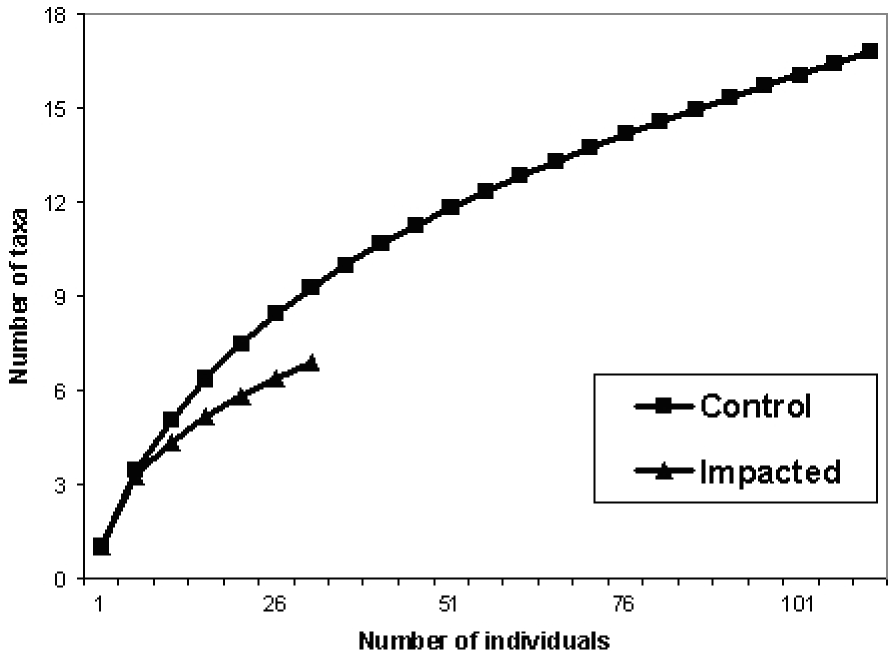
In all 24 sites were surveyed. Due to differences in sample sizes (pesticide-treated samples had lower number of specimens than control samples), we used rarefaction to compare samples from the control sites with the impacted sites. Computation was done using EcoSim 6.0 [7], drawing randomly a specified number of specimens from the sample. The process was repeated 1000 times generating a mean and a variance of species richness. Three classical diversity measures were computed: Shannon-Wiener, Simpson and Shannon's equitability [10].

Results

In all 6948 specimens were captured, of which 5325 from control sites and 1623 from impacted sites (Table 1). All the impacted sites had a lower species richness and fewer individuals as compared to the control sites. The number of specimens captured were significantly different between the control and impacted sites (t-test, $p<0.01$, d.f.=11). The number of specimens in the impacted sites represented between 8-77 % of the control sites. Taxa richness varied between 17-49 in the control sites and between 7-34 in the impacted sites, the differences being also highly significant (t-test, d.f. =11, $p<0.001$). The taxa richness in the impacted sites represented 25-69 % that of the control sites (Table 1, Figure 1).

Since the sample size was much higher in the control sites, we used rarefaction to obtain equal sample sizes (Table 2). Taxa richness was still higher in control sites at equal sample size when compared with the impacted sites except for one site, in which the sample size in the impacted site was extremely small (n = 31). The differences were still highly significant (t-test, d.f. = 11, $p<0.01$).

a.,



b.,

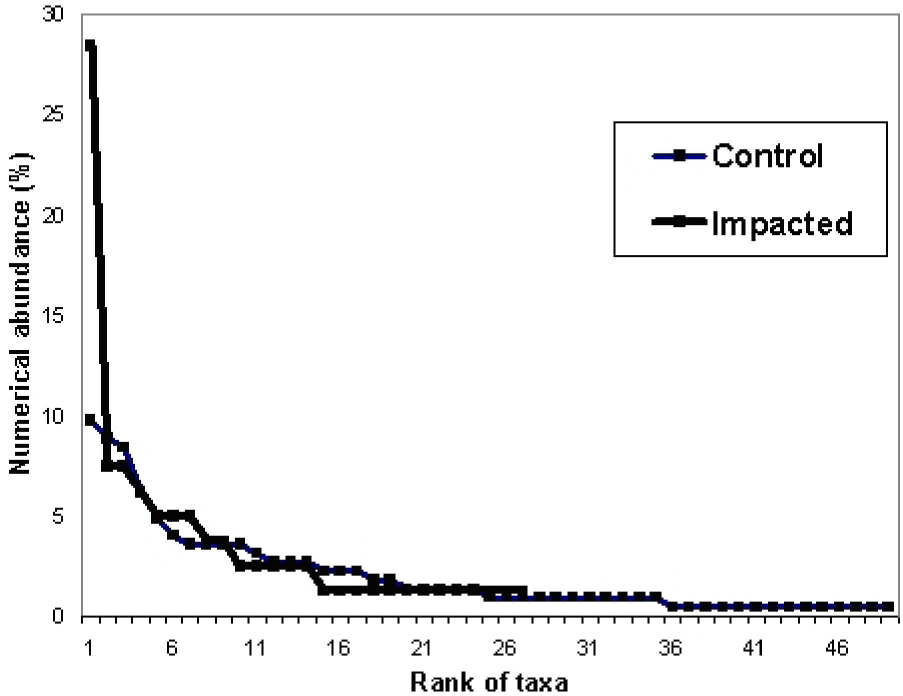


Figure 1. *(a) Rarefaction curve for the control and impacted sites cultivated with wheat (Chiajna site, 1998). (b) Rank of taxa in the control and impacted sites*

The impact of pesticides was not limited to a decrease in number of individuals and taxa richness, but also changes in species composition. In localized chemical treatments, a gradual recolonisation process was observed, through immigration from adjacent zones unaffected by pesticides.

Table 1. *Invertebrates captured with pitfall traps in control and impacted sites, number of specimens, number of taxa, and turnover of taxa after pesticide treatment*

Site no.	Crop	Number of specimens		Ratio impacted/control in percentage	Number of taxa		Ratio impacted/control in percentage	Number of newly recorded taxa in impacted sites	
		Control	Impacted		Control	Impacted		Number	Percentage
1	Wheat	986	195	19.78	47	22	46.81	7	31.8
2	Wheat	1663	672	40.41	32	18	56.25	8	44.4
3	Wheat	289	31	10.73	44	20	45.45	6	33.3
4	Wheat	91	70	76.92	20	9	45.00	6	66.6
5	Wheat	240	68	28.33	30	14	46.67	5	35.7
6	Wheat	580	280	48.28	49	34	69.39	9	26.47
7	Wheat	226	81	35.84	49	27	55.10	3	11.11
8	Lucerne	514	42	8.17	39	10	25.64	4	40
9	Potato	114	32	28.07	17	7	41.18	2	28.5
10	Potato	200	98	49.00	29	17	58.62	4	23.5
11	Corn	200	30	15.00	28	9	32.14	4	44.4
12	Corn	222	24	10.81	30	9	30.00	4	44.44

The newly recorded taxa most often were represented by phytophagous polyphagous species (especially Coleoptera) and by spiders (Aranea), or by characteristic aboveground arthropod species. Referring to trophic categories, the ratio between primary to secondary consumers was significantly different between treated and control samples (t-test $t=4.44$, $p<0.001$). The ratio was 0.94 ± 0.25 in control samples and 0.51 ± 0.19 in pesticide-treated samples. In the control crops samples, predator beetles (Insecta: Coleoptera) had the highest abundance and, through their size, Carabidae and Staphylinidae were dominant also in biomass. The dominance of predators as compared to the primary consumers, both in number of species, but especially in number of individuals, is very important because they represent biotic control factors, which maintain pest species at low levels densities. In the polluted crops samples the Coleoptera were also dominant, but were represented mainly by phytophagous species. In most cases, an increase in the abundance of spiders was also registered. In control samples the proportion of spiders among arthropods was 5.15 ± 3.87 while in the pesticide-treated samples the proportion increased to 17.73 ± 11.24, the values being significantly different (t-test, $t = 3.66$, $p < 0.05$).

We tested several classical descriptors of species diversity (Shannon-Wiener, Simpson and Shannon’s equitability). Overall they did not have good discriminating power, the worst ranking equitability, followed by Simpson’s index of diversity (Table

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3). Shannon-Wiener's diversity index correlated well with taxa richness in both the control and the impacted sites (control: $r = 0.61$, $p<0.05$; impacted: $r = 0.73$, $p<0.01$), while the other two indices were not correlated with taxa richness.

Table 2. *Taxa richness in samples before and after rarefaction (mean and confidence limits)*

Site no.	Taxa richness		Taxa richness in control after rarefaction			Difference in taxa richness[1]
	Control	Impacted	Mean	95% inferior limit	95% superior limit	
1	47	22	34	29.29	38.44	12
2	32	18	22	18.36	26.28	4
3	44	20	16.64	12.49	20.78	-3.36
4	20	9	18.04	15.87	20.21	9.04
5	30	14	18.97	15	22.9	4.97
6	49	34	36.03	30.85	41.2	2.03
7	49	27	33.28	28.77	37.78	6.28
8	39	10	14.25	10.41	18.08	4.25
9	17	7	9.17	5.75	12.58	2.17
10	29	17	22.45	18.77	26.12	5.45
11	28	9	12	8.31	15.8	3
12	30	9	10.97	7.59	14.34	1.97

[1]Computed between the taxa richness in the impacted site and the mean taxa richness in the control site at equal sample size (i.e. after rarefaction)

Table 3. *Diversity measures of the control and impacted sites*

Site no.	Shannon-Wiener		Simpson		Equitability	
	Control	Impacted	Control	Impacted	Control	Impacted
1	3.05	1.95	0.93	0.75	0.79	0.63
2	1.02	1.58*	0.39	0.70*	0.29	0.55*
3	3.10	2.82	0.92	0.92	0.82	0.94*
4	2.29	1.79	0.83	0.78	0.76	0.82*
5	2.47	2.24	0.84	0.85*	0.73	0.85*
6	2.66	2.88*	0.89	0.92*	0.68	0.81*
7	3.45	2.77	0.96	0.90	0.89	0.84
8	2.36	1.96	0.78	0.82*	0.64	0.85*
9	1.78	1.45	0.68	0.72*	0.63	0.74*
10	2.62	2.42	0.88	0.88	0.78	0.85*
11	2.50	2.02	0.86	0.85	0.75	0.92*
12	2.58	2.02	0.88	0.89*	0.76	0.92*

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Discussion

The experimental approach was not a classical BACI (before-after-control-impact). It attempted a more simple and practical approach, similar to the rapid assessment techniques being developed for monitoring and inventory purposes.

The use of diversity indices as a measure of species diversity is controversial and [9] even talked about the 'non-concept of diversity'. Dritschilo and Erwin [3] suggested that the use of diversity indices in impact assessment is redundant or, when used with ground beetles, even misleading or inconclusive in all cases.

For the purpose of our study, only the Shannon-Wiener index performed relatively well, despite it being influenced by sample size and the presence of rare species [10]. Taxa richness appears to be the best estimator and allows for comparisons between sites and/or experimental variants.

The use of rarefaction eliminates the differences between samples sizes. This type of analysis can be implemented in a simple monitoring system of agriculture landscapes that allows for the evaluation of various human impacts.

The induced changes were not always immediate. In some cases, in the first days after pesticide treatment, the number of species and specimens were drastically reduced, but in other cases their numbers decreased gradually, especially to the end of the respective period, when the toxic action reached a peak, probably as a result of accumulation and concentration of pesticides along the trophic chains [15], [20].

The disturbance induced by pesticide treatment triggered a species turnover of up to two-thirds of the initial species pool. The newly colonizing species were mostly polyphagous (especially phytophagous). Studies of the successional development of ground-dwelling insect communities on disturbed sites have shown that initial colonization is generally accomplished by scavenger and omnivorous species [2]. [6].

Focusing on certain indicator taxa might facilitate the task of monitoring human induced impacts. Duelli [4] suggested that carabids, staphylinids and spiders are good indicators for biodiversity. In addition, Pizzolotto [12] reviews the literature and suggests that good indicators of disturbances in ecological succession are also diplopods, acari and collembola.

Previous studies on ground level arthropod communities, revealed that among different indicators, the most important are the ratio between the number of specimens in control and polluted samples, the presence of the specific parasitoids of the crop pests, the zoophagous–phytophagous specimens ratio and the insects and Aranea specimens ratio [18], [20].

Primary consumers dominance in the polluted crops samples can be explained by the lack or diminished biological control action (from predators and parasitoids), and also because of their capacity, as phytophagous, to resist of the pollutant toxicity effects since they possess a larger resistence to pesticides and other toxic substances [15], [16].

The changes in the dominance pattern of primary-secondary consumers proves to be a good indicator of the biological diversity reduction and of the ecological imbalance induced by noxious factors [[18], [20].

The significant differences between species richness in control and pesticide-treated crops indicated that aboveground arthropod diversity can be used as a simple measure indicator of environmental quality in agrosystems.

REFERENCES

[1] Altieri, M. A. (1999): The ecological role of biodiversity in agroecosystems. − Agriculture, Ecosystems and Environment 74: 19-31.
[2] Bulan, C. A., Barrett, G. W. (1971): The effects of two acute stresses on the arthropod component of an experimental grassland ecosystem. − Ecology 52: 597-605.
[3] Dritschilo, W., Erwin, T. (1982): Responses in abundance and diversity of cornfield carabid communities to differences in farm practices. − Ecology 63: 900-904.
[4] Duelli, P. (1997): Biodiversity evaluation in agricultural landscapes: An approach at two different scales. − Agriculture, Ecosystems and Environment 62: 81-91.
[5] European Environment Agency (2003): An Inventory of Biodiversity Indicators in Europe, Technical Report no. 92, Luxemburg.
[6] Force, D. C. (1981): Postfire insect succession in southern California chaparral. − American Naturalist 117: 575-582.
[7] Gotelli, N.J., Entsminger, G.L. (2001): EcoSim: Null models software for ecology. Version 6.0. Acquired Intelligence Inc. & Kesey-Bear.
[8] Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V., Evans, A.D. (2005): Does organic farming benefit biodiversity? − Biological Conservation 122: 113-130.
[9] Hurlubert, S.H. (1971): The non-concept of species diversity: A critique and alternative parameters. − Ecology 52: 577-586.
[10] Magurran, A.E. (1988): Ecological Diversity and its Measurement. Princeton University Press, Princeton.
[11] Palumbi, S.R. (2001): Humans as the World greatest evolutionary force. − Science 293: 1786-1790.
[12] Pizzolotto, R. (1994): Soil Arthropods for Faunal Indices in Assessing Changes in Natural Value Resulting from Human Disturbances. In: Boyle, T.J.B., Boyle, C.E. (eds.) Biodiversity, Temperate Ecosystems, and Global Change, NATO ASI Series, vol. 120. Springer-Verlag Berlin, Chapter 15, pp. 291-313.
[13] Sousa, W. P. (1984): The role of disturbance in natural communities. − Annual Review of Ecology and Systematics 15: 353-391.
[14] Sullivan, T. P., Wagner, R.G., Pitt, D.G., Lautenschlager, R.A., Chen, D.G. (1998): Changes in diversity of plant and small mammal communities after herbicide application in sub-boreal spruce forest. − Canadian Journal of Forest Research 28: 168-177.
[15] Teodorescu, I. (1989): Contributions a la connaissance des effets de la pollution industrielle sur certaines biocenoses des agrosystemes adjacents aux sources d' emission. − Analele Universității Bucureşti 38: 71-79.
[16] Teodorescu, I., Stănescu, M. (1994): The industrial pollution effects upon some agrobiocenosis from the adjacent agrosystems around the emission sources. − Ocrotirea naturii şi a mediului inconjurător 38: 27-44.
[17] Teodorescu, I., Vădineanu, A. (1997): The pesticide pollution impact on the structure and dynamics of the arthropod associations. − Revue Roumaine de Biologie, serie Biologie Animale 42: 125-135.
[18] Teodorescu, I. (1998): Actiunea ierbicidelor asupra populatiilor de artropode din culturi. − Studii şi Cercetări de Biologie, seria Biologie animală 50: 11-36.

[19] Teodorescu, I., Vădineanu, A. (1999): Industrial emissions and pesticides impact upon insect populations. − Internationale Entomologen Tagung, Basel 116-118.
[20] Teodorescu, I., Vădineanu, A., Simionescu, A. (2001): Managementul impactului emisiilor industriale şi al pesticidelor asupra biodiversităţii agrobiocenozelor. − In: Vădineanu, A. (ed.). Managementul Capitalului Natural, Ars Docendi, Bucharest.
[21] Vandermeer, J., Perfecto, I. (1995): Breakfast of biodiversity: the truth about rainforest destruction. Food First Books, Oakland.

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