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Original Research

Carabidae in Landscape Research on the Basis of Literature, 2005-08

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Abstract

This paper is a synthetic presentation of the current state of theoretical knowledge and practical applications of *Coleoptera*: *Carabidae* in environmental research. An additional task is constituted by the assessment of applicability of these indication methods in investigations at the landscape level. The source of information was constituted by the database of scientific papers of ISI Web of Science. The search was narrowed down to journals published by two environmental science publishing houses: Elsevier and Kluwer. Papers including the criteria of a time interval of 2005-08 and keywords "*Carabidae*" and "indicator" were selected. The publications were classified into six thematic groups: rural, forest, urban/suburban, natural, mixed, and the group survey/theory.

Keywords: indicator, *Carabidae*, land use, habitat variables

Introduction

Previously, estimations of environmental diversity relied primarily on large mammals and birds. In recent years more attention has been directed to studies including smaller organisms such as invertebrates, including coleopteroids (in particular: *Carabidae*) and spiders (*Araneae*) [1-3]. The approach to landscape studies also has changed. Side by side with the well recognized socio-economic and landscape indicators (floristic, geobotanical) [4], indicators related to animals started to be used. The latter in the biological sense constitute organisms, parts of organisms or organism clusters, containing information on the state of the environment [5] by demonstration of interrelations between the biotic components, physical factors, and various land use forms. Hence, they are a valuable assessment tool in landscape studies. Good examples of application of bioindicators are provided by the successfully implemented programs: Soil biological site classification (BBSK) in Germany [6], Biological Indicator of Soil Quality (BISQ) in Holland [7], and Pesticide Occupational and Environmental Risk Indicator (POCER) in Belgium [8].

The purpose of this report is to show the current state of theoretical knowledge and practical applications of natural environment bio-indication, based on observations of occurrence of *Coleoptera*: *Carabidae*, founded on a broad literature survey from 2005-08. An additional task is constituted by the assessment of applicability of these indication methods in investigations at the landscape level.

Carabidae as Bioindicators

Carabidae are among the most known groups of invertebrates used in environmental bioindication studies [9-11]. The application of *Carabidae* is based on the well-founded knowledge of reactions from a group of species to the stress coming from the environment in which they live. Responses to disturbances provide reliable information on the condition of the population of species, constituting an important element of ecosystems. Changes in the population of *Carabidae* may get reflected in several ways: changes in the classification systems/ecological groups,

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modification of biomass, body lengths, diversification, or the number of species. High importance is attached to the above-mentioned systems of classification of *Carabidae*, which distinguish different groups of species on the basis of various prerequisites (Table 1).

Besides, *Carabidae* fulfil the formal criteria of a good bioindicator – the principles of their use in the investigations are legible and easy to apply, in particular:

(1) taxonomy and ecology are well recognized [17]
(2) acquisition of individuals is easy as standard catching techniques exist
(3) *Carabidae* constitute a group of organisms broadly distributed over the globe that occur in numerous ecosystems and in many regions, which enables making comparisons between locations
(4) particular groups of species differ as to their sensitivity and specialization for living in definite habitat conditions (systems of classification of *Carabidae*/ecological groups), which facilitates investigations and reasoning, in particular – on the basis of changes in the domination structure of the species and changes in the dominating survival strategy
(5) they react quickly to disturbances, and the response to stress is measurable in quantitative and qualitative terms and, additionally, their reaction reflects the differences in the changes taking place due to natural cycles or trends as distinct from those caused by the effect of anthropogenic stress.

Table 1. Prerequisites important for distinguishing *Carabidae* species groups [12].

Prerequisites	Groups of species
Way of wintering (e.g. [13])	- autumnal - spring developmental type
Habitat preference [14]	- forest - eurytopic - inhabiting open areas
Body length and feeding preference [9]	- small zoophags (predatory species >100 mg) - big zoophags (predatory species <100 mg) - hemizoophags (half-herbivorous)
Regimes of humidity [15]	- hygrophilous - mesophilous - xerophilous
Dispersion capacity [16]	- brachipteric (wingless species) - macropteric (winged species) - dimorphic species (some winged, others not, or equipped with barely developed wings)
Geographic ranges	- eurybionts (wide range of appearance) - stenobionts (narrow range of appearance)

Data Sources and Methods of Analysis

The source of information was constituted by the database of scientific papers of ISI Web of Science. The search was narrowed down to the journals published by the publishing houses Elsevier and Kluwer. From the database the papers were selected, fulfilling the following criteria:

a) time interval between January 2005 and October 2008
b) keywords, "*Carabidae*" and "indicator" in the abstract, keywords, or the text of the paper.

These search criteria were fulfilled by altogether 176 papers. After screening the abstracts, 82 papers were chosen for further analyses, the ones that considered space and addressed human activity in relation to *Carabidae* as environmental indicators. The chosen articles were subject to detailed analysis with respect to the leading subject matter, area considered, method of study, applications, and repetitiveness of the data set.

Results of Analysis of Thematic Groups

Out of the total number of 82 articles, 87% concerned concrete studies and 13% were devoted to summarizing studies in the form of surveys or theoretical concepts. The publications were classified into six thematic groups: rural, forest, urban/suburban, natural, mixed, and the group survey/theory (the latter also containing papers summarizing the results and conclusions from the reports, classified also in the preceding groups; breaking down this summarizing group would disturb the image of the state of art of a given theme). Taking into account only the first five groups, the studies devoted to the forest themes clearly dominated at 48%. The second group in terms of the number of articles is constituted by the "rural" papers, containing the ones 29% devoted to rural landscapes and agroecosystems. The subsequent one is the urban/suburban group, 11%, containing the reports connected with urban areas and post-industrial surfaces. There are fewer of papers classified in the "mixed" and "natural" groups – 6% each. The "mixed" group contains the studies, carried out simultaneously in various landscapes (e.g. urban and rural), while the "natural" group contains mainly studies devoted to riverside areas, peatlands, and moorlands.

The Forest Group

The themes of studies in the forest group widely differentiated, but there was a perceptible domination in this group of the articles concerning:

a) forestation (forest structure change) – replacement of the domestic species by other tree species, e.g. planting of coniferous forests in the place of deciduous ones [18-21], re-forestation with domestic tree species, and observation of changes in the grouping of *Carabidae* depending on the forest succession stage [11, 14], along with analysis of the habitat and spatial isolation [22]
b) extraction of wood material (fragmentation of the forest) – tree felling vs. the grouping of *Carabidae* [23-25], comparison of the effectiveness of different forest practices, e.g. felling, burning, grazing [26, 27]
c) forest condition after abrupt natural phenomena, along with the analysis of effectiveness of additional forest practices, e.g. wind breaks [28] or forest fire, as correlated with forest age [29]

Table 2. Characteristics of the *Carabidae* community used in forest group research. (Table shows in how many articles characteristic of *Carabidae* community was used for relevant habitat variable. Value after summation will not equal numbers of all articles because more than one relation among habitat variables and characteristic of *Carabidae* community in almost all works were analyzed, as in Tables 4, 6).

Characteristics of *Carabidae*	Habitat variables		
	Method of managing – forest practices	Forest functions	Assessment of pollution
Number of species	19	7	1
Other numerables (e.g. abundance)	17	6	0
Higher taxa	4	3	0
Ecological groups	14	6	0
Bioaccumulation	0	1	1
Body length	1	3	0
Gender	1	0	1
Rarity	0	1	0
Biomass	0	0	0

d) transfer of pollution with heavy metals – concentration in the soil environment, litter, and *Carabidae* [30]

In order to know the influence of the particular habitat variables, in the papers belonging to the forest group (the method of managing the forest – forest practices, forest functions, and assessment of pollution) various characteristics of the *Carabidae* (Table 2) were used.

In the majority of cases the analysis of relations between *Carabidae* and the habitat variables mentioned was accompanied by analysis of other interrelations (Table 3). Most often used parameters characterizing the environment were:

a) climatic – monthly and/or annual averages of precipitation and temperature
b) soil – pH, organic matter content, C, N, ratio C/N, and humidity
c) bedding structure – type and thickness of the litter layer, wood rests, dead wood, uncovered soil
d) concerning vegetation – compactness of tree canopies, height and circumference of trees, structure of the herb layer, species composition, coverage and height of mosses, vascular plants, bushes and trees, as well as forest age
e) other organisms – spiders, rove beetles, ants, slaters, daddy-long-legs, hymenoptera, potworms, earthworms, microorganisms, and others
f) landscape metrics – distance to the forest edge, degree of isolation of the patches.

The Rural Group

Publications classified in the rural group concerned:

a) the role of interfield balks and belts (natural and sown) depending on distance from the field edge [31], their composition [32], or their age [33]
b) the landscape structure [2, 34]
c) the manner of cultivating crops – organic or conventional [13, 35]
d) farming practices – fertilizer use, grazing [10, 36], or application of chemicals [37, 38].

In order to identify the influence of individual habitat variables, referred to in the subject matter scope of the articles classified to the rural group (land use, farming practices, assessment of pollution) various characteristics of the *Carabidae* were used (Table 4).

In this group, similarly as in the forest group considered before, analysis of the interrelations of the *Carabidae* with the habitat variables was accompanied by the analyses of other interdependences (Table 5), concerning:

a) climatic parameters
b) soil parameters – pH, C, N, P, humidity, soil structure
c) vegetation – species of vascular plants, biomass, height
d) other organisms – rove beetles, spiders, hemiptera, springtails, hymenoptera, diptera
e) landscape metrics – landscape composition, structure of boundaries, average area of a field.

Table 3. Characteristics of environment used in forest landscape research. (Table shows in how many articles relevant characteristics of environment were used for relevant habitat variables. Value after summation will not equal the total number of articles because more than one relation among habitat variable and a number characteristic of environment in almost all works were analyzed, as in Tables 5, 7).

Parameters characterizing the environment		Habitat variables		
		Forest management method – forest practices	Forest functions	Assessment of pollution
Climate		1	1	0
Soil	Physical	4	6	1
	Chemical	5	4	0
Bedding structure		10	5	1
Concerning vegetation		19	8	0
Other organisms		11	9	0

Table 4. Characteristics of *Carabidae* community used in rural landscape research.

Characteristics of *Carabidae*	Habitat variables		
	Land use	Farming practices	Assessment of pollution
Number of species	8	9	1
Other numerables (e.g. abundance)	7	10	1
Higher taxa	3	3	2
Ecological groups	5	4	2
Bioaccumulation	0	0	0
Body length	3	3	0
Gender	1	0	0
Rarity	0	0	0
Biomass	1	1	0

Table 5. Characteristics of environment used in rural landscape research.

Characteristic parameters of the environment		Habitat variables		
		Land use	Farming practices	Assessment of pollution
Climate		0	1	0
Soil	Physical	3	3	1
	Chemical	2	3	1
Concerning vegetation		7	7	2
Other organisms		3	4	3
Landscape metrics		7	6	1

The Urban/Suburban Group

The urban/suburban group contained articles devoted to three research problems:

a) assessment of the degree of urbanization [9, 39]
b) assessment of the degree of pollution with heavy metals [40, 41]
c) assessment of local biodiversity [42, 43]

In order to identify the influence of particular habitat variables (method of using, method of managing, degree of urbanization, and assessment of pollution) various characteristics of the *Carabidae* were referred to (Table 6).

Similarly as in the groups previously commented upon, in the majority of cases the analysis of relations between *Carabidae* and the habitat variables was accompanied by analyses of other relations (Table 7), most often associated with:

a) climate
b) soil – pH, organic matter content, Zn, Cd, Pb, Cu, and humidity
c) bedding structure – thickness of the litter layer, wood rests
d) vegetation – species composition; coverage and height of moss, vascular plants, bushes, and trees
e) other organisms – spiders, rove beetles, earthworms, microorganisms
f) landscape metrics – magnitude of patches, distance to the forest edge, degree of isolation of the edges

The Mixed and Natural Group

Articles classified in the "mixed" group concerned the influence of the salinity of the environment on the *Carabidae* – in connection with analysis of the characteristics of the habitat structures [3], or increase of humidity of the habitats [44]. The parameters referred to in the studies, were as follows: qualitative (species, ecological groups), and enumerative (numbers, densities, etc.), and in just one case – scarcity of appearance (species from the Red List). Just as in the remaining groups, analysis of interrelations of the *Carabidae* with the habitat variables was accompanied

Table 6. Characteristics of *Carabidae* community used in urban/suburban group research.

Characteristics of *Carabidae*	Habitat variables			
	Land use	Managing method	Pollution assessment	Degree of urbanization
Number of species	2	0	1	3
Other numerables (e.g. abundance)	2	0	2	3
Higher taxa	0	0	0	0
Ecological groups	1	0	0	3
Bioaccumulation	0	0	0	0
Body length	0	0	0	2
Gender	0	0	0	0
Rarity	0	0	0	0
Biomass	0	0	0	0

Table 7. Characteristics of environment used in urban/suburban group research.

Parameters characterizing the environment		Habitat variables			
		Land use	Managing method	Pollution assessment	Degree of urbanization
Climate		0	0	0	1
Soil	Physical	1	0	1	0
	Chemical	1	0	2	0
Concerning of vegetation		3	0	2	3
Other organisms		2	0	2	1
Landscape metrics		1	0	0	2
Bedding structure		1	0	0	0

by the analyses of other relations, concerning the following groups of characteristics:

a) climatic
b) soil – pH, organic matter content, humidity, salinity
c) structure of the bedding – thickness of the litter layer, uncovered soil
d) vegetation – species composition, coverage and height of vegetation
e) other organisms – spiders, *Coleoptera*: *Tenebrionidae*
f) landscape metrics – magnitude of the patches, distances between the patches

Then, the subject matter of the "natural" group encompassed the studies devoted to:

a) various methods of restoration of habitats e.g. the peat lands [45]
b) assessment of the degree of concentration and distribution of pollution with heavy metals in the soil and in living organisms (including *Carabidae*) on flooded areas [46]
c) assessment of the utility of *Carabidae* in the appraisal of environmental quality or of nitrogen concentration, e.g. over the moorlands [47, 48]

In almost every study a different set of indicators pertaining to the *Carabidae* group was used: quantitative and qualitative parameters, activity, and bio-accumulation studies. The analyses mentioned, involving the habitat variables, were accompanied by the analyses of interrelations with environmental characteristics pertaining to:

a) soil – pH, organic matter content, humidity, heavy metal content
b) structure of the bedding – thickness of the litter layer, uncovered soil
c) vegetation – degree of coverage, diversity and height of the vascular plants
d) other organisms – spiders, rove beetles, Collembola, and many others
e) landscape metrics – magnitude of the patches, distances between patches, degree of isolation of the patches

Character of the Study

Investigations with the use of the *Carabidae* take two essential directions:

a) study of the interdependences – what is having an impact on the organisms and in what manner is this reflected (58% of publications, but it is worth emphasising that of those, 13% address cognition of interdependence with identification of bio-indication mechanisms)
b) assessment/indication of the selected aspects of the environment with the use of the organisms – we know the reaction of the organisms to stress and with the help of this knowledge we conclude (42% of publications) (Table 8)

Scale of Study and Repetitiveness of the Data Set

This study had a differential spatial range: 37% were limited to a single plot/site/field/forest complex, 52% dealt with more than one plot/site/field/forest complex, but within a single administrative region, last of all 11% concerning multiple plots located in more than one administrative region.

Most often the method of study adopted was limited to a single season (30%) collection of information on *Carabidae*. The other schemes of data collection were two-season (e.g. spring and autumn) (42%), or enhanced to more than two seasons (28%).

Table 8. Quantitative distribution of elaboration devoted to different investigative problems.

Group	Interdependences	Interdependences with identification of indication	Indication
Forest	17	3	14
Rural	12	2	7
Urban/ suburban	1	1	6
Natural	1	1	2
Mixed	1	2	1

Interestingly, only two studies [49, 50] integrate multiple plots located in more than one administrative region with multi-seasonal data collection of *Carabidae*.

Discussion

In reports connected with heavy metal pollution, the most frequently applied descriptive parameter was the accumulation of respective elements in the soil and/or in living organisms. Besides, in all the thematic groups no distinct correlation was stated between the objectives of the study and the selection of parameters characterizing the *Carabidae*. Similarly frequently, quantitative parameters were used (numbers, densities, etc.) as the qualitative ones (species, ecological groups). At the same time, quite differentiated approaches were used in data collection (Table 9).

Yet, the studies other than inventorying or estimation of changes in the species composition after abrupt ecological catastrophes, concentrating more on monitoring and assessment of the state and the processes taking place in the environment, high significance was placed on classification of the *Carabidae* into the morpho-ecological groups (e.g. with respect to the capacity of dispersion or the manner of acquiring food). The morpho-ecological groups provide more information on the type of habitat, sensitivity to disturbances caused by human activity or the role that a given species plays in the ecosystem than species richness or taxonomic diversity [16]. In studies with the simultaneous use of many various groups of organisms, in order to simplify the technique of data collection and to decrease the time consumed by data processing, only assignment of individuals to higher taxa, families or orders, was sometimes practiced [25, 40]. It was less common to adopt as the characteristics of the grouping body length, sex, and scarcity of appearance (protected species). The essence of the measurement of body dimensions of the individuals from *Carabidae* refers to the assumption of the higher sensitivity of the larger species to the disturbances in the environment. Contrary to small species, with high dispersion power, the large species have lower movement capacities (they usually are wingless – the brachipteric species) and colonize new areas by wandering. Besides, the larvae of the bigger animals (much more sensitive to disturbances than the adult individuals) remain usually over many seasons in the larval stage, so that they have a lower chance of surviving disadvantageous conditions. Moreover, large species of the *Carabidae*, being predators, display higher sensitivity to negative impact from human activity than the remaining trophic groups.

Table 9. Examples of approaches of data collection.

Procedure	Methods
Collection of the sample	Traps (Barber type) [18]
	Sifting of the litter on the sieves [20]
	Traps spanned between the lower parts of trees/poles [22]
Designation of the individuals	Adult [10]
	Adult and larvae [31]
	Definite species [33]
	Only winged [22]
	Only wandering >4 mm [44]
Designation of body length	Length of the left cover (shielding wings) [33]
	Large ≥16 mm, medium = 8-16 mm, small ≤8 mm [51]
	Large >15 mm and small <5 mm [52]
	Large >10 mm and small <10 mm [23]
	Share of small species <9 mm [53]
Internal structure of the grouping	Species [32]
	Higher taxa [25]
	Divisions with respect to:
	- way of wintering [13]
	- feeding preference [9]
	- environmental preferences [42]
	- humidity regimes [15]
	- salinity regimes [3]
	- capacity of dispersion [23]
	- preferences as to the location of appearance (e.g. in the field) [31]
	- biomass [54]
	- sex [30]
	- scarcity of appearance [48]

Conclusions

There is a perceptible stream of studies, oriented at bioindication (studies of a strict bioindication orientation or studies of interrelations meant to identify the utility for bioindication). An important proportion of publications from the survey/theory group also concentrated on the consideration of the utility of the *Carabidae* in landscape studies. Bio-indication, similar to the case of another recognized bio-indicator group – earthworms (*Lumbricidae*) [55] – develops along two paths:

- identification of the current state of the ecosystem: single observation in time (single season), or year-round (accounting for at least two seasons)
- monitoring and assessment of the state of environment: over several seasons (usually more than a year of investigations) through the intermediary of the known reactions to stress and habitat requirements, having some reflection in the changes of the values of particular characteristics of the grouping

An analysis of articles confirms the very broad possibilities of applying *Carabidae* in the study of landscape, both in terms of the range of possibilities of the study location choice (rural, forest, suburban landscape etc.), and in terms of the subject matter of study. There is a distinct increase in the number of studies done for several plots/sites/fields/forest complexes in one area, and the still few supraregional studies that provide the possibility of making comparisons and a broader perspective for analyzing the results. Studies encompassing at least two seasons dominate, but there is also quite a significant number of articles, reporting from studies encompassing at least two years of studies. This is a very important aspect, as single-time-instant studies, through temporal limitation, show first of all the instantaneous state of the group of organisms, and hence also of the ecosystem. Thus, they do not diagnose the real state of the soil environment, and just a momentary response to the disturbing stress. Some species have a more uniform dispersion of appearance than other ones. Some of them reach the peak of their number during spring, and others in autumn [56]. On the other hand, already the one-year, but year-round, investigations allow for grasping the way the species appear. An increase of the study area and consideration of the entire year in the study (with spring and autumn) also increases the probability of collecting the species that appear in a non-uniform and close to seasonal manner.

It would be difficult to find a species or group of species of *Carabidae* that would associate all the properties of a good bioindicator. That is why requirements with respect to the indicators are being adapted to the character of the study (e.g. consequences of destruction/natural changes of the habitats, assessment of biodiversity, and effects of forest management practices). A species proper for monitoring purposes may turn out to be inadequate for inventorying, and vice versa. The species used for monitoring ought to be sensitive to changes and disturbances caused by human activity, while the species used for inventorying should reflect and identify themselves with a given bio-geographical zone, an area of exceptional character, etc. A similar situation exists for the species not having high habitat demands and those requiring definite habitat conditions. Species featuring higher demands are more dependent on the environmental conditions than the remaining ones [57]. So it is important to consider the environmental parameters that impact the *Carabidae*. Taking into account the soil parameters, the authors of publications included in the survey most often considered: acidity, organic matter, organic carbon, general nitrogen content, and humidity. High significance was attached to the bedding structure (especially in the forests): type and thickness of the litter layer, wood rests, uncovered soil, and parameters concerning vegetation (structure of the herb layer): species composition, coverage and height (of moss, vascular plants, bushes, trees). The most often applied landscape metrics were: magnitude of the patches, distances between the patches, isolation of the patches, distance from the edges. Moreover, in each of the thematic groups, side by side with the *Carabidae*, also other groups of living organisms were utilized (most frequently spiders, rove beetles, ants, springtails, earthworms and microorganisms), which broadened significantly the field of investigation, enriching it with the possibility of comparing the bio-indicators, and allowing for the acquisition of information on the interactions taking place in the ecosystem.

In summary, landscape studies, performed on the basis of the *Carabidae* should in the optimum setting account for both taxonomic diversity and the morpho-ecological groups of the *Carabidae* (using, as far as possible, also other groups of organisms), encompassing a number of other environmental variables (ranging from soil parameters to degree of urbanization), not being limited to a small experimental field, and accounting for at least one year of study (including two seasons).

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